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HYDRODYNAMIC PROCESSES AND INLET DYNAMICS OF CHILKA, A TROPICAL LAGOON ON EAST COAST OF INDIA

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Abstract: *The Chilka Lake, located on north-east coast of India has connected to the Bay of Bengal through three inlet mouths - the old mouth, the dredged mouth and the natural mouth. The old mouth got totally closed by natural siltation. The dredged mouth and the natural mouths are the main sources of sea water excursion at present. Regular field measurements of inlet positions indicate that both dredged mouth and the natural mouth are undergoing rapid changes in their cross-sectional dimensions. Width of the dredged mouth is getting narrower (presently limited to 200m) while width of natural mouth undergoin seasonal variations. The major rivers that discharge significant volumes of fresh water are Makara, Daya, Bhargavi, Luna and Kusumi. The discharge through these rivers is highly variable depending on the intensity of the monsoon. In 2007, the maximum fresh water discharge is 1100 cumecs where as in 2008 the maximum discharge is 8000 cumecs. The tidal propagation inside the lake is totally controlled by the topography. At Chilka offshore, the tides are 'Semidiurnal' where as inside Chilka the tides are 'Mixed, mainly semidiurnal'. During spring periods the tidal range gradually decreased from 2.1m at the offshore to about 1.2m at inside Chilka mouth. The currents at Chilka mouth and its offshore are tide driven where as inside lake the currents are influenced by combined effect of wind, tide and upland river discharge together with topography. At chilka offshore the maximum current strength is around 35cm/s, at chilkamouth around 50 cm/s and iniside lake it is 30 cm/s.*

Keywords: *Chilka lake; North-East coast of India; hydrodynamic processes; Inlet Dynamics.*

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INTRODUCTION

Coastal lagoons are buffer zones for nutrient storage and fluxes coming from land and oceanic environments. They consist of a main basin, running parallel to the coast, usually separated from the adjacent sea by formation of sand bars at their mouths (Barnes, 1980). Several forcings such as wind, pressure, astronomical tide, fluvial discharges etc can function simultaneously on these water bodies (Symonds et al. 1995) and lead to considerable spatial and temporal variations in water levels, currents, circulation, flushing etc, which in turn affect the biological production (Simpson et al, 2001). Yamano et al. (1998) studied the influence of seasonal variation of wind on the circulation in shallow water lagoons. Al-Ramadhan (1988) has investigated the spatial as well as temporal variations in residual water circulations resulted from non-linear interactions, density gradients, wind stress and fresh water influx into the lagoon. Assuming complete mixing within the estuary and a stationary distribution of fresh and salt water for a constant river flux, Ketchum (1952) has developed simplified mixing models for calculation of flushing time which were later improved by Dyer & Taylor (1973). Seasonal variability of tidal and non-tidal currents off Beypore, SW coast of India was studied by Dinesh Kumar et al (2004) and concluded that strong seasonal dominance was noticed in non-tidal currents.

Similarly, there are considerable studies related to seasonal fluctuations of water levels, currents and flushing rates of Chilka lake. Chandramohan and Nayak (1994) studied a detailed investigation on how to improve the flushing capacity of the Chilka lake. From the hydrodynamic point of view, the results reported by Raman and Prabhkara Rao (2006) indicate that the Cilka lagoon comprises four distinctive areas 1) the North-Sector- influenced mainly by fresh water most of the year, 2) the Central sector - corresponds to mixing of both fresh and saline water, 3) the Rambha region – the SW sector with deep waters constituted of mixed waters of fresh, saline and wind and 4) Open channel - completely renewed by oceanic waters during dry season and flooded with fresh water during rainy season. Jayaraman et al (2007) investigated the circulation and salinity structure in the Chilka lagoon by using model simulations. Mohanty and Panda (2009) have studied the wind and density circulation in the Chilka lagoon during summer and winter seasons and also mixing of water masses between different sectors of the lagoon. Most of these studies were undertaken based on field measurements in a limited area of one or two locations and for a limited time periods. Systematic data collection with simultaneous recording at several locations is lacking in these studies. Presently there are indications that the dredged mouth is getting silted up by natural processes and migrating northward in its due course (CDA 2008 and ICMAM-PD, 2009). In view of these changing scenarios of Chilka mouth field and model investigations on hydrodynamic processes such as water levels, currents, circulation, flushing etc were initiated and the results were presented in the paper.

CHILKA LAGOON AND DATA

Chilka, the tropical coastal lagoon, (Figure 1) located on north-east coast of India (Lat 19^{o}.19N to 19^{o}.54N, Lon 85^{o}.06E to 85^{o}.35E), with a water surface area of 900 km^2, oriented in SW-NE direction. Maximum length and breadth of the lake is 65 km and 20 km respectively. The lake is shallow with a mean depth of 1.7 m. The lake is connected to the Bay of Bengal through three inlet mouths; 1) the oldest naturally formed mouth near Arkhakuda, 2) the artificially dredged mouth in September 2000 by Chilka Development Authority (CDA) near Sippakuda and 3) the

naturally opened mouth on 1st August 2008 at Gobbakunda. As the old mouth got totally closed by natural siltation and most of the sea water excursion is taking place into the lake through the 'dredged mouth' and the 'natural mouth' at present.

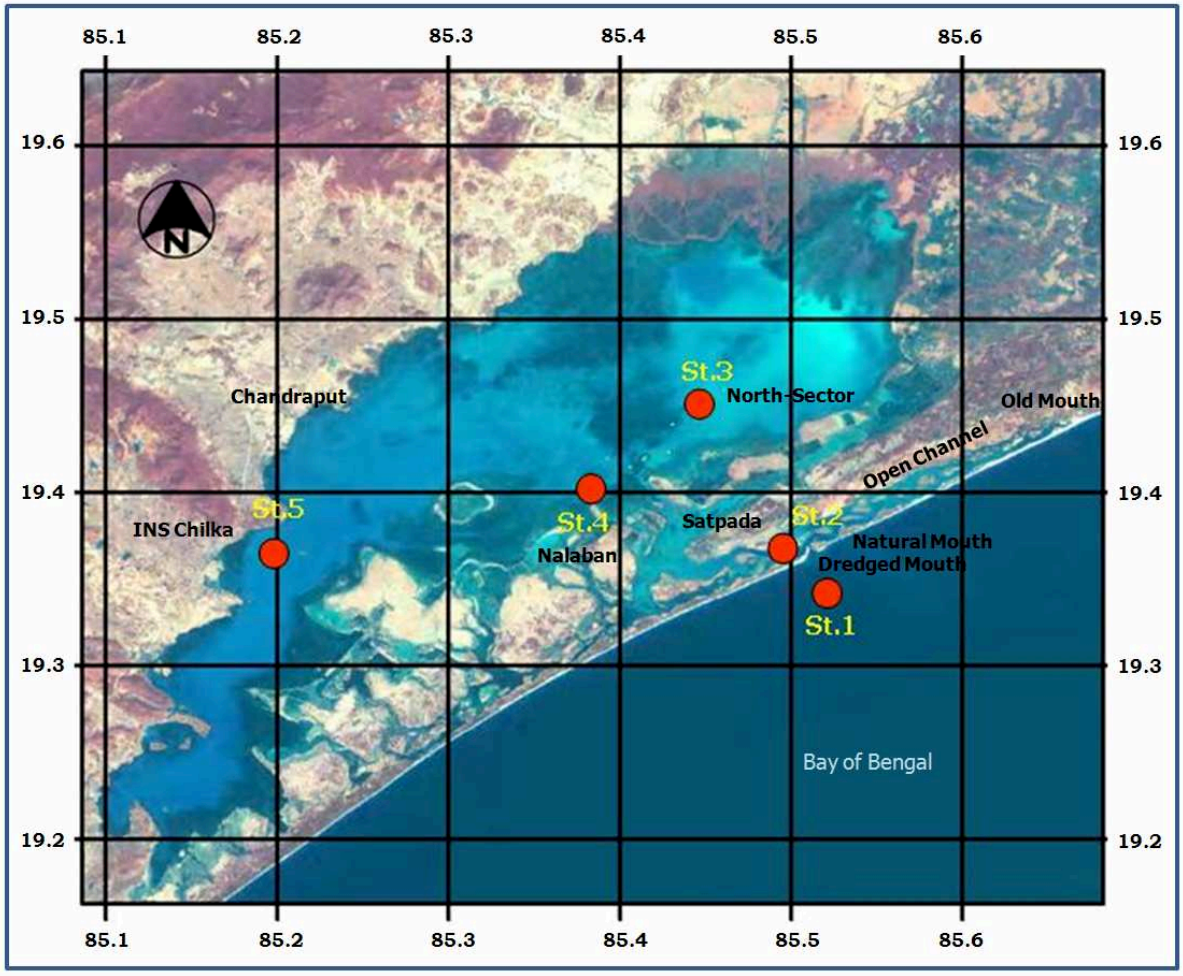

Fig.1. Chilka lake with station locations

For field measurements of water levels and flow velocities, total five stations were fixed (Figure 1) in chilka lake. At each station water levels and wave parameters were recorded by Valeport Wave and Tide Recorder (WTR) where as flow velocities were recorded by Aanderra Recording Current Meters (RCM). The WTR has an accuracy of ± 0.01m for water level. The RCM has an accuracy of ± 0.01 cm/s for speed and ± 4^o for direction. The parameters were recorded simultaneously at all the stations at 10 min intervals over a period of 30 days (20 December 08 to 10 January 09) in NE monsoon and 20 days (4 to 24 May 2009) in SW monsoon. Wind speed and direction were recorded at hourly intervals continuously from a fixed platform at two locations i.e., at INS Chilka, and at Satpada (Figure 1) by installing Thies Clima Automatic Weather Stations. The wind speed has an accuracy of 0.01m/s and direction ± 5^o. Bathymetry in the lake waters as well as in coastal waters off Chilka mouth was surveyed using ODOM echosounder integrated with DGPS and heave sensor. The echosounder has an accuracy of ± 0.02m in depth measurements, the DGPS has ± 1m in position accuracy and heave sensor has ±

2cm in pitch and roll movements in height. The river discharge data for various creeks has been measured at regular intervals of time over a period of one year.

RESULTS AND DISCUSSION

Bathymetry and Inlet Dynamics

Bathymetry of Chilka region (Figure 2a), reveals the presence of submerged shoals at a water depth of 5 m in offshore waters of chilka mouth. The shore south of the mouth is very gentle compared to the northern shore. Inside Chilka, the bathymetry is also highly variable from one part to other. The NW portion is the shallowest region where depths ranging from 0.5 to 1.5 m. The central portion is occupied with moderate depths of the order of 1 to 2.5 m. The SW portion (Rambha region) is the deepest portion with depths vary between 2.5 and 4.0 m. However the outer channel is occupied with deeper depths varied between 2.5 and 4.5 m. Chilka inlet positions for different months (Figure 2b) indicate that the mouth is continuous variations in its position with time. Both dredged mouth and recently formed natural mouths undergoing rapid changes in their cross-sectional dimensions. Width of the dredged mouth is getting narrower (presently limited to 200m) while width of naturally formed mouth getting wider (at present the width is changed to 700 m). The dredged mouth shifted by about 1 km during the past 8 years (2000-2009). Depth of the dredged mouth in December 2008 is 9.2 m while in December 2009 it is 9.2 m.

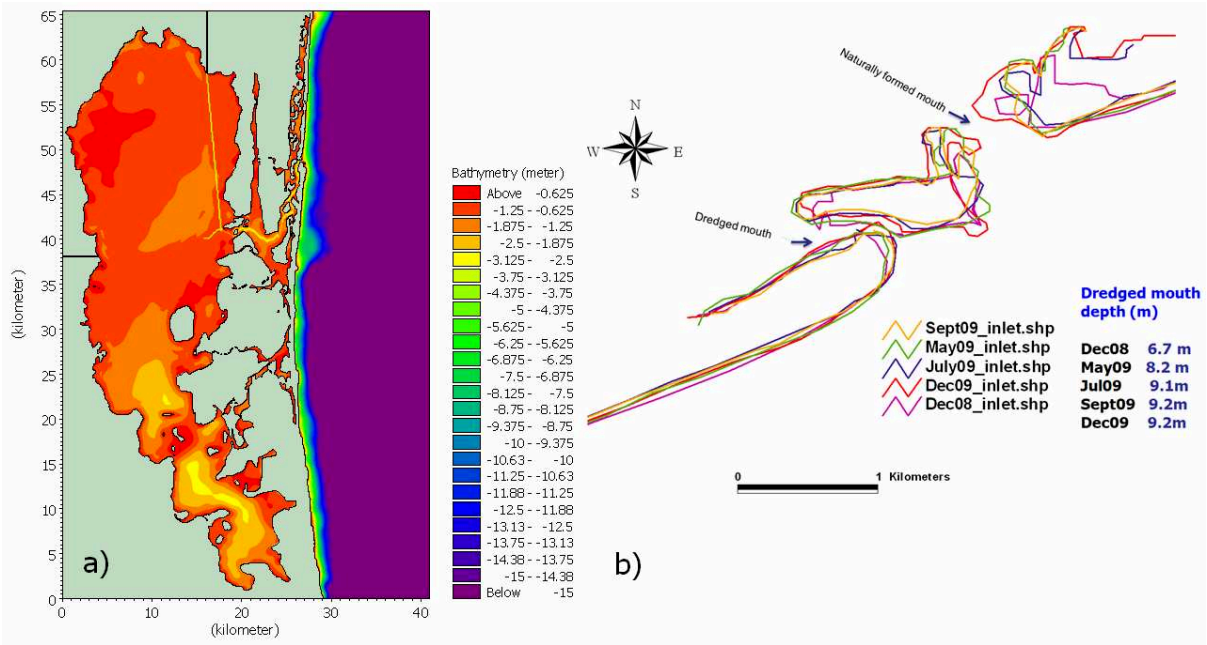

Fig. 2. Variations in Chilka Inlet Mouth during 2008-09

Seasonal Wind Pattern

Climate of the Chilka region is tropical, with two dominant seasons defined in terms rainfall patterns i.e., SW monsoon from June to September and NE monsoon from November to February (Ghosh and Pattnaik, 2004). Wind roses at Chandraput (Near St . 5) during NE monsoon (Figure

3a) indicate that the maximum speed of wind reached is 8.2 m/s where as during SW monsoon (Figure 3b) the maximum wind speed reached is 8.6 m/s. Most percentage of the winds blow from E and NE direction during NE monsoon where as blow from W and SW during SW monsoon. Wind distribution at Satpada (near St 2) during NE monsoon (Figure 2c) indicate that even though winds blow from E and NE direction maximum percentage of winds blowing from W. Similarly during SW monsoon (Figure 3d) most percentage of winds blows from E even though there are winds from W and SW directions. This clearly indicates that the wind pattern in the Satapda region (Eastern location of Chilka) is controlled by onshore and offshore wind pattern characteristic of land and sea breezes. However the wind pattern at Chandraput is controlled by seasonal reversal of monsoonal wind pattern.

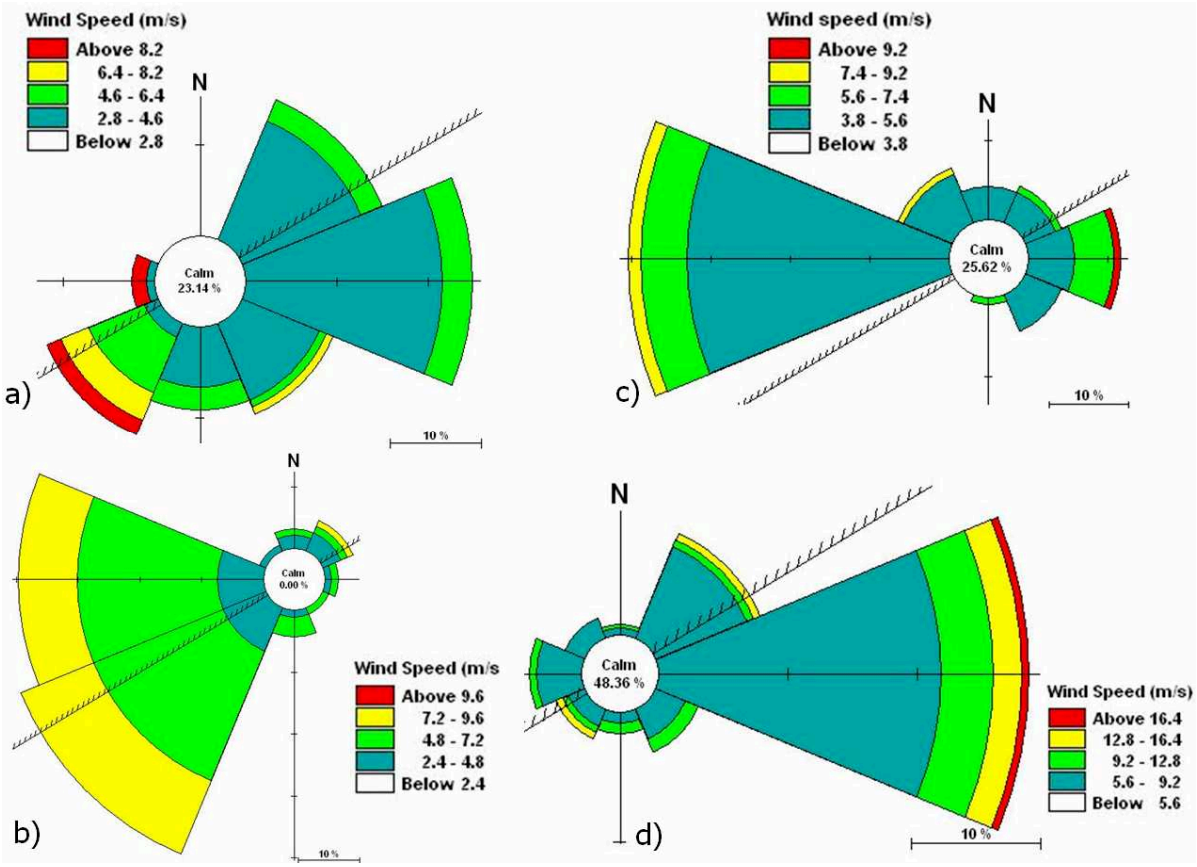

Fig. 3. Rose diagrams for a) & c) for Chandraput and Satpada stations under NE monsoon; b) & d) for Chnadraput and Satpada stations under SW monsoon

Upland River Discharge

Monthly distribution of total fresh water discharge from six major rivers (Daya, Bhargavi, Luna, Makara, Kansaria and Tarimi) into the Chilka Lake for 2007 and 2008 is shown in Figure 4. In general the fresh water discharge into the lake is high (500 to 8000 million cubic meters) during July to October. Maximum fresh water discharge in 2007 is 8000 million cubic meters where as in 2008 it is only 1150 million cubic meters. Thus the influx of fresh water into the lake is dependent on the prevailing monsoon activity of the region.

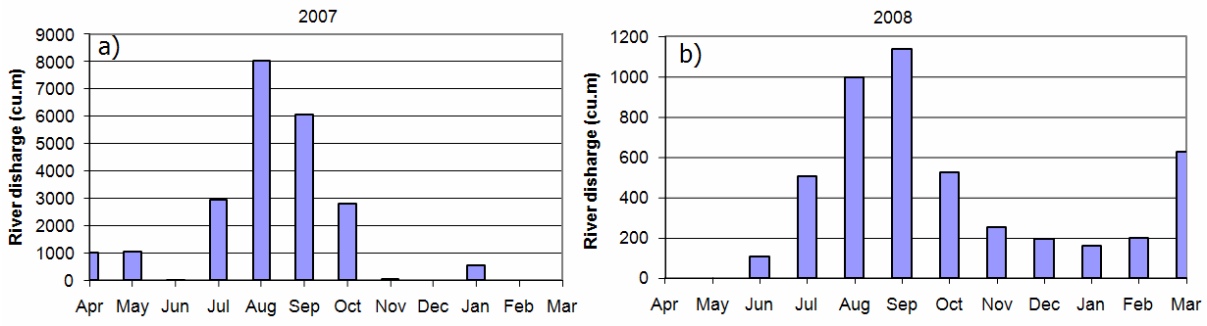

Fig. 4. Monthly distribution of fresh water discharge into the Chilka lake for the years a) 2007 and b) 2008

The percentage distributions of fresh water influx from different rivers (Figure 5) indicate that there is wide variation in annual discharge from each river. In 2007, Kansari and Bhargavi and Daya are the major contributors for fresh water influx and their percentage contribution is 32%, 25% and 29% respectively. However in 2008, the major contributors are Makara, Bhargavi and Daya and their percentage contribution is 47%, 22% and 12% respectively.

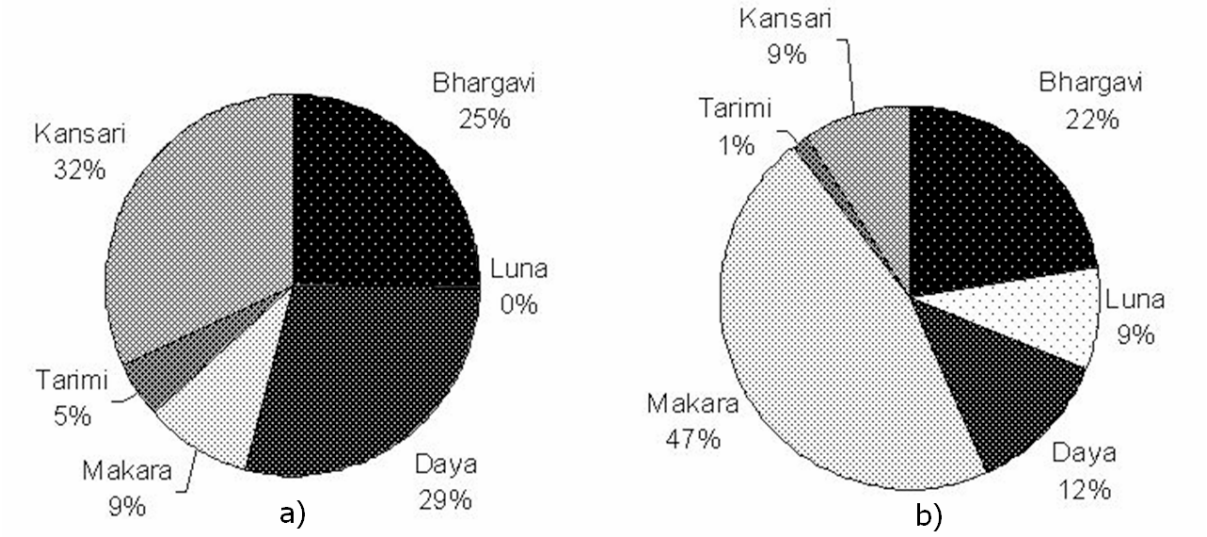

Fig. 5. Percentage distribution of fresh water discharge into the Chilka lake during a) 2007 and b) 2008

Tides and Tidal Propagation

Distribution of recorded tide at Stations 1 to 5 for NE Monsoon period (12 December 08 to 22 January 09) and SW Monsoon period (2 May 09 to 17 May 09) are shown in Figure 6. At all stations, the tidal variation is more or less remain same during both the seasons. The tidal curves indicate that the shape of tide is symmetrical at Sts. 1 and 2 (Figures 6a, 6b, 6f and 6g) where as at other stations the shape of tidal curve is highly asymmetrical. This indicates that the tide propagation from offshore region (St. 1) to Chilka mouth (St. 2) is not undergoing much change. However once crosses the Chilka mouth, the tide propagation inside the lake is drastically

controlled by the topography. At St. 1, the maximum tidal range is 2.1 m. As the tide propagates into the Chilka mouth the maximum tidal range reached is 1.2m, the same tide as it reaches at other stations (Sts 3, 4 and 5) the tidal range drastically falls to 0.05m. Thus it clearly shows that the tidal propagation is normal with in the open channel and beyond i.e. inside Chilka the propagation is very much due topography of the lake.

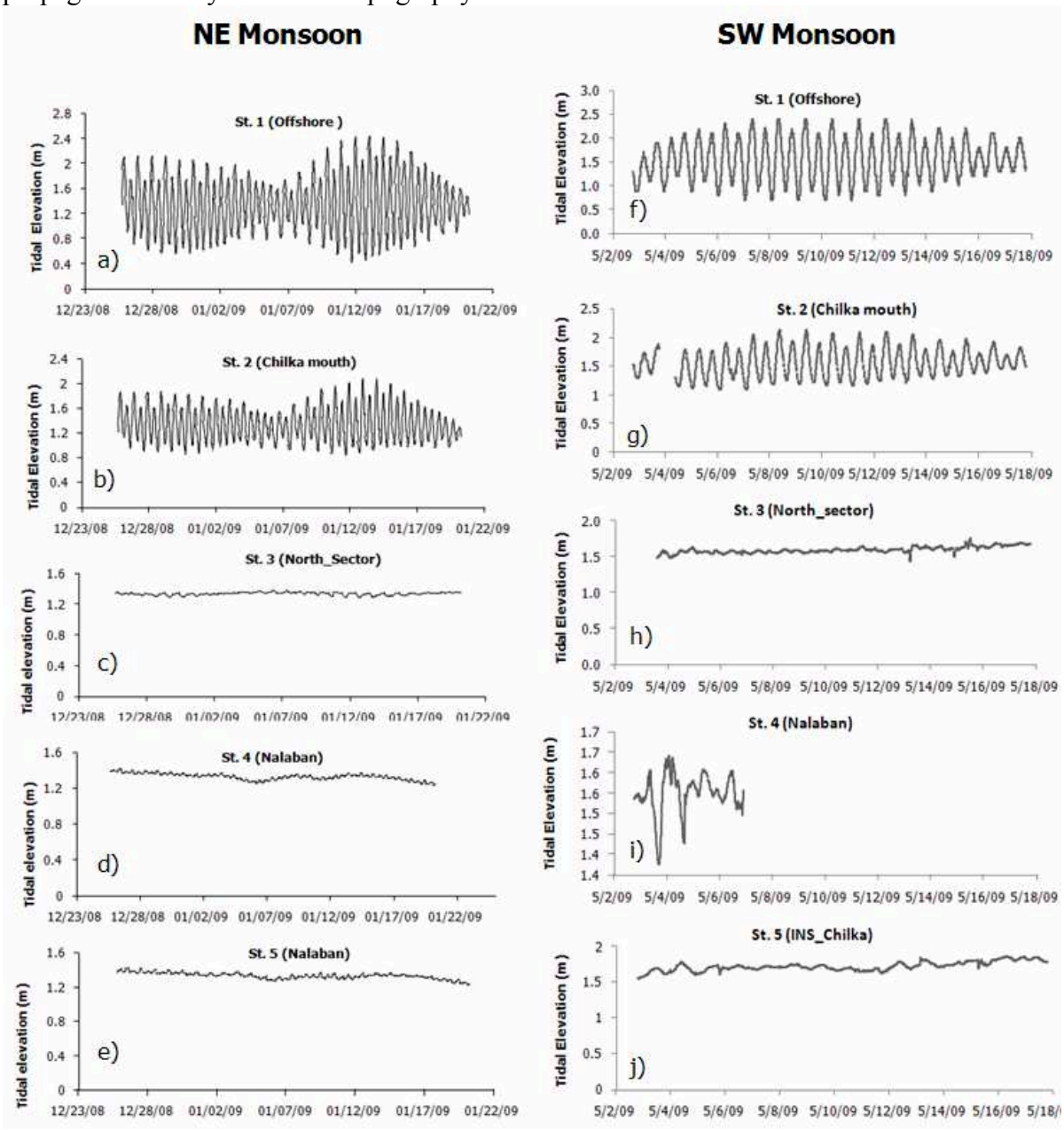

Fig. 6. Distribution of water levels at Sts 1 to 5 during NE Monsoon period (12 December 08 to 22 January 09) and SW Monsoon period (2 May 09 to 17 May 09)

To study the spatial and temporal variations in tidal propagation, harmonic analysis was performed for the recorded tide at 5 stations using the mike 21 toolbox (DHI, 2007). Semidiurnal M2 and S2 constituents dominate the amplitude of tides at the Chilka mouth. The form of the tides, as determined by the amplitude ratio f = (K1 + O1)/ (S2 +M2) is 0.46, which describes the

tides as 'Mixed and mainly semidiurnal'.

Currents and Circulation

Distribution of currents (Figure 7) at five stations (Offshore, Chilka mouth, Nalaban, North-Sector and INS Chilka) during NE Monsoon period (12 December 08 to 22 January 09) and SW Monsoon period (2 May 09 to 17 May 09) are shown in Figure 7. Current variations at all the stations are more or less remain same during both the seasons. Currents at Sts 1 and 2 (Figures 7a, 7b, 7f and 7g) indicate that they are controlled by tidal excursion of sea water. They run into the lake during rising tide and out of the lake i.e., into the sea during falling tide. Highest speeds of 60 cm/sec occurred at Chilka mouth (St 2). The second highest speeds are noticed at offshore location (St 1) where the speeds reached a maximum of 40 cm/sec. The third highest occurred at North-Sector where the speeds reached a maximum of 25 cm/sec. At other two stations (Sts 4 and 5) the speeds are only around 8 to 10 cm/sec.

The rose diagrams indicate that at Sts 1 and 2, the current directions are reversed with reversing tide. However, at other three stations the currents are in all direction of dial, indicating the influence of forces on water circulation other than the tidal force. On the whole it is observed that the tidal influence on current pattern is mostly limited to open channel are but beyond i.e., inside Chilka Lake, the currents are controlled by other factors such as wind, upland fresh water discharge, topography etc.

CONCLUSIONS

Chilka lake comprises four distinctive areas 1) the North-Sector, influenced mainly by fresh water most of the year, 2) the Central sector - corresponds to mixing of both fresh and saline water, 3) the Rambha sector - the deep portion constituted of mixed waters of fresh, saline and wind and 4) the open channel - completely renewed by oceanic waters during dry season and flooded with fresh water during rainy season. Bathymetry of Chilka is highly variable. Submerged shoals are formed at the mouth of the lagoon. The shore south of the mouth is very gentle compared to the northern shore. Inside Chilka Lake, the bathymetry is complex - the NW portion is the shallowest, the central portion is of moderate depths, the SW portion (Rambha region) is the deepest and the open channel is of deeper depths. Chilka inlet undergoes continuous variations in its position with time. Both dredged mouth and recently formed natural mouths are undergoing rapid changes in their cross-sectional dimensions. Width of the dredged mouth is getting narrower and shifting northward while naturally formed mouth becoming wider especially on seaside. Climate of the Chilka region is tropical, with two dominant seasons - the SW monsoon from April to September and the NE monsoon from November to February. Wind pattern at seaward end is controlled by onshore and offshore wind pattern characteristic of land and sea breezes. However the wind pattern on western end is controlled by seasonal reversal of monsoonal winds. In general the fresh water discharge into the lake is high (500 to 8000 million cubic meters) during SW monsoon season which undergoing appreciable variation year by year. Tidal propagation into the lake is dominant in open channel area i.e., within 4 km upstream but beyond the propagation is drastically diminished. Seasonal variation in current pattern inside is not much significant. The currents in the open channel are controlled by tidal excursion of sea

water but inside Chilka, the currents are influenced by other factors such as wind, upland fresh water discharge, topograhy etc.

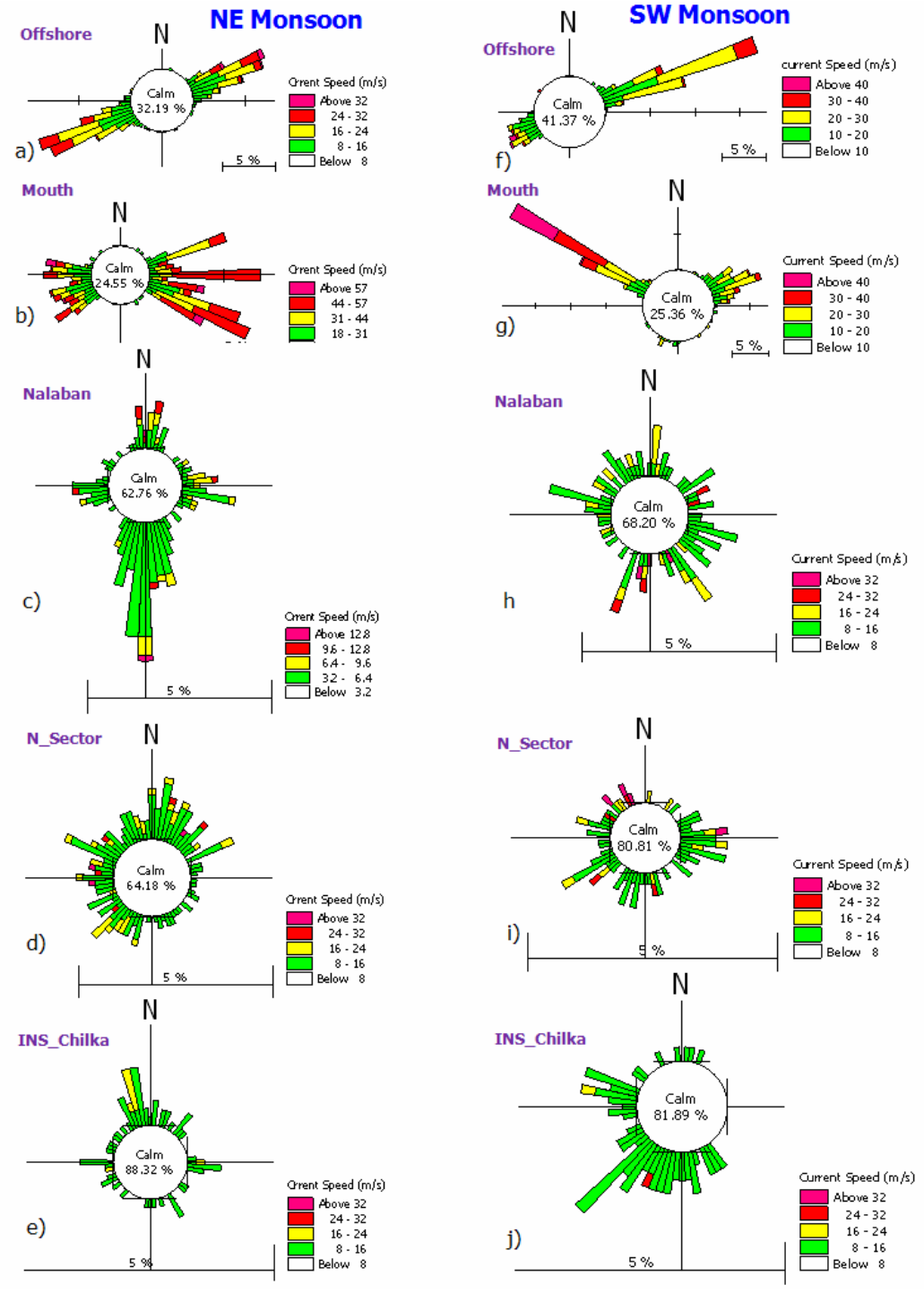

Fig. 7. Distribution of Currents at Sts 1 to 5 during NE Monsoon period (12 December 08 to 22 January 09) and SW Monsoon period (2 May 09 to 17 May 09)

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