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The Circulation and Flow Regime of Upputeru, Outlet Channels of Kolleru Lake, India

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Abstract

The Kolleru Lake is connected to the sea through Upputeru with two channels, old original mouth and new artificial mouth. The purpose of the new artificially dredged channel was to increase the discharge capacity of the lake, especially during extreme flood events, but it completely alters the Hydrodynamics of the Upputeru channel. The artificial dredging of the new channel mouth brings a seasonal shift in old mouth and makes old mouth shallower than prior construction of the new mouth. The shallow old mouth discharge water only when there is a surplus amount of water accumulated in the new mouth and also during extreme flood events. The seasonal shift of the old mouth is due to the lack of sufficient discharge from the main course of the channel, which was diverted through new mouth and because of seasonal change in the offshore circulation in the adjoining sea. The course of the new mouth was also modified by the action of waves, currents and tides of the adjoining sea as there is a change in the distribution of wave energies at both the river mouths due to different seasons. Reversal of flow pattern was observed at the river confluence, where the new channel was diverted from the old channel. Modelling studies on waves and currents were carried out using MIKE 21 PMS and HD to understand the dynamics of the flow pattern. Modelling studies show good matching with the In-situ data. Modelling studies as well as in-situ observations reveal important aspects of the flow conditions in and offshore upputeru channels and rootcauses for offshore river mouth shift.

Keywords: Kolleru Lake, Upputeru channel, Landsat, Modelling studies, discharge, offshore circulation.

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INTRODUCTION

Since ancient times, it is well known fact that civilizations develop along the banks of rivers and lakes as they provide a good livelihood for the mankind. The regions of fresh water channels near the confluence with the sea have become a focus for drawing attention of human beings during recent times owing to the several uses. Although river management has commonly occurred over the past 50 years, most studies have focused on the short or medium term behavior of estuarine flows, few studies have been conducted and little is known about the long-term estuarine response associated with river management schemes (Kjerfve & Greer, 1978) (McAlice & Jaeger, 1983). No systematic study has been done to understand the hydro-dynamic behavior of the Upputeru River. There is only a few researchers carried their studies on the brackish conditions and degradation of the Lake Kolleru is the largest fresh water lake in India. It covers an area of 308 km². It is situated between latitudes 16˚ 32΄ and 16˚ 47΄N and longitudes 81˚ 05΄ and 81˚21΄E and covers parts of West Godavari and Krishna districts of coastal Andhra Pradesh and is 30km inland from the Bay of Bengal. Kolleru serves as a habitat for migratory birds and serves as a natural flood-balancing reservoir for the Krishna and the Godavari rivers. The lake is fed directly by water from the seasonal Budameru and Tammileru streams and also connected to the Krishna and the Godavari systems by over 68 inflowing drains and channels (Prasad et. al. 2011).

Aquaculture, fish ponds and paddy fields exist around the upputeru river depend on its water. The river is quite narrow, meandering and shallow. A long and very narrow drain called Yanamadurru drain joins the river at its lower reaches. Usually, the water from this drain is almost insignificant. During the monsoon season and especially at the time of storms, cyclones and floods, both Kolleru Lake and Yanamadurru drain discharge high volumes of water to the river. The river is narrow and shallow, the paddy fields beside the river bank are inundated and remains for a longer time. In order to overcome the difficulty, a hydrological intervention by way of opening a new mouth during the 1970's just above the joining region of Yanamadurru drain into Upputeru river. This formed a mouth called 'new' or 'artificial mouth' to the river in addition to the 'old mouth'. The distance between the old and new mouth is approximately 7 km along the coastline (Prasad et. al. 2013). As there is no other significant work or literature is available on the study area, the present study provides important contribution towards understanding the flow regime and hydrodynamics of the upputeru channels of Kolleru lake and changes in the river mouth. In this paper, we carried out modelling studies on waves and currents using MIKE 21 PMS and HD to understand the dynamics of the flow pattern. Modelling studies show good matching with the In-situ data and reveal important aspects of the flow conditions in and off upputeru river. Satellite imagery data from Landsat 1973 to 2010 was analyzed and presented to understand the changes in the river mouth shift.

STUDY AREA

Kolleru Lake is a shallow lake with depths ranging from 0.5 to 2m. Higher depths are observed only in the central parts, whereas lower depths are encountered along the margins. Kolleru Lake maintains its connection with the Bay of Bengal through a 60km long, intricately meandering tidal channel called 'Upputeru River' (means salt stream). The upputeru river, the only outlet channel of Kolleru is narrow meandering and shallow with a stretch of about 60km between Kolleru Lake and the Bay of Bengal as shown in Fig. 1.

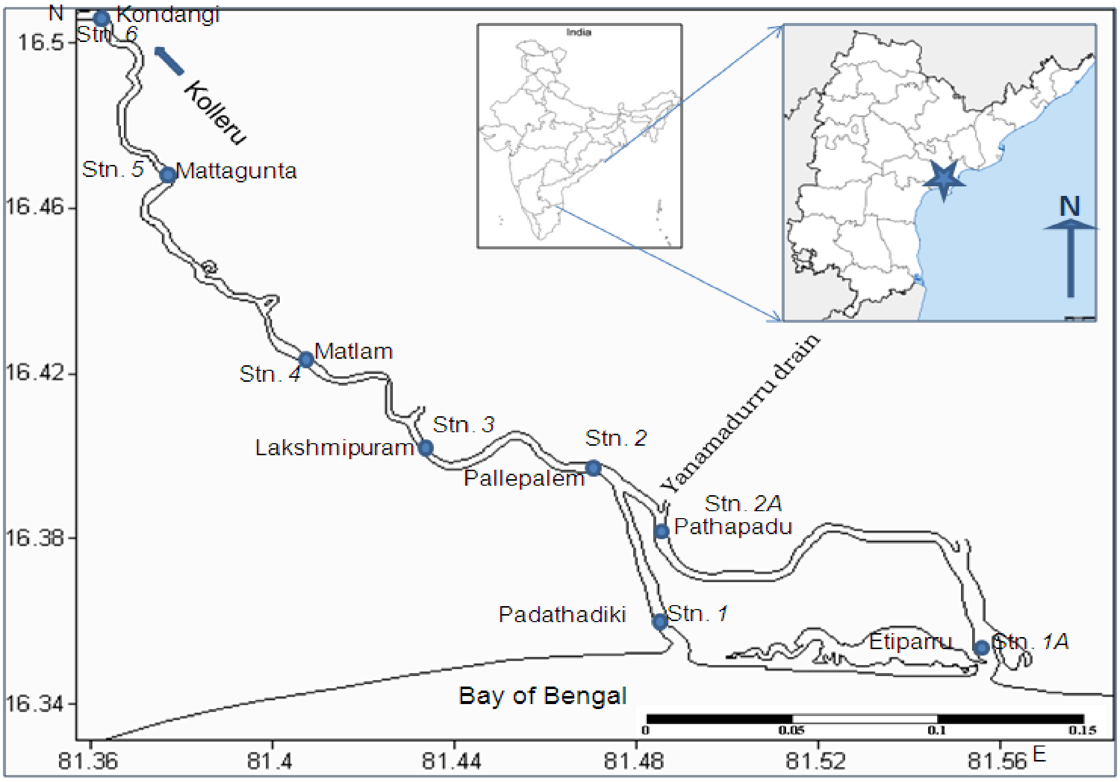


Fig. 1: Upputeru course – Study area map

Material and Methods:

The studies have been carried out through the collection of field data on Tidal variations, Water level and Currents to understand the spatial and temporal variations (Dyer and Ramamoorthy 1969). Four stations were selected along the river from both the river mouths for collection of data to study the circulation in the estuary and in offshore sea. The stations have been separated by 4-5 km distance in order to meet tidal excursion. In-situ data of current meter were employed to measure the current in the river. The accuracy of the instrument is about ±0.02m/s. The channel depth of the river was measured with a portable echo sounder. Graduated Bamboo poles have been used to measure depths near the shores where the depth is very less. The water level variation at every study location has been observed by employing tide poles. All measurements were corrected to the high water time. Depth cross-sections were obtained at every 2-3 km interval throughout the study area of the river. Based on the data the relief profile of the deep channel along the river has been worked out. The LANDSAT data from 1973 to 2010 were obtained from the earthexplorer.usgs.gov. The shift in the river mouth was observed in imageries of LANDSAT (missions 1-7) from the USGS EARTH EXPLORER in the bands of 1-7 having resolution 30 m & PAN band 8 having 15 m resolution.

MODELLING STUDIES

A two dimensional numerical model used to understand the hydrodynamics using MIKE 21 modeling Suit. The spatial and temporal variability of wave refraction (PMS), energy distribution and flow pattern (HD) in MIKE 21 (DHI 2007). The bathymetry of the study region for modeling studies was prepared from the surveyed bathymetry, digitized topo sheets from the survey of India. The data from other sources like C-MAP data are used to fill the data gaps. All the depths are referenced to chart datum. Grid resolution has been selected to 10 m after many iterations during the initial stage. The river boundaries are closed except at two locations towards the sea.

MIKE 21 PMS wave model (description and setup)

Mike 21 PMS simulations have been made to understand the wave conditions along the confluence of Upputeru. Mike 21 PMS model is a based on the parabolic mild slope equation (Berkhoff 1972). According to the climatology in this region, the predominant deep water wave height during the SW Monsoon ranges from 1-3 m and during the NE Monsoon it is around 1m and the wave directions are 135^{o} and 90^{o} during SW and NE monsoon respectively the model run was performed for the three different months during the year representing calm, SW and NE monsoon periods. Thus, waves of significant wave height 1 m with the time period 8 s were considered for the modeling. The channel boundaries are closed and open through the sea at two locations. We simulated the model under these conditions. The study region has been modeled for different wave approaches. The integral wave parameters like significant wave height (H_s) and mean wave period (T_m) are extracted at 50 m depth contour in Study region and are presented (Table 1).

Table 1: Mean wave climate in offshore waters (50 m depth) near the Study location (based on model data)

S. No.	Wave Direction	Hs	Tm	% Occurrence
1	E	0.90	6.40	1.46
2	ESE	0.76	5.57	9.00
3	SE	0.67	5.53	25.85
4	SSE	0.86	6.11	62.60
5	S	0.68	4.40	1.09

All the model parameters have been unchanged and the model is simulated for five predominant directions.

MIKE 21 Hydrodynamic model (description and setup):

Mike 21 Flow model has been used to simulate currents in the channel as well as in the offshore region of the adjoining sea of Upputeru channels to understand the circulation pattern. MIKE 21 Flow Model is a modelling system for 2D free-surface flows, can be applied wherever stratification can be neglected. The hydrodynamic (HD) model simulates water level variations and flows in response to a variety of forcing functions in lakes, estuaries and coastal regions. The model has been executed over a tidal cycle and calibrated with the measured tidal currents in the region of confluence during November 2010, March and May 2011. After successful calibration with the in-situ, the same calibration coefficients are used for the remaining model execution for the observations during different months. The bed resistance and eddy viscosity are used as the calibration parameters.

RESULTS AND DISCUSSION

Circulation pattern of Upputeru:

The adjoining sea of the Upputeru is the Bay of Bengal having three different conditions during a year are Southwest monsoon SW (June to September), Northeast monsoon NE (November to February) and a transition period between these two seasons. The off shore current was towards the west during NE monsoon and during the rest of the year the current was towards east. The coastal currents flow roughly parallel to the shore constituting a relatively uniform drift in the deeper water adjacent to the surf zone. The circulation near the new mouth and old mouth are quite complex as the tidal current, offshore currents and longshore current are interacting with each other and also wave current interactions are present. The currents were strong during the monsoon period & weak during the non-monsoon period (i.e. February, March).

The current was observed to be reversed at Pathapadu the river confluence region, where the new mouth deviated from the old mouth. During November 2010, the currents are weak along the channel with slightly higher speeds in the right entrance channel (towards *the old mouth*) than in the left entrance channel (towards *new mouth*) during high tide. At the new mouth, mostly the circulation is lateral mixing as the river discharge is cornered to the eastern bank of the river and sea water intrudes from the west bank. So the currents are strong on the eastern bank and weak on the western bank. Due to this reason the eastern bank of new mouth is deeper than western and also severe erosion is observed at the new river mouth as evident from the across depth measurements near new and old mouths as shown in Fig. 2.

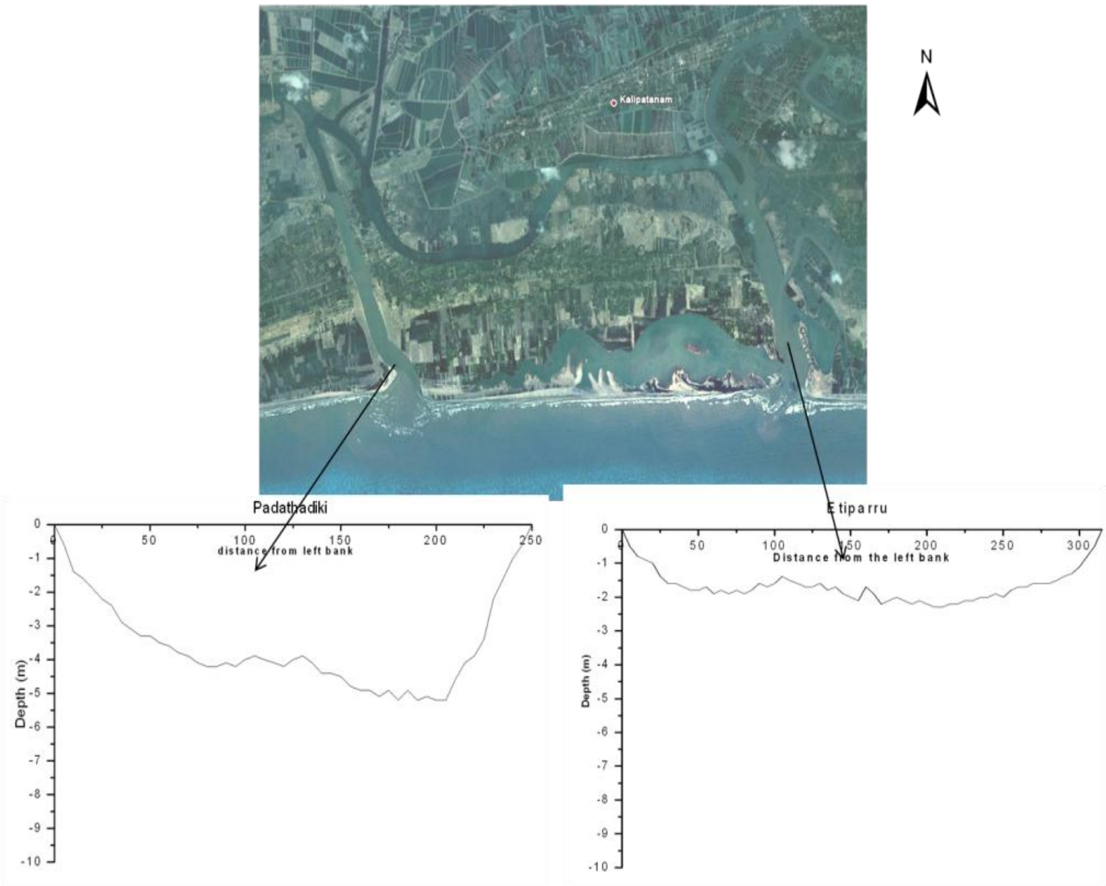
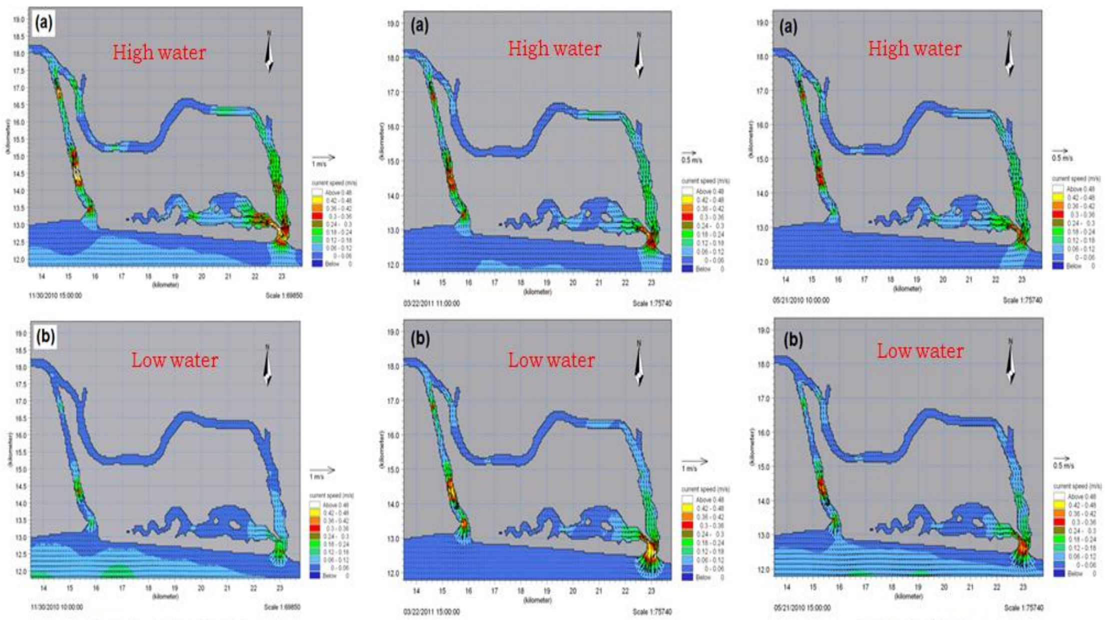


Fig. 2: Original and New mouths of Upputeru outlet channel
and their cross section depth

It has to be noted that the pattern of currents is quite different in the two channels, one with stronger currents and one with weaker currents. A similar pattern has been observed in the case of March and May 2011. The main reason for this peculiar behaviour of the right channel is due to its prolonged length of almost 12 km as compared to the left channel, it is just 5 km from the sea mouth. During the high tide when the waters enter the channel, the currents are directed towards the head and reach up to the sharp joining at around 5 km away, where another stream has been separated from the mainstream which leads towards right channel. As the tide becomes higher, more waters enter into the mainstream and some of the portion of water turns towards the right portion of the channel and will flow southward. The southward flow opposes the upward waters that enter from the right channel and thereby creating clam waters in the middle due to balance. We can notice an increase in tidal height in the middle of the right channel during this stage. As the tide progresses to low tide, the phase angle changes in the sea, this attracts waters towards it, which results in more water already piled up within the right channel forces into the sea with greater velocities. So the discharge is almost completely diverted to new mouth, leaving only one drain. Because of the new mouth, which is a straight cut from the sea, the flood and ebb tidal currents are significant only from this channel and so the sea water intrusion. The model simulated current during different conditions and different seasons are as shown in Fig. 3.



(i) November 2010 (ii) March 2011 (iii) May 2011

Fig. 3: Simulated currents along the entrance channels of the river

The shallow old mouth discharges water considerably only when there is a surplus amount of water accumulated in the new mouth and also during extreme flood events. We have observed time variability in the occurrence of the maximum and minimum water levels for the two seasons. A significant variance in the water levels during High tide and low tide are noticed.

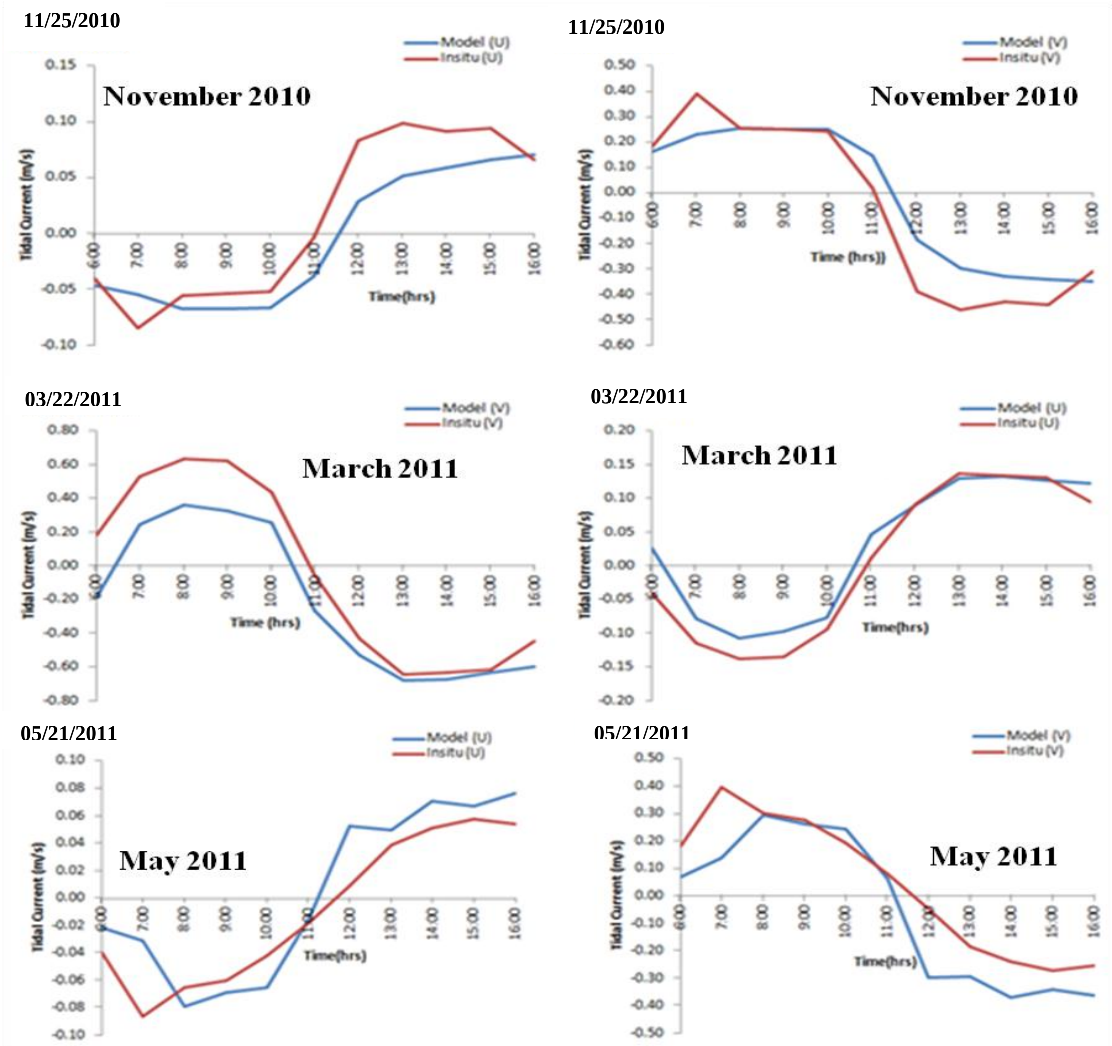


Fig. 4: Comparison of model derived and measured currents in the river

Fig. 4 shows the validation of *u* and *v* components of current speeds during November 2010 and March and May 2011. The tidal currents derived from the numerical model are well matched with the *in-situ* data.

River Mouth Changes of Upputeru:

Landsat images were used to observe the changes in the river mouth of the Upputeru River from 1973 to 2010 as shown in Fig. 5.

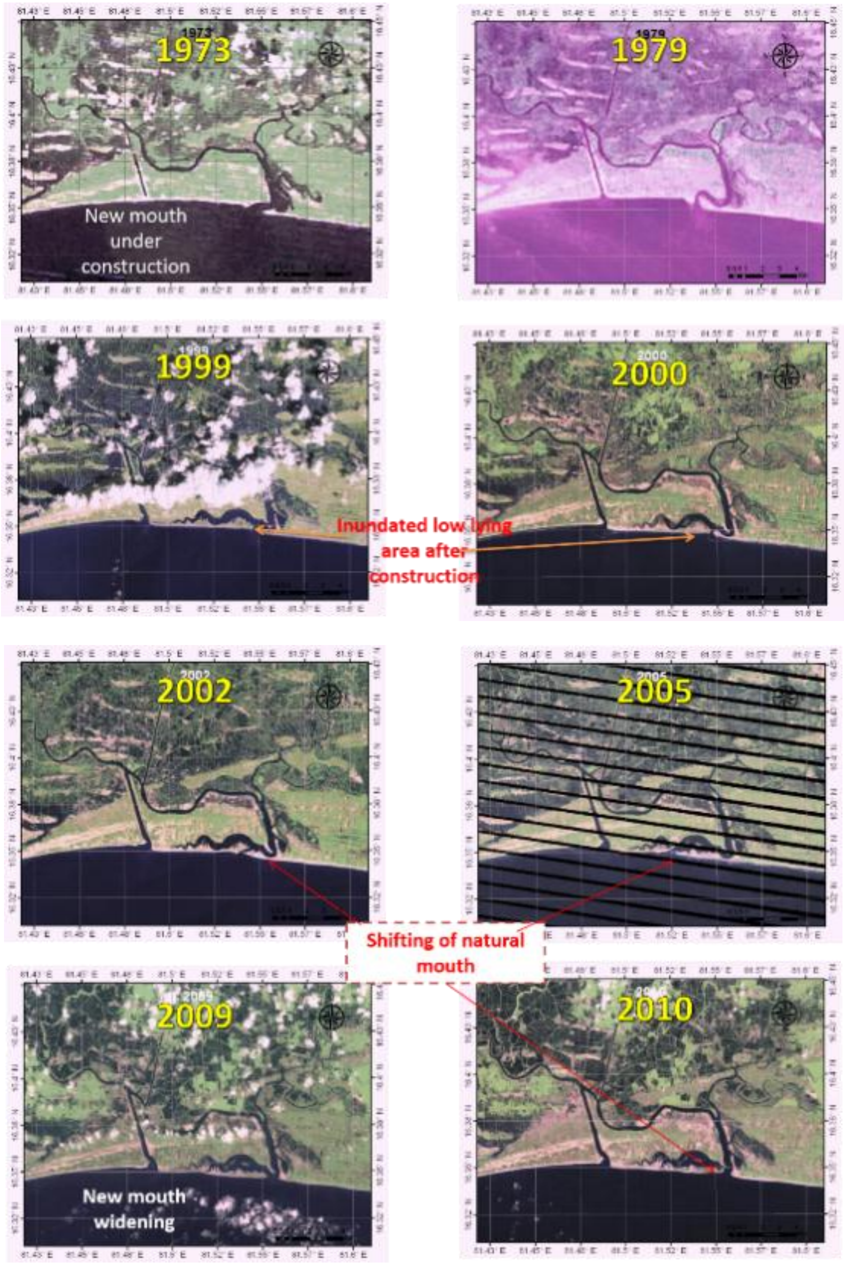


Fig. 5: Evolution of river mouth of Upputeru River observed from Landsat images

The *New mouth* (Left channel) was created during 1973. The course of *Old mouth* (Right channel) has been observed to be changed after the construction of the *new mouth* (1978). During 2002 shows that the connection with sea near the *Old mouth* was further strained and the mouth topography was transformed, inundating the lowland areas near the confluence. The Old mouth was dredged during 2010 and a developer connection with the sea near the confluence was observed. So to understand the changes of the river mouth, it is also important to know the effect of waves on the coast.

The study region has been modeled for predominant wave directions. The Simulation of waves from predominant directions off Upputeru channels is as shown in Fig. 6.

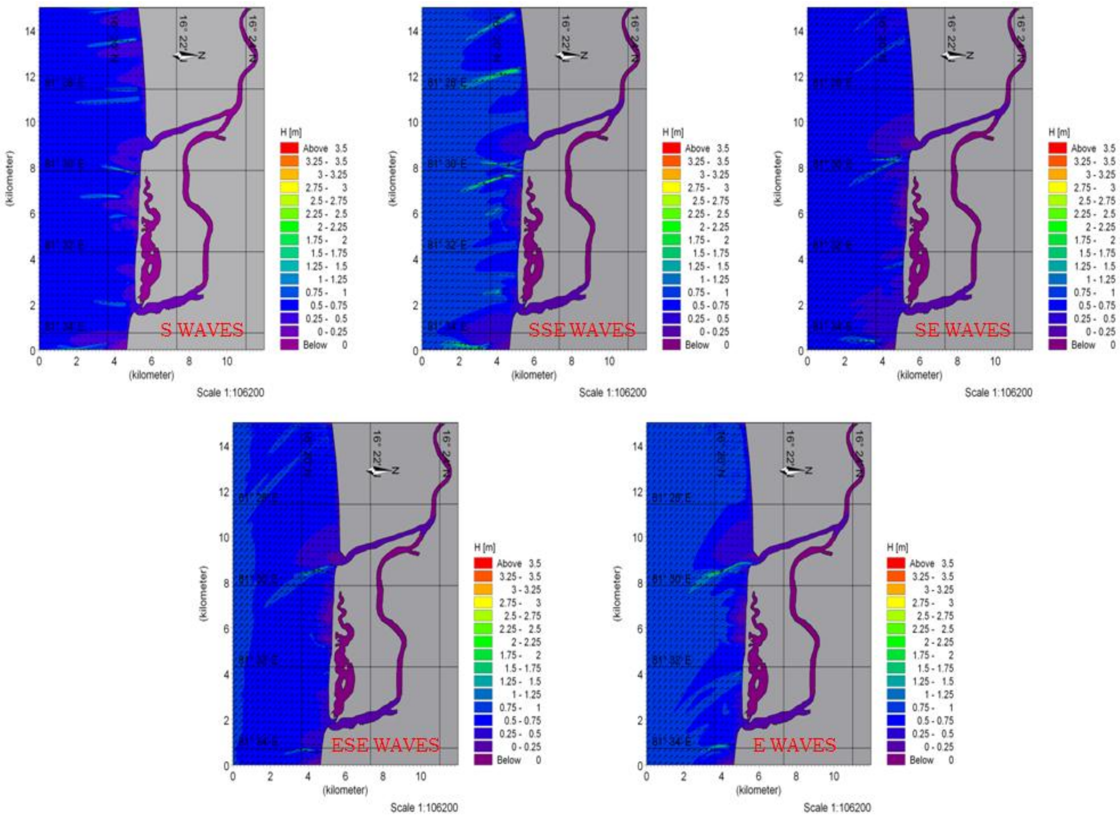


Fig. 6: Simulation of waves from predominant directions off Upputeru channels

As the coast is oriented in N-S direction, the waves approaching from SE and SSE directions are predominant in this region wave height ranging from 0.5 -1 m. It has been observed that the offshore waves have undergone refraction and shoaling due to different wave directions and offshore wave heights.

During the SW monsoon, the wave pattern shows an alternate convergence and divergence along the coast. More energy was concentrated in the eastern part of the domain and slowly divergence (lower wave heights) occurs along the western part. The maximum possible simulated wave height was 2.6m or above with a deep water wave height of 1m.

Similarly, in case of NE monsoon the wave refraction already started at deeper depths and the pattern shows as it reaches from more or less the same direction in case of SW Monsoon. There are large areas of divergence apart from small cells of convergence near the mouth of the Upputeru. The maximum admissible wave height with a 1m deep water wave height is 2.3m. This shows that the sea state is relatively weaker during NE monsoon. The convergence of waves is significant all along the region in between the two mouths of the river. Since wave convergence causes high wave energies, the region in between the mouths of the river shows erosion. The same pattern has been observed during both SW and NE monsoon seasons (Fig. 7).

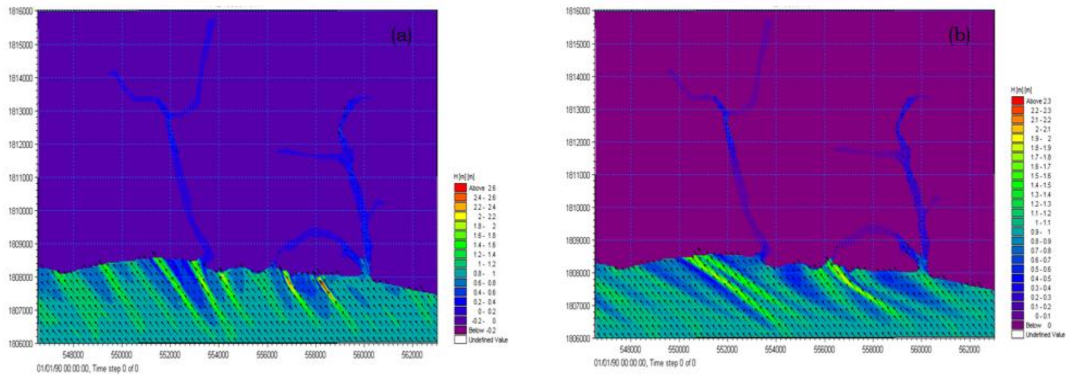


Fig. 7: Near shore wave refraction during (a) SW and (b) NE monsoon seasons

The wave divergence has been observed more or less near both the mouths during both the seasons. But, the region near the original mouth has been encountered more divergence during SW monsoon season with a little change during NE monsoon season.

The estuary has a complex morphology with a single channel and narrow banks at the river entrance and the bay mouth, and a bifurcated channel system (main and western channels, respectively) in the middle part that appears to affect the residual circulation (Kim & Voulgaris, 2005). At the new mouth the coastal and wave generated (long shore) currents are strong towards east during the SW monsoon and the cross flow from the river (discharge) is high but cornered towards the eastern bank of the river as said earlier. Therefore the currents are strong on the eastern bank of the river and weaker on the western side so we observe severe erosion on the eastern bank. Thus, we can observe slight erosion on the eastern coastal side of the new mouth and deposition on the western coastal side of the mouth. But at the old mouth, there is only 7 km stretch between the Upputeru channels where the coastal currents able to bring a small amount of sediment towards old mouth. During NE monsoon, at the new mouth there is no significant change even though coastal currents are towards westward the river discharge dominates the flow. But at the old mouth there is a change in the river mouth due to strong westward coastal currents and sediment supply from the Godavari River towards this mouth. Also during this NE monsoon season at the old mouth, discharge is very low and it can't be able to overcome against coastal currents and large waves as the main course of the channel is diverted to new mouth. The estuarine discharge of the river system and the river systems that join the coast would sufficiently modify the coastal circulation along the coast. (Rao, Dash, Jain, & Dube, 2007).

CONCLUSIONS

The Kolleru Lake is connected to the sea through Upputeru with two channels, old original mouth and new artificial mouth. The coastal region of the adjoining sea is strongly influenced by the seasonal change of monsoons and as the coast is oriented in N-S direction, waves coming from the SE and SSE directions are predominant in this region. So the angle of wave approach changes completely opposite in the contrasting seasons. Wave heights mostly range within 0.5 -1 m existing for all the predominant wave directions. The wave divergence has been observed near both the mouths during both the SW and NE seasons. But, the region near the *original mouth* has been encountered more divergence during SW monsoon season with a little change during NE monsoon season. The circulation near the new mouth and old mouth are quite complex as the tidal current and offshore currents longshore current are interacting with each other and also wave current interactions are present. In the new mouth, mostly the circulation is lateral mixing as the river discharge is cornered to the eastern bank of the river and sea water intrudes from the west bank. The shallow old mouth discharge water considerably only when there is a surplus amount of water accumulated in the new mouth and also during extreme flood events. The pattern of currents is quite different in the channels, one with stronger currents and one with weaker currents. The reversal of flow pattern was observed at the river confluence, where the new mouth was diverted from the old mouth. It was observed that there is a seasonal shift in old mouth and becomes shallower than prior construction of the new mouth. This seasonal shift of the old mouth is due to the lack of sufficient discharge from the main course of the channel, which was diverted through new mouth and also because of seasonal change in the offshore circulation in the adjoining sea. It was also observed the change in the distribution of wave energies due to differing seasons. The tidal currents derived from the numerical model are well matched with the *in-situ* data.

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