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RESEARCH ARTICLE

REJUVENATION OF LAGOONS ALONG THE EAST COAST OF INDIA, MANAGEMENT: ANTHROPOCENE APPROACH.

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Abstract

Coastal lagoons are a highly unique productive ecosystem, biologically conserving units located onshore in thickly populated areas from tropics to arctic. Each lagoon and coastal wetlands along east coast vary in their characteristics seasonally and geo especially. Many lagoons are under threat in countries like India, Brazil, Australia, Sri-Lanka due to hydrological, anthropogenic, geologic, pedologic and climatologic anomalies since the last 40-50 years. Further, the uncertainties of geologic, seismic and ENSO activities in the east coast of India is continuously shifting the strand line keeping pace with sea level rise indicating loss of coastal wetlands and lagoons. Studies on deformation of lagoons and anthropogenic activities near or in the edge of the barrier islands with SLR shall change the TI's behavior and accompanying ecology. Basin and ecosystem management is essential to combat the future exacerbation of lagoons along the east coast of India in the altering scenario of RSLR, temperature induced increased evapotranspiration, longshore drift and the paucity of sediment inflow to deltas. Present study envisages about lagoons, its classification, a comparative study of major lagoons along the east coast of India in changing CC, SLR and seismic activities as ESS unit. The causes, effects and ameliorating measures to combat 21st-century natural and anthropogenic scenario of lagoons are analysed.

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Introduction:-

Marine wetlands in India consists of both natural landforms like lagoons, sand beaches, mangroves, coral reefs, salt marshes, mudflats, creeks, stony rough terraces etc and anthropogenic geophysical structures like salt pans, aquaculture farms and creeks etc. The lagoons are highly useful and productive with an abundance of flora; fauna and avifauna and an indicator of paleo records. They have the conjoint morphology of saline, brackish and freshwater geo-bio system. The lagoons vary in their characteristics in pre, active and post-monsoon period with high sensitivity. Coastal Lagoons once formed, tend to exhibit hydraulically more dynamism, prone to diminution "geospatially lifespans" due to their shallow average depth (<2m) and restriction tidal inlets (TI's) to remain within 20% of total coastal length, <https://oceanservice.noaa.gov/facts/lagoon.html>. The lagoons possess a fragile ecosystem with three Eco-tones, (a) fresh water (terrestrial vegetation, salt marshes, mangroves, cyanobacteria's formation and seagrasses), (b) Brackish water (islands, marshy vegetation, sand dunes, brackish water flora and aqua-fauna) and (3) Marine (large sandy beach ridges, cliffs, outer channels, isles, beach, spits, Tidal inlets (TI's),

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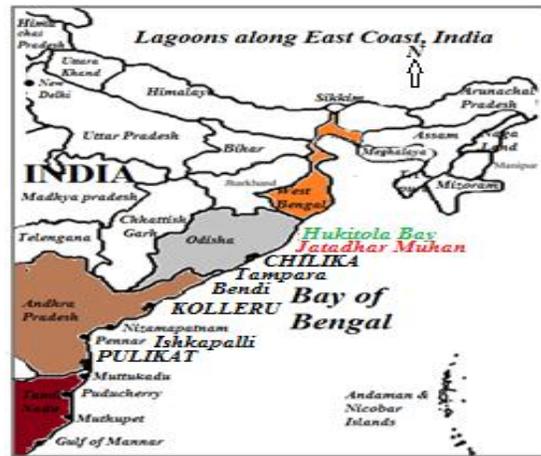


Fig 1:-Lagoons/bays along east coast of India

mangrove vegetation Rutger de Wit et al 2011^[1]. These eco-tones possess comparatively large population of species/communities /habitats within or on both sides (edge effect) within the lagoon, (<http://www.eoearth.org/article/ECOTONE?topic=58074>). Some of the world’s spectacular lagoons are the Nanuya Levu, Fiji, Lighthouse Reef, Belize, Blue Lagoon, Iceland, Comino, Malta, Laguna Colorada, Bolivia, Aitutaki Lagoon, Cook Islands and Chilika lake India (Fig 1). The coastal land records report 13% of the coastal track and 0.01% of the total water on the globe are covered by the estuaries, atolls and lagoons Isla F. I., 1995^[2], Miththapala, S., 2013^[3]. Countries like the W- coast of South America, Korea to SE Asia (China Sea coast), Canada, and the Scandinavian Peninsula have almost no lagoons.

Lagoon classification:

Lagoons can be broadly classified according to their number of tidal inlets or their salinity status. Lagoons are classified according to a number of TI’s in their barrier spit. They can be *estuarine* or *coastal*. According to salinity, lagoons can be classified as salinities <5 ppt, (*oligohaline*), 5 -18 ppt (*mesohaline*), 18-30ppt (*polyhaline*) and >30 ppt and less than adjacent seawater salinity is *mixoeuhaline* Rutger de Wit, 2011^[1] Fig 2 and Table 1

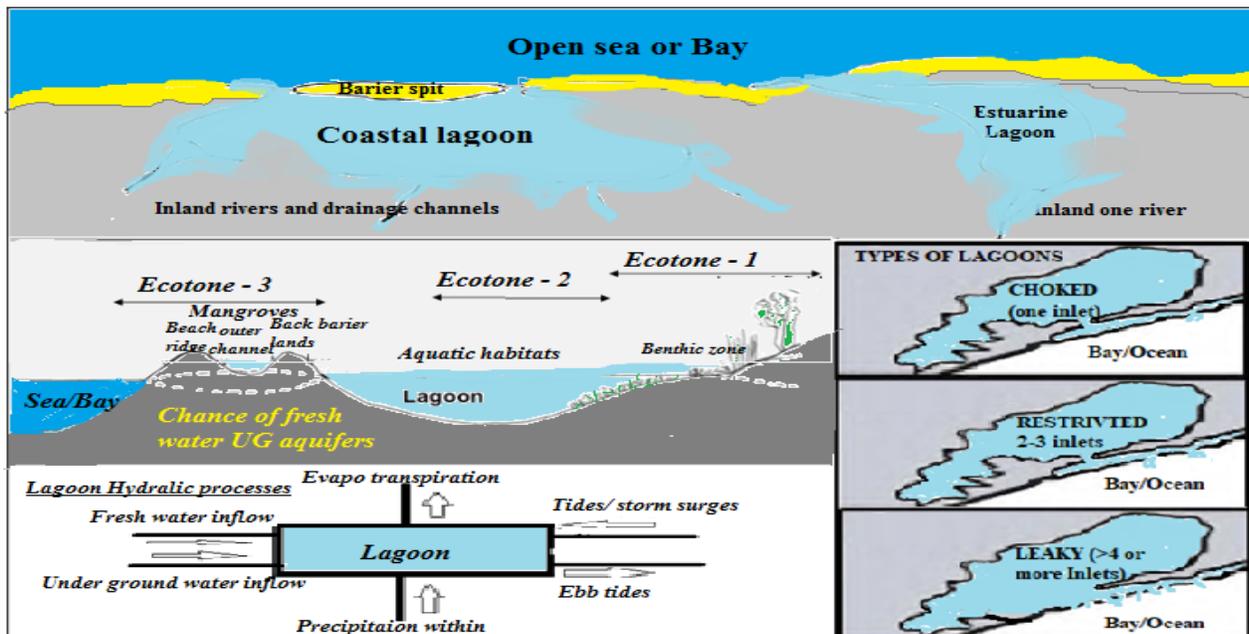


Fig 2:-Lagoon types, CS of a lagoon along east coast India and lagoon Hydraulic processes

According to morphology, topography, the lagoon can be estuarine lagoon and coastal lagoon. **Estuarine lagoon:** is partially bounded deep coastal form of brackish water with faster inland flow from drainage channels/ rivers with only one inlet to open sea with least residence time. **Lagoons** are wetlands whose major axis is generally coast parallel, shallow, brackish, with sluggish water exchange, and separated from ocean or bay by a spit or reefs with a higher resident time. These lagoons are formed during mid-Holocene sea level rise (≈ 5000 to 6000 years BP) in gentle sloping, progradation coasts during marine transgression (either submergence or emergence) where the tidal amplitude of adjacent ocean system is $2\text{m}-4\text{m}$ Kejerf B 1986^[4], and 94^[5]. In addition there are saline coastal marshes consisting of prawn aquaculture ponds, potholes, part of past tidal channels and rotten spots in the rims which were included in lagoon in past and are formed due to episodic events like erosion, subsidence, biological processes or anthropogenic acts Miller al al., 1950^[6]; Mariotti et al 2013^[7]; Schepers et al. 2017^[9]. Miththapala S., 2013^[3] classified lagoons based on water balance (positive, inverse and low inflow), based on geomorphology (coastal plains, a barrier built and tectonic estuaries) and based on stratigraphy (Salt wedge, strongly stratified, weakly stratified and vertically mixed).

Table 1:-The major lagoons of the globe according to their inlet function and K factor

#	Lagoon Type	Name of the major Lagoons,	Characteristics	Reference
1	Choked (K<0.3)	Koleru, Bendi, Nizmad, Mundel, Rekawa Lagoon (Sri Lanka), the Songkhla Lake in Thailand, Lagoa dos Patos, de Ara ruama Brazil, Fosu (Ghana) Lagoon Lake St. Lucia (South Africa), Lake Nokoué, Benin, Coorong (Australia), Songkla Lake (Thailand)	One shallow inlet, Diffusion only, No tidal current and less water level change (high-density gradient to low-density gradient, wind circulation, Long residence time, Tidal Sway reduced by 5%, May become saline or hypersaline arid/ or subarids.	Miththapala S., 2013 ^[3] Kjerfve B., 1986 ^[4] and 1994 ^[5]
2	Restricted (0.3 < K < 0.8)	Barnegate Bay, Little Harbor, USA, Upper Lagoon, East Sri Lanka, Laguna de Terminos, Mexico,	Transition, Vertical mixing due to gradient due to both diffusion or advection	^[5] 1994B Kjerfve -
3	Leaky (K>0.8)	Gulf of Mannar, Wadden Sea Netherland, Mississippi sound, USA,	Advection only, free exchange of water, Multiple wide tidal inlets	^[5] 1994B Kjerfve -
4	Intermittent open Estuarine	Batticaloa lagoon Eastern, Sri Lanka, Puttalam lagoon northwestern, Sri Lanka.60 in SE Australia,	Lagoons formed: short-term closure of river mouth (storm/Tsunami/drought) seasonal and exist until the river flood breaches the spit.	Pollard D A, 1994 ^[10]
5	Estuarine lagoon (tectonic formation)	Hurunui Hapua, New Zealand, Guaymas Bay, Mexico. Venetian Lagoon, Italy, Hapua lagoon along Canterbury coast, many small lagoons in Sri Lanka.	non-estuarine river-mouth lagoons (hapua) near sea-river interface of a river estuary by a storm spit (usually seasonal and breaching of spit occur they are in low or spasmodic rainfall region.	http://inspire.ec.europa.eu/codelist/EventEnvironmentValue/SettingestuarineLagoon

Global scenario of lagoons:

Wetlands contribute 45% of the globe's productivity and its contribution to the ecosystem is estimated to be 20 trillion dollars, wetland atlas 2012^[11]. The lagoons are universal wetlands in the globe along with the coastline from tropics to poles but the numbers are less in higher latitudes. The percentage of the lagoonal system of the continent vs. the world statistics are Africa (17.9%, & 18.7%), North America (17.6%, & 33.6%), Asia (13.8%, & 22.2%), South America (12.2%, & 10.3%), Australia (11.4%, & 6.8%) Europe – (5.3% & 8.4%) Barnes R. S. K., 2010^[12]. The gulf coast of America is the longest lagoon with the length of 2800km. New Caledonia, situated in South Pacific is the largest saline/brackish water lagoon followed by the Great Barrier Reef, Australia. The New Caledonia lagoon have water spread area of 23,000 Km² with ≈ 9000 IUCN identified with rare/endemic species within six marine clusters. Some prominent freshwater lagoons are Murray mouth Lagoon, Australia, Kalametiya lagoon, southern Sri Lanka. The brackish coastal lagoons are Chilika Lake, India, Jubho Lagoon, Sindh, Pakistan and

Bundala lagoon in southern Srilanka. The hypersaline lagoons are Mundel Lagoon, Sri Lanka, Coorong, South Australia, and Laguna Madre, USA, and Hapua, New Zealand. Sri Lanka, a small island has a number of lagoons (8 lagoons >100ha and total 89Ha) comprising of area 7589 Ha ranging from 3ha to 1000ha in its south, southeast and east coast where there is less inland drainage Balsurya A., 2018^[15].

Review of literature

Hutton James, 1788^[14] reported that the earth is unstable and transactions are continuous due to the interaction of geologic, biologic activities and biogeochemical evolutions. These evolutions manifest in form of different physical ecosystems including the lagoons. Depending upon their characteristics, lagoons can be classified as estuarine, intermittently closed and open lagoons (ICOLs) and closed Nicholas et al., 1981^[15]. The other compartmentalization made by Kjerfve B, 1994^[5] was leaky, restricted and choked.

The climate was warm, dry and drought situation was prevailing in ancient India from 2000yrs BP to 3500years BP (fall of Harappan civilization). From 3500yrs BP to 5000 years BP monsoon was strong, dry and warm (>approximately present). The sea level changed 6m lower than the present level whereas during post-Younger Dryas period i.e. 5000yrs to 9000yrs the monsoon activities were very strong and the MSL was 40m lower than the Anthropocene period. Since the last 1200 years, India has witnessed sea level rise (2mtrs), including changes in vegetation and climate whereas Naidu P.D. 1999^[16], Mishra et. al., 2018^[17]. coastal areas are thickly populated, vulnerable to major landfills of the earth. Woodroffe et al 2005^[16] mentioned about the discrepancy of formation age, timing and degree of the MHHS (Mid-Holocene High Stand) and the characteristics of post-Holocene sea level fall which favored formation of lagoons. Clark et al., 1978^[97] recognized 6 sea-level historical patterns/ proxies along coastline either emerged or submerged, or both in transitional regions. The sea-level curve, which proposes two Holocene high stands at 5000 and 2800, 14C yrs BP and Woodroffe et al, 2005^[18] mentioned from microfossil records about an MHHS after 3000 BP (14C yrs) of at least 0.5 m. Lagoons (from Italian word Laguna) are larger brackish water bodies separated from sea or bay or gulfs by a spit made of sandbars, coral reefs, barrier reefs, or other natural/artificial barriers (Kennish et al., 2010^[20]; Kjerfve, 1986^[4] &1994^[5]. Ponton et al., 2012^[21] have mentioned the act of aridification and salinization in Bay of Bengal between 3000 to 1700 years BP.

The beach profile, an effective natural mechanism, causes the wave to break and dissipate their energy. The shoreline change occurs when breakwaters upset the natural equilibrium between beach sediment and the littoral drift pattern confirming a new equilibrium, Ramesh et al., 2002^[22]. One of the causes are XENs (xeno-ecological niches due to landfills, urban population, industrial activity, mining, and farmland) have altered the ecosystem in last few decades from 1900 (300 KT/day to 3 Gigatons [Gt] /day in 2012 and may increase to 6 GT by 2050 Hoornweg et al., 2013^[23].

Tamil Nadu coast has more accretion during the Dec Tsunami 2004 so that the coastal sand has increased to 34.24% from 32.31% and the water bodies reduced from 49.66% to 45.83% indicating the estuaries and the lagoons along TN coast is reducing in dimension. The Chilika barrier spit (south Odisha coast) has increased the number of tidal inlets and the water spread area has increased after the Tsunami 2004 Mishra et al 2017^[24]. Odisha has 480Km coastline out of which sandy (57%), muddy (33%), marshy (10%) and have least rock coastline and having water depth 10m-15m in the offshore region and longshore sediment transport @ 997594m³/year Sanil Kumar et al., 2006^[25].

The east coast of India is vulnerable to rise in MSL @ 0.76mm / year (Visakhapatnam) and shall submerge the coastline due to large storms striking the coast and flat continental slope Shetye et. al.,1990^[26] Unnikrishnan et al 2008^[27]. During the pre- Holocene epoch (11700 to 7000 years BP), continental shelves remained dry during the last glaciation and became flooded in mid-Holocene owing to heavy rainfall. The inundation filled up the coastal low lands, modification of sedimentary landforms and eroded some topographic highs which resulted in the formation of the sand barriers along the coastal front and finally the lagoons Davis et al., 2004^[28].

The end Holocene epoch (\approx 11700 years old) was reported and commencement of the Anthropocene epoch was unofficially declared by Cruzen-2000^[29] and, Crutzen et. al., 2002^[30]. Addition of the Anthropocene epoch to global time scale is under research in full swing after a first atomic explosion, 1945, Zalasiewicz et al 2008^[31], 2017^[32], 2018^[33]. Some researchers claiming to establish the truth that both the epochs are coeval Elis et al, 2016^[34] and 2018^[35], Kluiving et al 2016^[36] and the new epoch is yet to be officially stamped.

Reasons for study:

The study is undertaken to analyze the impact of anthropogenic interventions on the lake/lagoon dimensions and characteristics, land use and land cover of the catchment, the pollution rate, salinity, inland flow etc during great acceleration period of the Anthropocene Epoch. The study also highlights the significant changes in biodiversity and ecosystem associated with anthropogenic activities including sensitive issue of degradation of the panoramic lagoons along the east coast of India.

Lagoon characteristics and classifications:

The coastal lagoons are generally formed, maintained and sustained by transported sediment and do not feature in high tide coastal zones (amp>4m) and in steep and rocky coasts. The coastal lagoons become swampy when sea level is low but become sandy and look like a lost bay/gulf at high MSL. The salinity designates the lagoon as freshwater (<0.5%PPT), brackish (0.5% to 30% PPT), saline (30% to 50% PPT) and hypersaline (.50% PPT) depending upon evaporation rate and the basin soil, Miththapala, S., 2013^[3].

For lagoon characteristics, the Roseby Number ($R_0 = \frac{U}{L \cdot \Omega}$) up to 1.25 is negligible, <https://upcommons.upc.edu/bitstream/handle/2099.1/3409/41241-9.pdf> The Coriolis force ($F_0 = 2\Omega \sin \phi$ where Ω is angular velocity of earth= 7.29×10^{-5} rad/ sec and ϕ is the value of Latitude, zero at pole and increases with latitude, which influence the flow direction entering the lagoon and the river mouths, currents to squeeze the right shore line in Northern hemisphere, Poincare waves (oscilatory huge waves of large wave lengths in large lagoons), seiches and shoreline parallel currents and waves (Kelvin waves) Cohen A. S. 2003^[37], Mishra et al 2016^[38].

The Richardson number ($Ri_e = \frac{\Delta \rho \cdot g \cdot Q}{\rho \cdot \omega \cdot U^3}$) where gravity (g), density (ρ), Angular vel. (ω), and Q influx and Velocity (U) which determine the turbidity and density of saline water inside a lagoon (For well vertical mixing the Ri_e .value is 0.07. The parameters showing morphology of the lagoons is **governed by factors in Table 2.**

Table 2:-Physical morpho-dynamics of different major lagoons along the East coast of India

#	Influencing Factor	Equation	Physical terms used	Effect	Applicable to the East coast, India	Reference
1	Wave phase velocity (γ ratio)	$C=K_1 \cdot g \cdot d$ $C_1=K_2 \cdot g \cdot (d+h)$ $C_2=K_3 \cdot g \cdot (d-h)$	$K_1, K_2, K_3,$ consts, $g=$ accl ⁿ due to gravity, $d=$ Hor..dist., $h=$ amplitude,	Transforms the shoreline	Wave breaking, Chilika Coast, (γ ratio=0.78)	Kar Sujib, 2018 ^[39]
2	Break depth index (γ_b) of coast & Irribaren No. (ξ_{∞})	$\gamma_b = H_b/h_b$, & $\xi_{\infty} = m/\sqrt{\lambda_{\infty}}$ $\lambda_{\infty} = H_{\infty}/L_{\infty}$,	$m=$ beach slope, $H_{\infty}=$ wave ht., $h=$ water depth $b=$ incipient of breaking pt. $L_{\infty}=$ wavelength h (deepwater)	$\xi_{\infty} \leq 0.5$ (Spilling) $0.5 < \xi_{\infty} < 3.3$ plunge $\xi_{\infty} \geq 0.5$ Surging/ collapse, plunging breaker(vortex form penetrates coast under water	Chilika Coast Collapsing breakers and plunging & Pulikat coast tidal surging	Galvin C., 1972 ^[40] , Benoît .et. al., 2007 ^[41] Camenon et al., 2007 ^[42]
3	Gamma ratio (γ)	$\gamma = \frac{H}{d}$	Where $H=$ Wave ht. & $d=$ depth	$\gamma=0.6$ for flat beach & $\gamma=1.2$ for steep beach	$\gamma=0.6$ Chilika coast, $\gamma=1.2$ Pulikat coast	Sujib Kar, 2018 ^[40]
4	The surf scaling factor (ϵ)	$\epsilon = (a_b / \omega^2) / (g \tan^2 \beta)$	$a_b=$ breaker ampl, $\omega =$ incident wave radian freq. ($2\pi/T$; $T =$ period), $g=$ gravity & $\beta =$ beach /surf zone gradient.	$\epsilon < 1.0$ (compl ete reflection $\epsilon \leq 2.0$ – 2.5 strong reflection & $\epsilon > 2.5$ wave plunging, $\epsilon > 20$, spilling breakers occur	Chilika coast ϵ ranges from 13-27(plunging) $\epsilon < 2.5$ AP & TN coast (Pulikat Coast)	Guza et. al., 1975 ^[39]

5	Coriolis force (F) [KN]	$F = \frac{2\omega v \sin\phi}{g}$ or $F = 2\tau v \sin\phi$	$\omega =$ angular Vel of earth, $\tau =$ is Coriolis force parameter, $\phi =$ wind direction	High in the East coast (Odisha coast) reduces gradually from Sirkara (N) to Sirkara South	20-25KN = Chilika Coast 10-15KN Pulikat coast	(Mishra S. P. 2016) ^[38]
6	Long Shore sediment Transport (LSTR) (Q_u) 10^3Kg/Sec	$2.27H_{sb}^2 T_p^{1.5} m_b^{0.75} d^{-0.25} \sin^{0.6}(2\theta_b)$ Hsb = significant wave height, $T_p =$ Wave period(peak), $m_b =$ beach slope causes breaking,	$Q_u =$	LSTR decreases from north to south, $d_{50} =$ median size of beach particles, $\theta_b =$ braking wave angle	Chilika Coast= 1.1MMT/year Uputeru,Koleru =1.98MMT/yr Pulikat coast= 1.68MMT/year	(Mishra S P 2016) ^[39]
7	Peclet No(P_E) [Advective-diffusive transport]	$P_E = (UD)/K_x$ where $D =$ distance $U =$ Velocity, $K_x =$ effective diffusivity (Hor), For lagoons $K_x = 10\text{m}^2/\text{sec}$ to $1000\text{m}^2/\text{sec}$		To assess advection vs. diffusion transfer in flushing state of the lagoon, $P_E \leq 3.57$, Advection behavior	Choked =>small P_E , Restricted $P_E =$ intermittent & for Leaky P_E is large	Vogel S., 1981 ^[44] and Zimmerman J.T.F., 1981 ^[45]
8	Flushing time (FT) Knudsen's Relations	Water Budget : $V_{out} = V_{in} + R$ (Inflow) Salt Budget: $V_{out} * S_{out} = V_{in} * S_{in}$, If T_s flushing time & T_f Fresh water filling time/sec, V_f , R fresh water in lagoon & river inflow $T_s = V/V_{in}$, $T_f = V_f/R$ & fresh water fraction $f = (S_0 - S) / S_0$. S_0 is fraction of oceanic salinity		Flushing time small the lagoon (choked), lagoon flushing time medium (restricted) very small flushing time (leaky lagoons)	Flushing time: Chilika :4-5days in outer channel & 132days northern sector, science direct. com /science/article/pii/S027843431630348X	https://www.mt-oceanography.info/ShelfCoast/notes/chapter15.html
9	Filtering efficiency, (F_E)	$F_E = (RI - NF)/RI$ Where $RI =$ the input rate from inland rivers (+ve), $NF =$ net flux at the entrance channel (+ for export and - ve for import.		$F_E = 0$ (Influx= out flux no deposit) $0 < F_E < 1$ traps river input, silting, $F_E > 1$ lagoon traps river & ocean inputs	For Chilika and Pulikat $F_E \leq 1$ and other lagoons on EC, India, $F_E \geq 1$	Kjerfve and Magill 1989 ^[46]
10	Residence time, (retention time)	The time taken for any water influx to leave a lagoon by TI's into the sea (For the Chilika 4-5 days in the outer channel (OC) and 132 days at the northern sector (NS) Mohanty et. al., 2015 ^[52] , Pulikat: 18.5 days (flood days)		http://shodhganga.inflibnet.ac.in/bitstream/10603/74144/16/16ha_https://pter%208.pdf www.google.com/search	Chilika: 179days (1990), 110days (2000) and 100days 2009, Pulikat lake Av.36 days	Ranga Rao V. et al., 2012 ^[47] , Dronkers et al., 1982 ^[48] .
11	Repletion Coefficient (K)	$K = \left[\frac{T}{2\pi a_0} \right] \left(\frac{A_c}{A_n} \right) \left[\frac{2ga_0}{(1 + 2gLn^2r^{-\frac{4}{3}})^{\frac{1}{2}}} \right]$ where the tidal range of ocean $2a_0L$, Or $K = \frac{1}{K_2} \sqrt{\frac{1}{K_1}}$ where K_1, K_2 are King sinlet friccttion & frequency		L, r & a_0 length & hydraulic mean radius, the area of TI, A is the surface area of the lagoon, T tidal period & $n =$ manning's friction (0.01-0.10) and g is gravity.	Choked ($K < 0.3$), Restricted $0.3 < K < 0.8$, Leaky ($K > 0.8$), Chilika has $K = 0.004-0.008$ (spring tide) & 0.007 to 0.014 (Ebb tide)-2009	Keulegan, 1967 ^[49] , King, 1974 ^[50] http://nopr.niscair.res.in/bitstream/123456789/34880/1/IJMS_Sahoo et al 2016

Formation of the East Coast of India

Murthy et al., 2012^[51] stated India has drifted away from East Antarctica at the knee-fold lengthways along the east coast, (bight) along NE-SW ridge of Krishna-Godavari Basin and formation related to the Kolleru and the Pulikat lake. But the Chilika Lake was formed as a separate block not related with Mahanadi delta and EGB hills as result of Mesozoic tectonic activities. The Chilika lagoon and a part of SMD were attached to EGB-Rayner block during

Indo-Antarctic collision. The Rodania assembly, moving south, collided with Western Australia was a part of EGB-Rayner Block or localized reworking of late Neo-proterozoic–Cambrian event gave rise to Chilika, Chatterjee N., 2008^[52], Das et al 2012^[635] and Gupta S., 2012^[54], Mishra et al., 2015^[55].

The Indian coast is based upon on a plate with the firm base but it consists of variable landform due to storm, swale wave environment, and inland sediment, Sujib Kar, 2018^[39]. Lagoons formed along the EC of India are within sandwiched areas between the EGB Hills and the 85⁰ Ridge in the Bay of Bengal, (BoB). The interspace between BoB and EGB hills is occupied by six major large deltas whose apex is extending up to 130Km inland formed by east flowing rivers.

These rivers are the Subarnarekha, the river system of Mahanadi tri delta, the Vansadhara, the Godavari, the Krishna, the Pennar, the Cauvery, the Bhaigai and many small rivers. Mostly small river estuaries have lagoons/wetlands for its monsoon flood absorption as the rivers are ephemeral and longshore drift deplete the estuary depth during nonmonsoon. The lagoons/wetlands cover three states i.e. Odisha, Andhra Pradesh (AP) and Tamil Nadu (TN) with West Bengal coast having no lagoons or bays.

The East Coast Marine marginal zone:

Indian territory has 7517km of coastline out of which 6031 Km is the coast lies in the mainland. NCCR (National Center for Coastal Research) has surveyed the entire coastline (1990 to 2016). It is reported that 2156.43Km (33% of coastline) has been eroded and 1941.24Km accreted and rest inclusive ports, harbors, and coastal protected areas are stable. The EC of India is \approx 2300Km extending from Kolkata to Kanya Kumari is a blend of prograding or retrograding and amalgamation of sub-aerial, fluvial and submarine coast with variations in the northern and the southern stretches. The coastal lengths of different states along EC of India are WB (282.2Km), Odisha (436.1 Km against 476.4Km NHO 1970 and 432Km RBA 1980 assessment), AP (971.27 against 960Km NHO 1970 and 973.7Km RBA 1980 assessment), Tamil Nadu (824.92Km including Pondicherry against 1000 Km NHO 1970 and 937.5Km RBA 1980 assessment), [National Hydrographic Office (NHO), Dehradun and Survey of India in 1970 and the Rashtriya Barhat Ayog (RBA)], According to recent NHO 2011 the length of Odisha, Andhra and Tamil Nadu and Puducherry coasts are 667.12Km, 1272.55Km, 1064.98Km and 42.11Km respectively. The variation in length indicates more irregularities in coastline has occurred between 1970 and 2011. CWC report, 2016^[56]. The increase in coastline substantiates more inundation of marginal marine zone and favoring formation of more lagoons, backwaters and bays in low lying areas along the east coast in near future. The states with a high rate of erosion vulnerability along the EC of India are 63% of West Bengal, 57% of Pondicherry and 41% of Tamil Nadu coasts respectively. Odisha coast has been expanded by 50% during 1990 to 2016 (CWC report, GOI, Dec 2016, P-7)^[56].

Lagoons along East Coast of India:

The major lagoons along mainland EC, India are the Chilika, Bemdi, Kolleru, Nizamapatnam, Pennar, Pulikat, Mutukadu, Puducherry, Kaliveli, Muthupet, and Gulf of Mannar lagoons. The lagoons along western coast are Astamudi, paravur, Vembanad, Astamudi, Paravur, Murukmpuzha, Ettikulam, Velli, Talapady and many small lagoons along Bombay coast, Gujarat, Diu, and Lagoons of Lakshadweep.



Fig 3:-The changes in Ekakulaspit and barrier islands in Hukitola bay 1929 -2017

Indian Territory accommodates 13033 numbers of natural coastal wetlands comprising of area 41401.16 Km² out of which the largest coastal wetland in intertidal mudflat 2931 numbers covering 24136.42Km² where Gujarat state shares 22603.65 Km² Ramachandran P., 2012^[57].

Erosion and accretion of coastal landforms are continuous processes. India has 10204 natural coastal wetlands spread over areas of 37039.71Km² and 2829 numbers of manmade coastal wetlands with 4361.45Km². Out of 178 numbers (area 2460.44 Km²) natural lagoons along the coastal tract of east and west coast of India, only 17 lagoons are major and rest are of small and of less importance (source: National Wetland Atlas http://www.iomenvi.in/pdf/docu%20ments/COP11_BOOK_Final.pdf). There are thousands of lagoons having area <1Ha to > 10000Km² but average size for consideration of a lagoon is >80Km² (median size), Barnes R. S. K., 2001^[12].

The transformations of Hukitola Bay (**Fig-3**) and Kakinada Bay formations are similar in nature. The configuration indicates the barrier Island is getting stabilized from the southern fringe. There are continuous making and breaking of the barrier islands along the coast to close the concave intrusion of the sea to the mainland. The Palk bay is different as it is a straight separator between Arabian Sea and Bay of Bengal (The Ram Setu or Adam's Bridge).

The characteristics of lagoons of EC of India has steep sea bed slope (Except Chilika lagoon), the short continental shelf of 20Km, low tidal range (1m to 4.5m), beach consists of fine yellow sand (red sand south TN) and large mud flats. Very high net littoral sediment flow to the north (0.5 MMT at Pulikat and Iskapalli lagoons to 1.5MMT Kolleru lake and Chilika (1.0MMT). The coasts of the lagoons encounter BoB disturbances (CS, SCS, VSCS and super cyclones) frequently and over washed by Tsunamis in December 2004. Physical features of three major lagoons such as Chilika, Koleru, and Pulikat is submitted as under Table -3:

Table 3:-The geomorphological characteristics of the three major lagoons along EC of India

#	lagoon features	Chilika lagoon	Koleru Lagoon	Pulikat Lagoon	Reference
1	Coordinates	19.85° N/85.479° E	16.65°N/ 81.217° E	13°56N/ 80°21 E	www.google.com
2	State/dist. in India	Odisha(Puri, Khordha, Ganjam)	AP(Krishna,Khammam & West Godavari	AP(96%),TN (4%)(Nellore(AP),Tiruvallur(TN)	Wikipedia
3	Present Status	Restricted	Wetland transformation	Choked	
4	Main inflowing rivers	Daya, Bhargovi, Makara, Salia	Budameru Thammileru Ramileri, Gunderu streams & 68 D/C's	Aarani (south), Kalangi (central), Swarnamukhi (North),	http://www.rainwaterharvesting.org
5	Lagoon Salinity Status	Brackish & Sluggish Salinity 8 to 15.7ppt rains, 22 to 28.5 ppt winter and 32 to 35 ppt in summer	Shallow stagnated, (2.5 to 11.8ppt) Highly saline in Upputeru – (Kottada, Panchekal amarru ,Pedayadlagadi	Endorheic Brackish salinity 4- 32ppt rise, to 52ppm http://www.rainwaterharvesting.org/pulicat_lake	Wikipedia, Mohanty D et. al., 2015 ^[59] , Vijayalakshmi et. al., 2017 ^[60] ,
6	Formation age	≈4000years (Richa Arya et al., 2006)	Coastal lagoon before 6000 yr BP	6000yrs BP(mid-Holocene MSL peak rise	Bhattacharyya et al., 2013 ^[61]
7	Tidal Inlet (present)	Multi-Variable San patna, Arakhakuda,	long canal Upputeru near Vil. perantala kanuma	3 TI's, Durgarajpatnam Pulinri Kuppam , Kondurupalem TI's 130 to 80 m wide, 1.7m depth @ 0.5m/sec velocity of flow	Papastergiadou et al.,2008 ^[62] , Ramesh et al 2000 ^[63]
8	TI Position	The northern part of the spit	The central part of the spit	Southern part spit	Satellite imagery
9	Max water spread area(1165 in 1846 (1500Km ² in 1400 to 1500AD),	901Km ² (1930), 180.38 km ² (more 100.97 km ² in rainy days(2006)	460 km ² (2002) http://shodhganga.inflibnet.ac.in/bitstream/10603/	Nageswar Raoi et al 2014 ^[64]

	Km2)			75108/10/10_chapter202	
10	Min water spread Area	906 in 1846, present Av. Min775Km2	135Km2 (5m contour line) 70.7 Km2	260 km2	Sterling 1846 ^[65]
11	Av spread Area(Km2)	≈1011Km2	901 Km2 (1970), 493 Km2(Anon, 2007) 308Km2 (present)	461 Km2	Mishra S. P. 2016(thesis) ^[66]
12	Coastal length	64.3Km (71.6Km in 1400 to 1500 AD)	39km long , lake is 35Km inland	60km, but 36Km present (64Km, 1500AD)	Wikipedia,
13	Width	100m-1500m	and 22km broa	0.2 to 17.5 km	Ramesh et. al., 2001 ^[67] &, CDA
14	Depth	0.5m - 4.2m (Av 1.5m)	0.5m to 3-4m in high floods & even 10m	1.0m (≈6m in channel zone)	Ch.Sabastian Raju, 2016 ^[68]
15	Rivers inflow& Flood absorbing	Daya,Bhargovi,Salia. Nuna, Ratnachira, Makara (46 d/cs)	Tammileru (36%) Budimeru(26%) Ramileru, Gunderu	Arani, Kalangi and Buckingham Canal (south) & Swarnamukhi	Ramesh et al 2002 ^[22]
16	Major Sediment accumulation	Northern sector	lake bed is rising at 2.5 cm/year (Lakes in India.html)	Southern zone 6.06 mm/yr to 15 mm/ yr (≈10.05 mm/ yr)	http://shodhganga.Inflibnet.ac.in/bitstream/10603/74144/16/16_chapter
17	Own Catchment	1777Km2 Mahanadi delta and western catchment 2800Km2	6121Km2,(4763 km2) upland,1358.km2 delta	Arani River: 764Km ² Kalangi river: 475Km ²	www.pressreader.com/india/the-hindu/20181202/281904479243773
18	Birds sanctuary	Nalabana	Atapaka:1.5 km	Nelapatu	
19	Av. R/f lake area	1075mm/yr (19991-2014)(Krishna Pr.)	1000mm/year	810.6mm normal	Wikipedia
20	Fishermen , lake users	2,00,000fisher folk in 151 villages	148 rural settlements (50 in the lake bed and 98 belt Villages)	30-40 Th 2006 (148 villages 1Lakh(2016)	Raj et al., 2006 ^[69] , Saraswathi et al 2016 ^[70]

Chilika lagoon (Ramsar site 229):

The Chilika, Odisha is the largest coastal lagoon in India, (Ramsar site 229) is a shallow, brackish, pear-shaped lagoon lying parallel to shore. Though a gulf in past, the lacustrine area of the Chilika has reduced from maximum 1165km² and minimum 906 km² in 1950s to present av. area max. ≈1011 to minimum ≈770 Km², in 2012) Sterling A. 1846^[65], Mishra S. P. 2016^[71]. The coastal length has been reduced from 70.81 km to ≈63.4 km, max width from 32.2 km to ≈20 km. The lagoon consists of Northern sector (shallow marshy land), Central sector (Breeding ground for aqua habitats and freshwater flow), Southern sector (Stable and deep) and the outer channel with isles and tidal inlets for hydrodynamic activities. Towards south, a canal (Palur) is running which discharges to Bay via the Rushikulya river. The NS, CS, SS, and OC had depth ranges between 0.5 and 1.5m, 1 to 2.5 m, 2.5 and 4.0 m 2.5 and 5.5 m. respectively. The shallow lagoon has av. depth ≈1.5m in 2015, Mohanty et al., 2015^[72], and Wikipedia. During monsoon and non-monsoon periods, there is a maximum tidal variation of 1.15m at Sipakuda. A dynamic parallel barrier spit towards the north of sandy ridges is extending ≈32Km of av. width 100 m towards the north, and 1500m in southern coast Panda et al 2012^[73]. The spatial and human changes of 3 major lagoons are in Table -4 and Fig-4.



Fig 4:-The Chilika lagoon, Odisha

Table 4:-The LU/ LC changes in South Mahanadi delta including Chilika catchment 1972 to 2012 during pre and Great acceleration period of Anthropocene.

#	LU/LC	Items	1972	1975	1990	1999	2011	2012
	Source		Wetland Int.,2012	Ojha et al., 2013	Wet land Int.2012		Wetland Int.2012	
			Km2	Km2	Km2	Km2	Km2	Km2
	Population Density	Puri	230.42 (1971)	286.88 (1981)	428 (1991)	431 (2001)	488 (2011)	488 (2011)
1	Settlement	Rural/veg	135.94	126.29/622.9	131.01	479.67	179.59	470.8
2		Urban	36.08	31.88	73.77	55.48	113.04	110.29
	Total		172.02	210.09	204.78		292.63	
3	Agriculture		1918.14	879.83	2006.85	1686.08	1761.45	1257.3
4	Forest	Dense	567.75	679.05	417.91	436.67	287.98	613.78
		Open	77.55	128.56	159.04	218.62	403.99	242.52
		Scrub	574.58	508.71	422.59	469.16	436.72	455.77
		Plantation	75.57	24.11	99.92	48.31	138.57	34.71
	Total		1295.45	1340.43	1099.46	NA	1267.26	NA
5	Lake area	Open water	829.84	NA	778.17	NA	699.08	NA
		Aquatic plants	27.57	NA	77.82	NA	119.43	NA
		Marshes	14.72	NA	23.59	NA	15.45	NA
		Aqua culture	00	NA	11.68	17.61	120.02	51.59
		sand	40.83	15.79	27.36	7.19	33.22	3.12
	Total		912.96	1034.11	918.62	910.48	987.20	887.35
6	Swamps	Marshes	116.24	128.37	121.86	116.16	97.88	136.02
	Settl +Vege	Stabilized(Rabi)	413.86	759.15	413.56	469.16	381.00	
		Water logged	58.09	12.63	82.60	74.85	60.31	
		Total	588.19		618.02		539.19	
	Total area considered in GIS		4847.74	4077.50	4847.74	4846.64	4847.74	4301.5

Source: Wetland International south Asia and CDA – 2012 <https://www.idrc.ca/sites/default/files/sp/Documents%20EN/Chilika-Framework.pdf>, Population density: Source - District Statistical Handbook, Orissa & Census of Orissa, <http://cesorissa.org/soe/Demography.pdf>

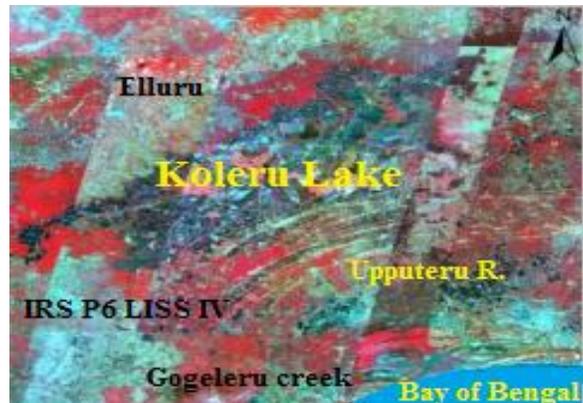


Fig 5:-35Km inland within Godavari Krishna delta, Kolleru lake in AP

Kolleru Lake (Ramsar site 1209):

The present shallow freshwater swampy/ marshy lake, Kolleru in AP, formed as a coastal lagoon in past (>6000 yrs BP). Kolleru was no longer a lagoon but a lake which is of area 180.19 km² water spread area and 645.9Km² covered by pisciculture ponds Fig 4. The loss of lake area was 109km² between 1967 and 2004 (37yrs) and major loss was due to the conversion of 100≈Km² from the lake to pisciculture ponds. Present water spread area is ≈308 Km² (variable), width (10Km) and maximum depth of 3m with numerous parallel beach ridges between 1st (adjacent to Bantumilli village) and the third strand line (Peddapalem and Uralagonditippa villages) with a narrow channel, 70 km² spread of marine water body called Goguleru Creek and series of relict sandbars Vijayalakshmi et al 2018^[74]. A marshy land of 135Km² is found around the Upputeru river with beach ridges Eruva Mamata, 2009^[75]. With periodic coastal changes, the Kolleru Lake and Gallery creek (Lagoon) lies in the third strand line.

Pulikat Lagoon:

Pulikat lagoon, the second largest in India lies in the SW border of AP and TN (TN 4% & AP 96%) is extending from Durgarajapatnam village in North to village Pulikat (the tidal inlet) in the south and is connected with Buckingham canal used for navigation channel. The Pulikat lagoon is facing deteriorating water quality and downsizing due to sedimentation from 1970 onwards Raman et al., 1975.



Fig 6:-Pulikat lagoon in East Coast, Andhra Pradesh & Tamil Nadu

Kourzeneva et al. 2012^[76] have reported that the endorheic Pulikat lagoon with brackish water has been reduced to av. area ≈300km² and av. depth reduced to 1.0m. At present, the shallowest region is Arambakkam jetty and Veynadu Island has depth 0.2m. The water spread area has been reduced from 691.54 Km² in 1972, 514.89 Km² in 2005, and 354.53 Km² in 2015 reducing the lacustrine area by 337.03 Km² 43years Saraswathy et. al., 2016^[77]. The lagoon is polluted by the inflow of sewage by Buckingham canal of Ennore city. The average sedimentation rate of the lagoon is ≈1.23 cm/ yr (≈ 1.2 m/Century Ramesh et al 2002^[78].

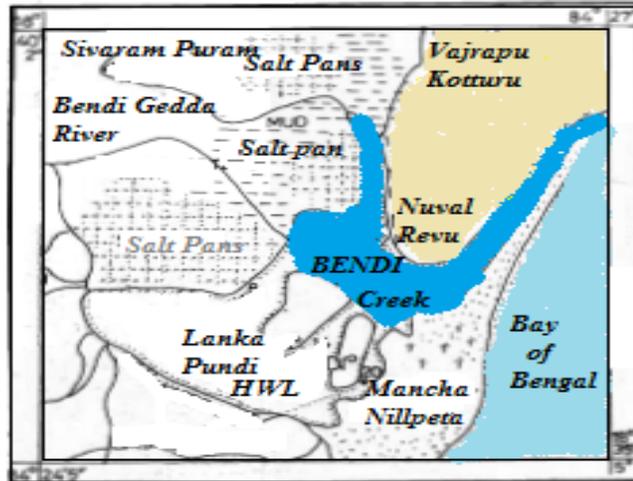


Fig 7 :-Bendi lagoon, with salt pan,(Andhra Pradesh)

Bendi lagoon:

Bendi lagoon (Lat 18° 40' N and Long 84° 26' E) is near the Vajrapukotturu village of Srikakulam district and lies in the estuary of the Bendigedda river (Fig 7). The small brackish water area is between the Vansadhara and Nagavali estuaries palaeontological society.in/vol 35/v4.pdf. The salinity varies from 26ppt to 39.5ppt. This tropical high Temp is favorable for the assemblage of low diversity ammonia group of benthic foraminifera mostly in winter reported by John Murray in the book "Ecology and applications in Benthic Foraminifera, 1988.

Nizampatnam Lagoon:

Nizampatnam lagoon is backwater of length ≈ 17 Km and of area 1825 Km² situated in the south of Krishna delta (Fig 8) and Gundlakama, Romper and Upputeru rivers are feeding to the backwater. The depth varies seasonally from 8m to 15m and the coast is having wave amplitude 1m-1.75m. Holocene transgression followed by progradation is the cause of formation of the stripped lagoon Rao P. S. et al 1990^[79]. The lagoon was an active port in 12th-13th century AD but became nonfunctional due to sediment carried to the lagoon from Krishna delta. Nizampatnam lagoon and its periphery are occupied by mudflats/ beach ridges (224 km²), mangroves and backwater (289km²) which is vanishing gradually by erosion in the 21st century, Ch. Anil Babu et al, 2015^[80].



Fig 8:-Iskapali Pondapalli Lagoon, AP

Iskapalli-Ponapudi lagoon:

The small Iskapalli lagoon (Lat. 14° 40'–14° 45'N and Long. 80° 05'–80° 10'E) in the NE part of Penner delta. It has the barrier spit of length is ≈ 8 Km and width 2.5Km and situated in AP state, India and covering an area 2.4Km²

of Iskapalli, Kurru, and Ponapudi. The lagoon is of Holocene origin (1720 to 2043yrs) is fed by a small river 22Km long Pailderu river and the barrier spit island is Kuratipalem. The lagoon was ≈ 10 Km² spread, ≈ 8 km long and ≈ 2.5 km wide is of Holocene evolution, U-shaped, circumscribing the Kuratipalem Island with the inland source a drainage rivulet of 22km length Raiders. The lagoon was much wider and extended in past and squeezed at present Seetharamaiah et al 2005^[81]. (Fig-8)



Fig 9 :-Kalivei lagoon at velupuram, TN

Kaliveli Lagoon

Numbers of coastal water bodies are in Puducherry Union Territory and some of the important lakes like Ousteri Lake and Pondicherry lagoons are connected with Chunnabar River in Tamil Nadu. Kalivelli lagoon (lat. 12° 05' to 12° 15' N and Long 79° 59' to 80° 15' E) is located at Marakkanam in the estuary of the Yada-yanthittu river and, 18Km from Pondicherry spreading over an area of 68km² and TI is at Yedayanthittu estuary opening to BoB near UPPUKali creek. The seasonal brackish water dying lagoon in Coromondal coast, Villupuram district of Tamilnadu and a breeding ground and shelter for ≈ 20000 birds in winter. The Kaliveli backwater is 2.5 km long and of width 370 m. The pH varies from 6.95 to 10.11 and salinity 4.27 to 35.5 ppt. Since last 1980, the marshland near the mouth has been converted to salt pans and the shallow lagoon has been encroached for prawn farming and the existence of lagoon is under threat Silambarasan et al, 2017^[99] (Fig 09)



Fig10:-Muthukadu lagoon,Kanchipuram,TN ?

Muttukadu lagoon:

Muttukadu bar built Lagoon (Back Water),near Chennai, popularly called Kovalam backwater (lat. 12.49 N and long 80.15 E) lies parallel to BOB (Fig 10) is a shallow estuarine water body of 0.87Km², of total length 20Km bifurcated in N-S direction after length 3Km, width 800m-1500m, and average depth 1-2m situated in Kanchipuram Dist. of Tamil Nadu having salinity 22.67 to 48.40ppt. with two TI's one dredged and other natural Bharathi et al 2012^[82], Manakadan R. 2014^[83] Vasudevan et al 2015^[84], [http:// www. Sipcot cuddalore .com/ downloads /cheyyur_power_plant _](http://www.Sipcotcuddalore.com/downloads/cheyyur_power_plant_)

Muthupet Lagoon:

The Muthupet lagoon (lat. 100 20' N and Long 790 35') is located in near Cauvery delta within its five distributaries, in Tiruvarur Dist. of Tamil Nadu (**Fig 12**) and is the estuary of Muthupetai river covering an area of 13.32Km² width 1km, depth 0.3 – 1.2m and tidal amplitude 0.15-0.3m and the volume of water stored 9.6 x 10³ Cum and repletion period (τ) is 1.4days (**Fig 11**). The TIs opens to Palk Bay. The shallow lagoon has av. the depth of 1m and famous nursery area of Oysters and nursery for marine aquafauna, a shelter for arctic avifauna Khan et al 2013^[86], Rao N. R., 2016^[87]. The Physicochemical character of the lagoon is pH (8.18-8.47), Salinity 31.89 and 43.61 ppt, and DO 3.71 to 5.30mg/lit. <http://www.casmben.vis.nic.in/Database>. Picha varam Back Water, (lat. 11°20' to 11°30' N and long. 79°45' to 79°55' E) a marine estuarine wetland of 262.5 ha and the barren mud flats of 1238.50 ha. and lies in confluence point of the rivers like Uppanar and Coleroon in SE coast of India near Chidambaram in Cuddalore district, TN. The wetland is extending in the rim of the Muthupet lagoon, from \approx 2Km² in 1970 to 4.9Km² in 1998 [http://planning.commission.gov.in/reports/E_ F/Picha varam .pdf](http://planning.commission.gov.in/reports/E_F/Picha_varam.pdf).



Fig 11:-The Muthupet lagoon, TN (source: Google)

Gulf of Mannar lagoon:

The shallow Gulf of Mannar Lagoon (lat. 080 48' – 090 20' N and Long 780 10' to 790 15' E) is a coral coastal water body (Leaky Lagoon) of depth 0.3m to 1m with coral spread area of 94.3Km² and the lagoon lies west of Bhaigai delta near Rameswaram (large Polyped corals) to Kanyakumari (small polyped ramose type corals) from Pamban to Peikkarumbu of TN. The Physicochemical character of the lagoon is pH (8.0-8.5), Salinity 25-45 ppt, and DO 1.0 to 6.0mg/lit MOEF, GOI. The lagoon is encompassed by 21 islands (3 islands submerged under Tsunami). **Fig -12**. The marine seascape is of 10 km band 364.9 Km of coastal landscape of area 10,500 Km² in Ramanathapuram, Tirunelveli, Tuticorin, and Kanyakumari districts. The Gulf cum lagoon is fed by Vaippar, Gundar, Palar, Kottakkarai Rivers from WGB Hills. The islands vary from 0.25 Ha to 130 Ha with total area 6.23Km² with coral reefs around the offshore of islands covered by the sand and vegetation. Mannar Island is the largest area of 126.46 Km². It is connected to the main island of Ceylon Anthony Raj 2013^[88].

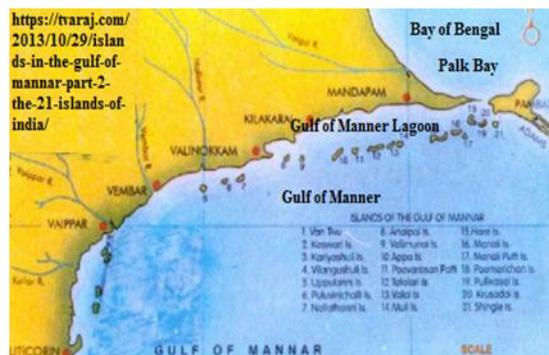


Fig 12: Gulf of Mannar lagoon, Rameswaram, TN

Issues related to lagoons in future perspectives:

The change in the characteristics of a lagoon may be due to natural and anthropogenic factors. The natural factor like climate change plays pivotal role along with phenomena like global warming, MSL rise, wind, tide and calamities like drought, flooding, earth quake, and volcanic eruptions. The anthropogenic causes are inland hydraulic structures resulting in sediment paucity, coastal infrastructures, beach deforestation, demographic urbanization, industrialization, and pollution. Anthropogenic pressure at regional scale, like increase in CO₂, GHG emission and deforestation, increased global warming (large-scale ice melt), being aggravated by human actions at the global, regional and local scales and resulting in increasing water spread area of the earth and inducing coastal erosion Tessler et al., 2017^[89], Lageweg et. al., 2017^[90], Dornbusch, 2017^[91]

Earth System Science (ESS)

Earth system science (ESS) is solicitation of earth as a system of science related to cryo, pedo and magnetosphere along with Atmosphere, Geo, Hydro, Biosphere (adding anthroposphere) of the earth using the principle of Uniformitarianism (There are inviolable laws of nature that have not changed in the course of time), the Steno's Four Stratigraphic Laws for Sedimentary Rocks and Actualism (The Present is the Key to the Past) Johnson et al, 1997^[92]. ESS is the combination of astronomy, geology, meteorology and oceanography. The volcanic and seismic activities of Indian Ocean can correlate the ENSO, monsoon, Bay disturbances and Tsunami activities that affect the East coast, the thalassian/the coastal lagoons. It is used to predict vagaries of future meteorological hazards, climate changes and the natural hazards occurring on the globe. Based on stresses imposed on the Geosphere-Biosphere Programme (IGBP), Committee National Research Council (NRC) and the earth system framework, NASA introduced study of the Earth System Science (in 1987) apply ESS to develop prediction system using complex computational methods such as remote sensing, GIS, Cloud and global databases technology to diagnose hominids as the basic transcendent species of the Earth systems. ESS studies have the objective to comprehend the changes occurring on Earth and the impact on life and developing public indulgence in researches on the issue using NASA aerospace tools, research, and exploration missions [https://notendur.hi.is/oi/Historical %20Geology%20pdf/1-](https://notendur.hi.is/oi/Historical%20Geology%20pdf/1-),

Global warming and Sea level rise:

Sun-earth geometry regulates the climate change but global warming can be natural or an offspring of the anthropogenic carbon emission. Global warming is the long term warming continuous processes of our earth and world's surface temp. was estimated as increased 0.74 ± 0.18 °C during the 20th century changed the Global sea level rise (GSLR) and regional (RSLR). To address climate, the RSLR along the east coast of India associated with borehole studies reveals that paleo shoreline was at Kanuru from 8420 to 8300 yrs BP which is now 4 to 5Km from the present shoreline Udaykumar P. 2014^[93] (Fig-13)

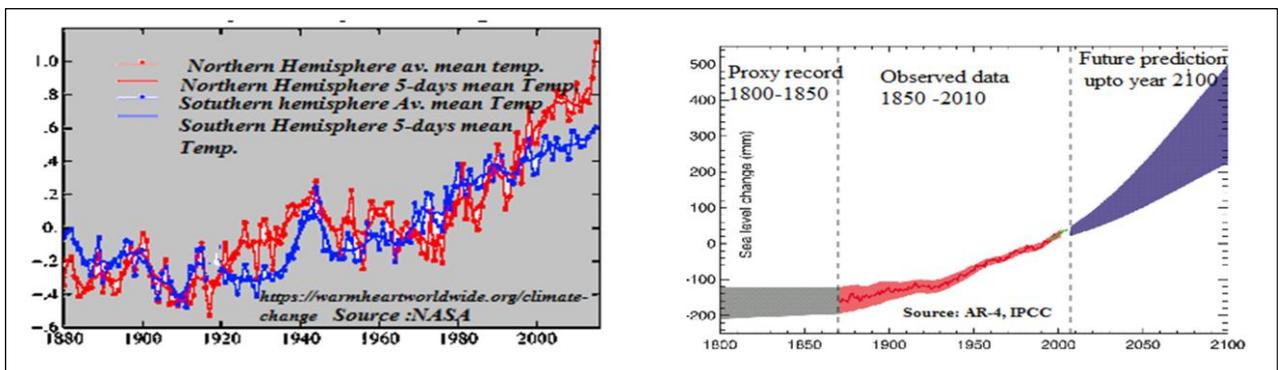


Fig 13:-Global land-ocean temperature (Source: NASA)Fig : (a) Northern Hemisphere mean temp. changes (b) Northern hemisphere average MSLR

Current anomalies related to SLR:

Coastal landform along East Coast India was cyclic (either prograding or eroding or temporarily stable). Satellite observations, however, show that since 1993, the sea level has been increasing at a rate of approximately 3 mm/yr, which is significantly higher than the increase before fifty years. GSLR in the 20th century measured ≈ 170 mm Bindoff et al. 2007^[94] and predicted to rise exponentially in the 21st century due to rise in SST and upper air temperatures shall continue inducing GSLR to 50-140mm by 2050 and 60-330mm by 2100 above the reference year

1990, Rahmstorf 2007^[95]. Indian coastline is 34% erosional, 28% depositional inclusive EC of India. The present status of coastline >40% erosion of EC India is West Bengal (63%), Pondicherry (57%), and Tamil Nadu (41%). The depositional coasts are Odisha (51%) and Andhra Pradesh (42%), CWC-Delhi 2016, http://cwc.gov.in/CPDAC-Website_Paper_Research_Work/Status_Report.

Sediment influx through inland rivers, exploitation of GW, Anthropogenic pressure, isostatic rebound and geologic extreme are the causes of regional sea level rise (RSLR) in Bay of Bengal which had inundated 1.7m/100 years during 1870 to 2004 against global MSLR of 0.48m/100yrs (Bindoff et al. 2007^[94], Unnikrishnan 2007^[95], Rahmstorf S., 2007^[96] Church et al., 2013^[97] UdayKumar et al 2014^[98]. The RSLR shall be more frequent due to urban flooding, drainage congestion, flooding, and more frequent storm surge inundation, whereas GSLR is due to SST temp., ice loss from glaciers and freshwater mass exchange between oceans and land by damming Syvitski J P M 2008. It is estimated that $\approx 5.5\%$ of the deltas shall be submerged and 3.4 million people affected by 2050 along EC of India shall have to shift inland and 4100 km² of the marine zone shall be lacustrine by 2100 Ericson et al., 2006^[99] Parmanik et al., 2015^[100].

The shallow gradient and low lying areas along the coastal lagoons are sensitive to RSLR. The MSLR/RSLR shall have the landward retreating shore front shall remain unchanged when the SLR will be moderate Bruun 1962. If SLR shall high, landward retreat of spits could not self-renovent/reconstruct rapidly and low lands will be inundated including the lagoons http://shodhganga.inflibnet.ac.in/bitstream/10603/2628/8/08_chapter%201.pdf, Samba Siva Rao and Vaidyanadhan constructed four strand lines during the Holocene considering beach ridge to the Krishna Delta within 6500 Yrs BP to 2050 Yrs BP in the Godavari Delta and Mahalick et al 1996^[101], constructed five strandlines (A to E) along Odisha coast.

RSLR along EC, India and Sea level fluctuation are prominent during Anthropocene period i.e. from 1950 onwards on onset of the unofficial Anthropocene epoch. Sediments transported by large rivers transmitted to the sea but from small rivers deposited in marine marginal areas and form lagoons, swamps and backwaters and mangroves along the east coast. Unnikrishnan et al 2007^[95] reported that RSLR trend is constant @ + 0.73 mm/year along Visakhapatnam coast by, to rise +0.43 mm/year rise along Puri coast, and @ ≈ 4.7 mm/year at Hoogly. The rise is the outcrop of tropical cyclones, tides, waves, and coastal erosion tidal ingression, sand encroachment, sedimentation and human activities such as urban solid wastes, urbanization, industrialization, dams, ports and harbor activities etc. Farooqui et al 2016^[102].

Due to MSLR/RSLR, the lagoon barriers retreat landward and will make the spits steep and narrow and shorter in length and shall affect lagoon-sea exchange. This will make the spit vulnerable to breaching and leading to the formation of more inlets. More inland floods shall affect the flushing frequency and increase in salinity. The ecosystem shall change with species variety due to change of nutrition and contaminations shall lead to eutrophication, nutrient imbalance, and its associated adversities.

Temperature

The temperature study for past 100 yr, global av. SAT has raised by 0.76 °C and is predicted to rise further by more 1.1–6.4 °C by end of 21st century (IPCC report, 2007^[103] & 2013^[104]). Anthropogenic activities have increased the average temperature towards the fag end of 20th century and early 21st century, Ring et al 2015^[105]. SST rise shall vary regionally/ sporadically and will be moderated by normal climate deviation, Smith et al. 2011, The greatest warming is expected to occur at high latitudes in winter (IPCC 2007^[103]). 2°C rise in the average maximum temperature can have dangerous carbon sequestration but it shall be catastrophic when it is projected to 4.0⁰ C rise Angus Ian 2015^[106]. Surface Air Temperature (SAT) and Sea Surface Temperature (SST) affect the shallow water bodies and slow-moving water. The rate of SST and SAT anomalies are reflected to change in air temperature strongly which influence the water temperature of slow-moving, shallow water bodies such as coastal lagoons. The carbon sequencetion has been increased which is increasing the SST by 0.3 °C and is likely to continue to increase through the next century (IPCC 2007^[103]). Long-term data for temperature of coastal lagoons water is unavailable, yet it can be presumed that the shallowness and low flushing rates of coastal lagoons shall store more energy within and the water temperatures shall increase and depletion of DO shall occur affecting species grow in lagoons and estuaries Woodward 1987^[18], Turner 2003^[107]. Particularly the restricted lagoons with low flushing rates and high nutrient inputs like lagoons of EC India may exhibit hypoxic events and change the species composition D'Avanzo et al, 1994^[108].

Precipitation

There will be an increase in events of extreme rainfall Guhathakurta et al 2008^[109], along Odisha and Andhra Pradesh coast causing a change in drought-flood cycles, more ET, change in GWT and soil moisture along EC India. The effects of increased rainfall shall increase runoff, include the increased delivery of sediment and nutrients to lagoons Orpin et al. 1999^[110]. Increased nutrient inputs may accelerate the eutrophication of lagoons, especially those with low flushing rates with sea level rise, turbidity will reduce. Light penetration and the photosynthetic activity of submerged aquatic vegetation in shallow lagoons compound the risk of eutrophication as highly nutrient Loret et al. 2008^[111]. In addition, reduced light penetration can inhibit the feeding ability of visual predators Horppila et al. 2004^[112]. Pre-monsoon trend in rainfall and rainy days events along the EC, India (1951 to 2011) exhibits an increasing trend in TN and south Andhra coast whereas there is a decreasing trend in rainfall in rest of east coast lagoon catchments Jain et al., 2012^[113], Mohapatra et al, 2006^[114]. The heavy rainfall events have increased due to increased low-pressure events (Storms, trough lines and westerly's). There shall be more flushing flows to the lagoons in EC India and fluctuate cyclic salinity of the lagoons and outflux of the aquatic vegetation and maintain the eco-health.

Tsunami effects:

There is no previous record of the devastation caused by Tsunami prior to Dec 1881 when there was an earthquake of M=7.9 at Carnicobar which generated 1m waves followed by a volcanic eruption in Aug 1883 at Krakatoa volcano, Vietnam creating a surge of 2m at The 20th-century tsunami of June 1941 was recorded an Andaman earthquake of intensity M= 8.1 creating tsunami surge of 1m height at Chenei. The 26th Dec 2004 tsunami have generated tsunami surges affecting Andhra Pradesh coast, TN (both east and west) of wave height 3-10m and Pudduchery coast (maximum at Karaikal wave height of 5m to 10m) and caused severe damage particularly to lagoons, wetlands and backwaters along the coast along with fatalities of ≈200000 people. Later in 22nd Dec 2018 due to collapse and eruption from Anak Krakatau volcano, the Sunda Strait was expected to cause Tsunami waves along Indian coast poses an imminent threat to the wetlands along the east coast of India. The continued tectonic activities along Indian ocean may deform the coastal lagoons/wetlands along the east coast of India due to the formations of large waves. <https://weather.com/en-IN/india/news/news/2018-12-25-indonesia-tsunami-disaster->

Oceanic disturbances:

Meteorological occurrences like Cyclonic storms/ Tsunamies affect lagoons through surges, overwash events, bypassing by erosion from wind and waves and develops/destroys spits and the barrier beaches along the coastal front. The East coast of India slammed >1000 Bay of Bengal cyclonic storms in the 20th century out of which >400 were by CS, SCS, VSCS or super cyclones which made the coast most susceptible to coastal deformations of lagoons. Last 20 years (21st century) is the most crucial years for the lagoons along EC India. A large numbers of SW monsoon cyclonic storms slammed or passed through the EC India in 21st century from BOB 05 (1998), Bob 03(B) (2003), Yemin (2007) to Phethai (2018) has shattered the spits of the lagoons along the east coast near and adjacent to the place of slamming. The Chilika coast is most vulnerable to BoB disturbances for the last decade like the VSCS Phailine, (2013), Hudhud (2014). The numbers of cyclones received along coastal states of Odisha, Andhra Pradesh and Tamil Nadu (including Puducherry) from 1891 to 2017 are 107 numbers, 86 numbers and 65 numbers respectively Mishra Ashutosha 2014^[115]. According to BMTPC Atlas, the coastal districts along the east coast of India has a high risk of severe cyclones are Nellore, Godawari (East), Srikakulam and Guntur in (AP) Kendrapada, Bhadrak, Jagatsinghpur Puri and Ganjam in Orissa; Kanchipuram in Tamil Nadu along the wetlands/lagoon coasts <https://ndma.gov.in/images/cyclones/cyclonepronedistrict.pdf>.

The global warming and warm climate will augment the intensity of tropical cyclones with reduced frequencies globally during the 21st Century whereas the number of storms in the Indian Ocean and Bay of Bengal would increase particularly in lagoons/major wetlands lying along the east coast of India, Mishra et al 2014^[116]. The coastal districts occupying lagoons— are highly prone to slamming of Bay disturbances are Kendrapada, Jagatsinghpur, Puri, Khordha, Ganjam in Odisha, Srikakulam, West Godavari, Krishna, Nellore, Chitore in Andhra Pradesh Tiruvallur, Kanchipuram, Villupuram, Cuddalore, Nagapattinam, Thiruvarur, Puddikotai and Ramanathapuram in Tamil Nadu and Pudducherry Mohapatra et al 2015^[117]

The east coast lagoons along the east coast of Indian tropics, the erosion is along the northern fringe of the estuary and accompanied by erosion whereas the southern fringe gets deposited where the shoreline is moving towards the mainland **Table -5**.

Table 5:-The status of lagoons/wetlands along the EC of India, erosion and accretion and storm slamming coast

Sl	State	Name of the major lagoon /water body	Districts	Type of coastal wetland	inflowing rivers/drains	Mouth /coast type	Av.wave period (min)	Storm 1891-2017	Max surge ht. (more)
1	Odisha	Bhitar Kanika	Kendrapada	BW	Baitarani	E /A	3-10	16/(4S)	≈6-9
2	Odisha	Hukitola Bay	Jagatsinghpur	Bay	Brahmani	E/A	3-10	14/(3S)	≈6-9
3	Odisha	Jatadhar Muhan	Jagatsinghpur	Lateral Channel	Jatadhar	A/E	4-8	14/(3S)	≈6-9
4	Odisha	Ramachandi	Puri	Estuary	Kushabhadra	E/E	4-8	6/(1S)	≈5.5
5	Odisha	Chilika	Puri,Khordha/Ganjam	Lagoon	Daya,Bhargovi, Salia	S/E	4-8	17/(9S)	≈3.2
6	Odisha	Tampara	Ganjam	Lagoon /Salt pan	Local drain	A/A	3-8	11/(8S)	≈3.0
7	AP	Bendi	Sikakullam	Lagoon	Bendi Gedda	A/A	3-8	12/7 (S)	≈2.7
8	AP	Kakinada Bay (Goutami mouth)	East Godavari	Bay	Motipalem,P edda,Koringa,	A/A	3-15	17/(4S)	≈3
9	AP	Kolleru	Krishna,West Godavari	BW	Upputeru, Goguleru	A/A	3-15	18/(8S)	≈4.0
10	AP	Nizampatnam	Nizampatnam	Lagoon	Gundlakama, Romperu	A/A	4-12	5/(3S)	≈5.5
11	AP	Iskaplalli	Nellore	Lagoon	Pennar	E/E	3-12	18/(8 S)	≈5
12	AP/TN	Pulikat	Nellore (AP)	lagoon	Kalangi,Aranji	A/A	3-12	18/(8S)	≈3-4
13	TN	Muttukadu (Back water)	Kanchipuram	Lagoon	No river		2-9	13/(8S)	≈7.0
14	Puducherry	Kaliveli	Velupuram	Lagoon	Yadayanthittu,		2-9	3/(3S)	≈4.5
15	TN	Muthupet	Tiruvarur	Lagoon	Muthupetai		2-9	3/(3S)	≈4.5
16	TN	Gulf of Mannar	Ramanathapuram	Leaky lagoon	Vaippar,Gundar, Palar, Kot takkarai	A/A	3-9	2/1(severe)	≈11.

AP: Andhra Pradesh TN: Tamil Nadu, EG: East Godavari, WG West Godavari, BW: Backwater, L.C: Lateral Channel, CS: Cyclonic storms, .S: Severe storms: SCS, VSCS, Super Cyclones, E: erosion, A: Accretion

Source: Kankara et al. 2015^[118], V. Sanil Ku.et al, 2006^[25], Mohapatra, 2015^[117], ncrmp.gov.in/cyclones-their-impact-in-india

In the last 200 years, at least 2.6 million people may have drowned due to storm surges and causing a range of other damages and devastations Nicholls et. al., 2006^[119]. The tropical cyclone Sidr in Bangladesh in November 2007 and cyclone Nargis in the Irrawaddy Delta of Myanmar in May 2008 are recent reminders of the potentially devastating impacts of severe weather phenomenon and storm surges in less developed countries. According to the Bangladesh Disaster Management Information Centre (report dated Nov 26, 2007), 3,243 people were reported to have died and the livelihoods of 7 million people were affected by the tropical cyclone Sidr (<http://www.reliefweb.int/rw/RWB.NSF/db900SID/EDIS-79BQ9Z/> Open Document).

The consequences of RSLR become acute during storm events because the rise in Sea level during storms interact to erode barriers and produce high storm surges, rapidly redistributing barrier sediment. During periods of high storm surge, water moves rapidly over the barrier as overwash, which delivers sediment eroded from the front of the barrier onto the back barrier flat and into the lagoon. Increased storm intensity shall increase breaches of the barrier islands causing TI's and enhance flushing rate and increase the salinity of the lagoons

The VSCS Phailin 13th Oct 2013 and 2014 along Chilika coast, and 14th Nov. 1984 the Sriharikota with pressure 984.1mb and gusting wind speed 170-200 kmph had changed the lagoon characteristic from a choked to a restricted

one. The 3-4m high floods forced opened 7 numbers of new tidal inlets in the southern sector of the Pulikat lagoon flushing out the lake biodiversity, vacating the fishes, prawns to Bay of Bengal, lost faunal (avi, aqua fauna and the habitats) and made the lake users bankrupt as they lost fishes and their fishing gear and silting up the canal system.

Anthropogenic concerns:

Lagoons along EC India are harnessed for pisci-culture, shrimp and prawn culture, energy sources, biotechnology, tourism, transportation, shipping, and varied anthropogenic usages. These factors with other related activities have put immense stress on the lagoon ecosystem which has been brought out in the subsequent chapters.

Anthropogenic emissions:

Apart from sun-earth geometry, the main cause of global warming is GHG emissions of mainly CO, CO₂, CH₄, SO₂, SF₆, oxides of nitrogen (NOX), HFCs (hydro-fluorocarbons), PFCs (perfluorocarbons), and NMVOC (non-methane volatile organic compounds) due to industrial and commercial activities. The subcategory of anthropogenic GHG gasses are CFC (11,12 and 113), Halon (1211 and 1301), HCFC 22, CCl₄ (CTC), Methyl halo is also generated due to industry exhausts and residuals, emissions from the vehicle, electronic appliances, and gadgets. These polluting gases with toxic industry effluents discharged into the lagoon are a threat to the existence of flora, fauna, and avifauna.

Ports and harbors:

Port and harbors, sea walls, fishing jetties along the oceanic front, debonding of mangrove are the anthropogenic activities (like armoring, dredging, sand mining, Seawalls, bulkheads, breakwaters, and erosional wakes) that affect the coastline of a lagoon. The activities augment the longshore sediment transport and transform the spits of the adjacent lagoons.

Embankment stabilization:

Sea level increase and an increase of intensities of storms in 21st century slamming the lagoon coasts have threatened the low-elevation areas. The lagoons have a numbers of islands within which accommodate mostly the low economic group (fishermen, ecotourism service suppliers, and allied communities). In the 20th century these islands were not protected by gherri bundhs and there was free flow for smooth discharge of floods. The construction of gherries has changed the hydrodynamics of the flow system of the lagoon, the fluvial status, nutrient inflow, ecosystem and salinity of the lagoons. The flow of additional nutrient from the increased settlement, agriculture, pisciculture firms have altered the pragmatic values associated with fisheries, habitats, real estate, and tacit values. The modern avenues and alertness warnings could not reach the weaker section to evacuate promptly to avoid inundation like new Orleans communities during Hurricane Katrina in 2005 Finch et al 2010.^[120]

Salt Marsh loss:

India is the 3rd largest common salt producer of the world after China and the USA. The series of lagoons along the EC India are rimed with salt ponds of the complex low lying countryside of developed coastal settlement areas, profitable waterfronts, agricultural areas. The salt marshes lie in low lying areas with the heavy tidal influence of EC of India. It is mostly associated with estuaries/lagoons that provide prime habitat for a special variety of bioturbation, plant species, crab herbivory, and salt production to augment socio-economic activity. India has 6major areas of salt marshes. The RSLR increases the erosion of existing salt marshes and add up to open water zones. Though great run of Kutch a terrestrial salt marsh covers the largest area of 7500Km². Almost all lagoons cover salt marshes. The lake borders used for the salt pan in EC of India are Tamil Nadu (Tuticorin, Vedaranyam, Covelong), Andhra Pradesh (Bendi, Chinnaganjam, Iskapalli, Krishnapatnam, Orissa (Ganjam, Huma, Sumadi). Production of common salts in the salt pans having lagoons in the year 2016-17 are Odisha (9TMT), AP (401TMT), and TN 2400TMT at the cost of the lagoon area <http://www.saltcomindia.gov.in/home.html?tp=asp>.

Imprints of Fringing of deltas

Coastal lagoons get terrigenous sediment from inflowing streams/ rivers comprising of flocculated silts and clays and deposited at entry or exit point of the water body. The lagoons also transport sediments by the littoral drift near shore through tides, surges, and waves. When there is an imbalance of exchange in the influent system the reconstruction of the barrier spit occurs. The paucity of Indian deltas positioned along the EC of India due to anthropogenic interventions like the construction of hydraulic structures inland have reduced the flushing floods frequencies and the sediment inflow to the lagoon which triggers the coastal erosion Nageswara Rao et al., 2011^[121]. ruffle the coastline of the Bay of Bengal. Delta building process is hindered for sediment paucity,

increased settlements as numbers of dams, barrages are constructed in the inland river restricts flushing flow and corresponding sediment and demographic explosion have tempted people to have new settlement in the rims and within the lagoon area Syvitski, et. al., 2008^[122], and 2011^[123].

Longshore Transport (LST) along East coast India

The shock during landfall and slamming/ slashing of the storms and the tsunami surges causes major changes in the barrier island and the tidal inlets of the lagoon. Similarly, drought and excess evaporation due to heat waves in the hinterland induce the spits to deform the lagoon's shape and size. In addition to inland sediments, the longshore drift along the east coast of India plays important role in reconstructing the beach, wetlands, and lagoons along the East coast of India. The direction of net LSTR is south to north and vice versa during the month of November and December but the net LST is towards the north for the whole year. The maximum Longshore Sediment Transport Rate (LSTR) was $\approx 1 \times 10^6 \text{ m}^3/\text{yr}$ along Chilika coast South of Guguleru creek (Kolleru coast) to Chilika northern coast Sanil Kumar et al 2006^[25] **Table 6**,

Table 6:-The shoreline configuration, quantity and direction of LSTR along the east coast of India

Place along EC	Shoreline configuration	Latitude	Longitude	Direction flow	Net LST	Gross LST	Lagoon/wetland Associated
		⁰ North	⁰ E		Cum/yr	Cum/Yr	Cum/yr
Periyathalai to Vatakkottai	NE-SW Coast	8.28	77.892	South	1500	251300	Gulf of Manner
Tiruchendur	NE-SE Coast	8.32	77.934	North	64100	7500	Gulf of Manner
Kanirajapuram	NE-SE Coast	9.107	78.383	North	117447	45979	Gulf of Manner
Narippaiyur	ENE-WSW coast	11.745	79.768	South	36600	122500	Gulf of Manner
Muthupettai	ENE-WSW	10.789	79.399	South	5200	8900	Muthupet lagoon
Puduvalasai	NWN-ESE coast	9.383	78.939	South	5300	42900	Mandapam , Palk Bay
Vedaranyam	N-S coast	10.375	79.848	North	51100	94100	Kodiakadu, Point of Climate WL
Tarngambadi	N-S coast	11.029	79.851	North	200600	369400	Uppaner Estuary
Puducherry	N-S coast	11.916	79.812	North	134400	237000	Kalivelli lagoon
Periyakalpet	NEN-SW coast	12.029	79.836	North	486900	657600	Mutukadu BW
Tikkavanipalem	NE-SW Coast	17.665	83.285	North	177000	405000	Ishkapalli lagoon
Nizamapatnam	E-W Coast	15.905	80.668	North	222000	502000	Nizamapatnam lagoon
Machlipatnam	NE-SW Coast	16.19	81.14	south	840000	1280000	Kohler Lake, Guguleru creek
Gopalpur	NE-SW Coast	19.239	84.887	North	830046	949520	Tampara lagoon
Prayagi,Chilika	NE-SW Coast	19.244	84.892	North	887528	997594	Chilika
Puri	NE-SW Coast	19.798	85.831	North	735436	926637	Kushvadra channel
Astarang	NE-SW Coast	20.191	86.548	North	NA	134100	Jatadhar Muhan
Paradip	NE-SW Coast	20.317	86.611	North	NA	134100	Hukitola bay

In view of imminent danger to the survival to lagoon ecosystem and its biodiversity, it is imperative on the part of planners and stakeholders to adopt an integrated approach to safeguard and at the same time rejuvenate the lagoons on most immediate basis. These water bodies are lifeline of our survival and any piecemeal or isolationist approach would jeopardize the existence of mankind in the long run. The measures submitted below for rejuvenation of the lagoon ecosystem are to be viewed in the context of constant friction between the issue of “development “and “environment”.

The author does not claim to prescribe panacea for this complex but significant problem area. The article outlines the intention of the author here to stimulate wide-ranging debate and interest to adopt a practical approach to anticipated rejuvenation of lagoon ecosystems in the East Coast of India in future.

Effects of climate change and SLR:

Rejuvenation of lagoons along the EC, India is expected due to impaired flooding and the increasing lacustrine area in the coastal low-lying coastal areas, augmented coastal erosion, coastal ecosystems transformations (mangroves, salt marshes, lateral channel formation, islands and coral reefs), backwater formation in small drainage channels, saltwater intrusion in UG aquifers, changes in flood delta in the middle and upper marginal zone, large impacts on the ecosystem, species, and finally the Homosapiens.

Management of Lagoons along EC. India:

After the introduction of Earth system science (ESS), the events, causes, effects and their interdependence in lagoons /wetlands along the east coast of India are studied and the ameliorative measures were taken on priority basis as human need to protect themselves from Meteorological and geologic extreme events. The protective measures are

Watershed management:

Basin watershed management with long-term catchment treatment plan and effective management land use to avoid sedimentation of lagoons.

Hydraulic activities:

Hydraulic structures on the inflowing rivers and preparing regulated rule curve for the flood management of the basin to provide required flushing flow to the lagoons to avoid sedimentation.

Benthic zone activities:

Proliferation of Ipomeas, water hyacinth, planktonic growth and seagrass in ecotone-1 i.e. in the benthic zone augment sedimentation of the lagoon which is the main cause of diminution of lagoon area along EC of India. Plan to save the lagoon from the aquatic plant growth by developing 3F's i.e. fish, flood and flushing.

Save aqua-fauna:

It is required to keep the lagoon clean, save the fishes from destructive fishing practices using technologically advanced fishing gears to maintain sustenance of the aquatic habitats and flourish the lagoon's limnology, sedimentology and environment. Save aqua-fauna and restrict ecotourism that will reduce pollution aiding the proliferation of weeds, attract avifauna and aquatic habitats to the lagoon.

Environmental management:

GHG gas emission and maintaining CO₂ level, are the prime indirect factors to save the lagoon to decline in future. Basing upon Ecosystem services consideration, it is required to demarcate such key issues, make state-level policies to save the world from global warming and acidification and also save the lagoon from the severity of RSLR.

Climatic Model studies:

The sensitivity analysis through regular GIS and model studies of coastal areas to the plausible range of climate change can be attempted and recorded regularly. The suitable scenarios of RSLR/GSLR, Irradiance and solar radiation temperature anomalies of both land and sea, changes in BoB disturbances, Indian Ocean Tsunamis, annual ENSO activities (El Nino, La Nina and La Nada activities) should be well studied and imparting analysed helping preparedness/ alertness well in advance to develop short term and long-term actions.

Water quality management:

Appropriate actions needed to maintain salinity, water quality by devoiding the lagoon from urban /industrial wastes especially avoiding plastics, E-wastes and radioactive wastes. For a healthy and stable lagoon and its biodiversity maintain water quality, avoid pollution, sedimentation and well-planned waste disposal in the urban areas of the catchment

Polito-socio-economic stresses:

The meteorological extreme events, erratic land use of marine marginal areas, and political-socio-economic stress zones should be identified and to be considered illegal.

Study of CZ and beach nourishment:

It is high time to consider the entire coastal zone of EC, India as an ESS subsystem of science. By using NASA's tool study is needed for the rhythm of terrestrial and oceanic bionetworks changes and their impacts overexploitation of flora, fauna, avifauna, and aquafauna of the global geo-bionetworks. The identification of flagship effects such as nondisposal of non-bio-degradable wastes, demolition wastes, and prohibition of using coastal wetlands as dump yards should be done on priority.

Coastal instability along the east coast: The erosion and accretion of the shoreline of the east coast have pragmatic impact on the at the interface of land especially the lagoon/waterbody's dynamic geographic features,

Mining/Port/Jetti activities:

The lagoons were the old harbors and ports in past without huge infrastructural activities. The huge concrete structures in the vicinity of port near the lagoons coast are destroying the ecosystem and contaminating the lagoon. Present ports and harbors, mining activities on and offshore, shipping and oil exploration/spills and chemical spills degrading the lagoons nearby.

Management strategies:

To ensure Integrated Coastal Zone Management (ICZM), legislation and regulations for Revised Protected Areas (RPA) adjacent to India's EC territorial water and coastal zone management of lagoons/watersheds and their capacity/resilience to multifaceted ecotones need to strengthen mechanism during its rejuvenation in future under RSLR scenario.

Conclusions:-

The key observations during the study are Lagoons along the east coast of India form in the estuaries of small rivers and the suitable landform is sandy or muddy low-lying coasts under mild soil slope. The Coastline is ever changing and the RSLR along the west coast of BOB are prominent. Capacity building and effective coastal zone management by identifying the constraint zones should be built up as a national policy during its reconstruction in 21st-century RSLR scenario and EC line erosion and accretion.

The fragile coastal lagoons along the east coast of India have multifaceted challenges of different dimensions to the immediate landform near the ocean (wetlands) as it is the frontline to face climatic glitches. The spectrum of biodiversity anomalies in recent past and future prospect are in the hands of nature but triggered by the Homosapiens. It is high time to evaluate the pragmatic values of future changes and the lagoon managers/stakeholders should take timely suitable action to ameliorate the anticipated impact and threats irrespective of their social, political, economic and anthropogenic influences to save the highly nutrient zone and their fragile ecosystem.

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