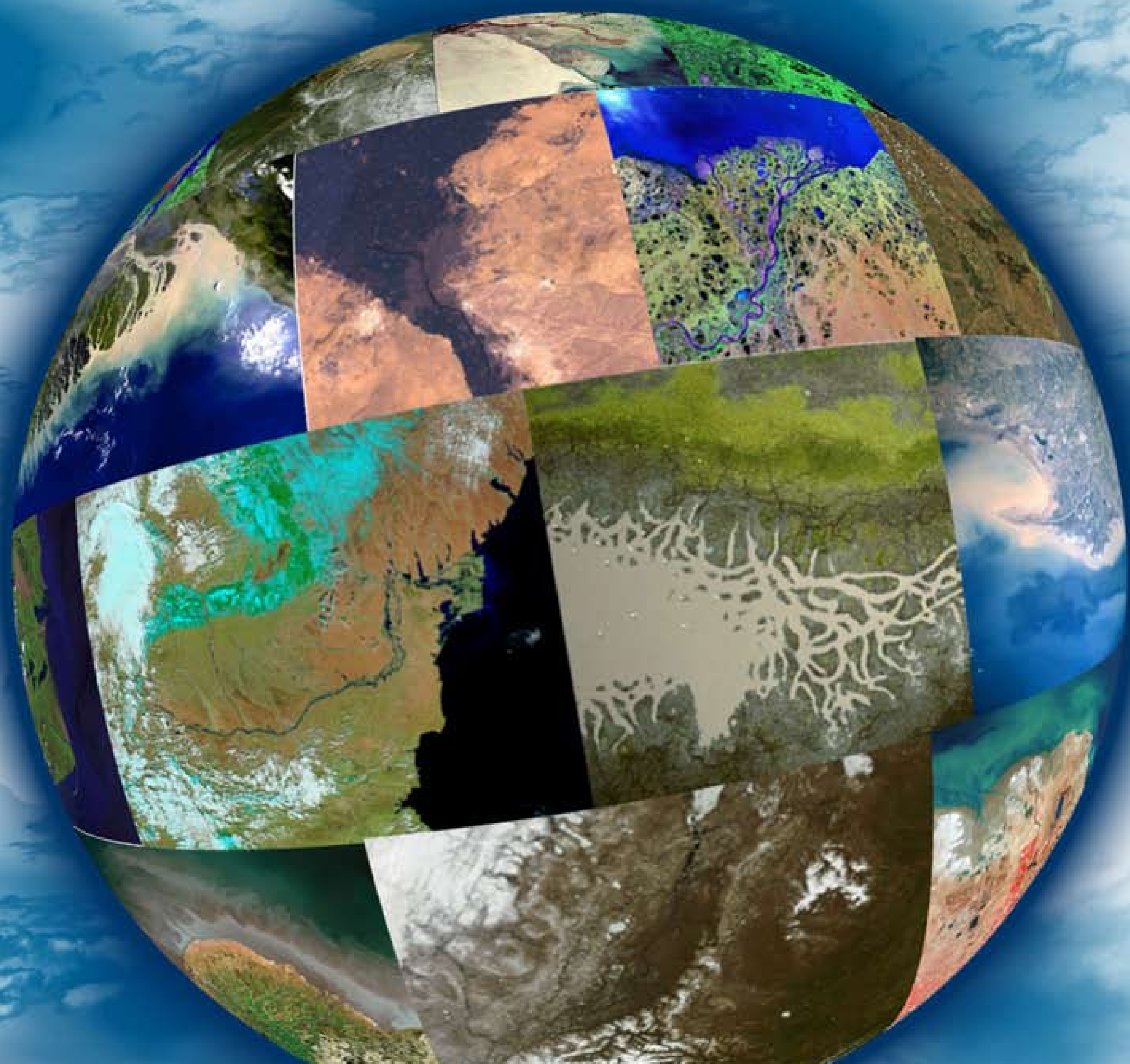
DELTAS

COASTAL VULNERABILITY AND MANAGEMENT



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DELTAS: COASTAL VULNERABILITY AND MANAGEMENT*

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Editors

RAMESH RAMACHANDRAN
PURVAJA RAMACHANDRAN
AHANA LAKSHMI

Institute for Ocean Management, Anna University Chennai, Chennai - 600025. INDIA

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S.A.Swamynathan

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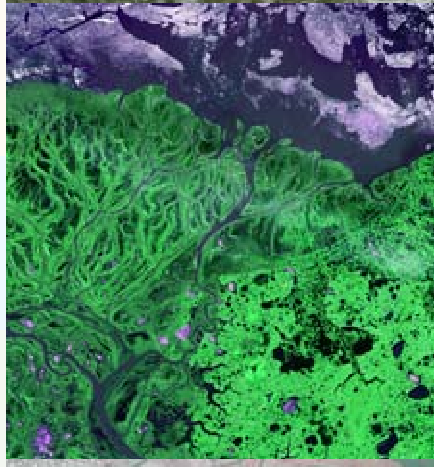
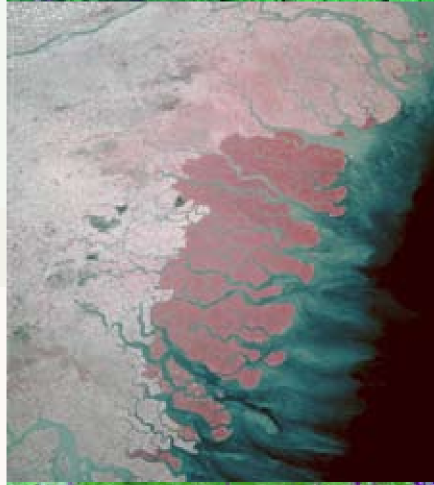




Picture 1: Uses of the delta region: AGRICULTURE
Source: http://labour.icsf.net

Picture 2: Uses of the delta region: AQUACULTURE
Source: http://www-tc.pbs.org

Executive Summary

Deltas may be described as the dynamic interplay between land and sea forcings at the coastal zones that can be studied at a range of scales. Coastal zones have to do with processes far offshore either on the ocean side or the hinterland. Global coastal zones provide a host of goods and services and are the major location of the biogeochemical cycling of nutrients.

Coastal zones are vulnerable because of the extensive anthropogenic activities that take place here. As the number of new activities such as tidal and wave energy plants, oilfields and mariculture systems increase, the stress on the coastal areas is on the rise. This International Workshop addresses a few key questions that require a basic understanding for the proper management of the deltaic regions as follows:

- How do deltas form?
- What are the stresses that have built up over the years?
- What are the areas where management focus should be directed?

Recent studies of deltas all over the world have clearly indicated increasing vulnerability to flooding due to sinking of deltas due to a variety of reasons such as sediment compaction due to removal of gas, oil and water from the delta's underlying sediments, upstream trapping of sediments in dams and reservoirs as well as floodplain engineering. Deltas being areas of intensive agriculture and settlements also see large amounts of nutrient inputs which reach coastal waters resulting in eutrophication and pollution related problems.

To obtain an overview of the vulnerabilities and management of deltas in the coastal zone, especially in Asia, an international workshop was held at the Institute for Ocean Management, Anna University Chennai, Chennai, India, in December 2009. The workshop focus encompassed not only the geology and biogeochemistry of deltas in the coastal zone but also the social sciences aspects. The workshop had five sessions as follows:

1. Types, formation and characteristics of Deltas
2. Biogeochemistry and Nutrient Budgeting of Deltas
3. Nutrient Budgeting for Muddy Coastal Waters
4. Global Climate Hazards and Vulnerability
5. Human Perspectives

There were keynote addresses and technical presentations in each session and also a separate poster session. The sessions covered a range of approaches to delta studies. This report uses the papers presented at the workshop to provide an overview of various aspects of deltas in Asia. At the end of the sessions, there were discussions on the "way forward". It was observed that apart from focusing on scientific (including geological, chemical and biological) studies, deltas need to be seen as socio-ecological systems with social aspects and hazard mitigation needing more research and action. The changes in sediment fluxes in some cases were changing the dominating force in the delta. Shoreline changes need to be better mapped and ability to forecast future changes based on past records has to be developed. The role of the biology of fine sediments in the nutrient budget in estuaries needed more study as models developed based on laboratory studies were not successful in the field as the micro-organisms inhabiting the mud changed its characteristics in many ways. The new LOICZ model for muddy waters is easy to use and would unravel a new dimension for research on muddy coastal waters. Nutrient management is a key issue in the coastal zones and understanding the role of mangroves in carbon sequestration and developing nutrient budgets for lagoons and estuaries could help in identification of major nutrient sources.

People living in deltas are vulnerable to a variety of hazards. They have, for the most part, natural-resources dependent livelihoods such as agriculture and fisheries. Floods and droughts take a toll on agriculture and the increased groundwater usage for irrigation is leading to reduced water availability as well as deteriorating groundwater quality. Post tsunami interventions have benefitted fishermen in some areas but the resources are stressed because of various reasons. While villages behind mangroves can be shielded from effects of cyclones, it is the bottom-up approach in disaster preparedness that actually enables people to overcome disasters. The move is also towards an adaptation framework which may require higher capital influx but is more effective in the long term especially with climate change effects impacting deltas.

In summary, deltas are seen vulnerable to a series of stresses and impacts. Many of the activities and issues are cross-cutting in nature and hence, better communication amongst researchers and workers in these areas are necessary. Deltas need to be seen in the future as socio-ecological systems and high focus on the human interactions in deltas is needed.

Picture 3: Uses of the delta region: FISHING

1. Introduction

1.1 ABOUT THE WORKSHOP

Deltas are terminal parts of river courses towards the seas and oceans and are under the influence of both rivers and seas. For this reason, they are often considered as systems of large rivers–deltas–coasts–seas/ocean macro-systems. Being the confluence between land and sea, deltas can be considered as one of the most reactive and sensitive continental systems, as they are subjected to swift changes at any variation of rivers and/or seas forcings . Most deltas today began to form ~8000 years ago when rising sea levels due to melting of glaciers resulted in the landward migration of the shoreline, retreat of river mouths and formation of estuaries. 87% of the Earth's land is connected to the ocean through river systems, and the sediments are present as a normal product of the freshwater cycle. Because 61% of the Earth's human population lives along a coastal boundary (and is expected to climb to 75% by 2025), the activities along these river basins can have a huge environmental impact[2].

Deltas worldwide are extremely important from a human view point. Many cultures developed along large river valleys and even today, deltas are areas of high population density. More than 50% of the world's population lives in Asia and most of Asia's population lives in deltaic areas. During the past century, deltas (as well as the other components of the river-delta-coast-sea macro-systems) have been subject to ever increasing pressures from the explosive development of humankind. Drastic changes in land use (towards urbanization as well as agriculture and industrialization), overexploitation of natural and living resources and the blocking of the natural evolution because of damming/embankments and changes in channels' courses are only a few examples of the ways humans altered the deltaic systems. As a result, most of the deltas worldwide have been subject to degradation which negatively impacts the development of neighboring human communities. There are just a few happy cases when deltaic management proved to be successful, and one of the main causes of failure is the lack of an integrated planning of management in all the systems of the river-delta-coast-sea macro-system[1].

More than 80% of the world's total area of rice paddies is in Asia, and the rice paddies are mostly in deltaic lowlands[3]. Modern cropping methods require extensive irrigation and the use of fertilizers and pesticides. The result is the abstraction of water by various irrigation schemes which include impoundments; as well as the steady increase in the usage of chemical fertilizers. Runoff from these cultivated areas as well as untreated and partially treated municipal wastewaters reach estuaries and the coastal zone resulting in eutrophication. Understanding nutrient budgets and the role played by coastal ecosystems in providing biogeochemical cycling services is steadily improving with new components being added to models to make the process of forecasting better.

1 Report on the international workshop "River deltas: evolution, environmental challenges and sustainable management" 2006 http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA473722&Location=U2&doc=GetTRDoc.pdf

2 Bianchi, T.S. and Allison, M.A. (2009) Large-river delta-front estuaries as natural "recorders" of global environmental change. In: Proceedings of the National Academy of Sciences; (PNAS) Vol. 106 no. 20, 8085-8092

3 Asian Deltas, http://unit.aist.go.jp/igg/cug-rg/ADP/ADP_E/a_about_en.html accessed February 12, 2010

The Institute for Ocean Management, Anna University Chennai, conducted an International Workshop in December 2009 at Chennai, India, to understand the current environmental status of Asian deltas from various viewpoints, e.g., changes in shoreline morphology, runoff, nutrient and sediment loads, coastal ecosystems, human activities, etc., and to synthesize these data for future assessments and management.

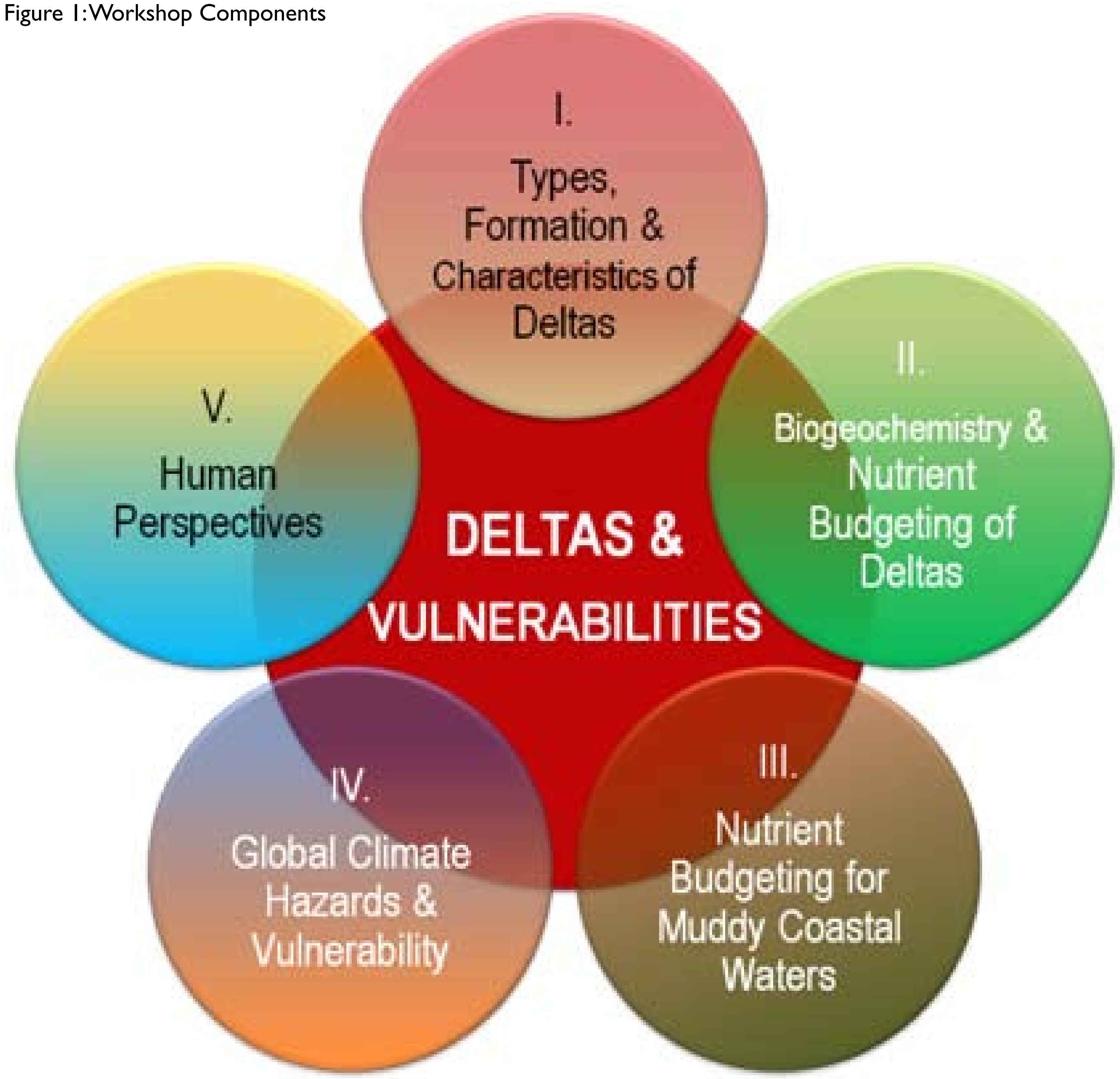
The workshop was inaugurated by the Vice Chancellor of Anna University Chennai, Prof. Dr. Mannar Jawahar. Dr. R. Sellamuthu, Additional Chief Secretary and Development Commissioner, Government of Tamil Nadu, presided. There were five technical sessions: each of them featuring keynote lectures and technical presentations:

1. Types, formation and characteristics of Deltas
2. Biogeochemistry and Nutrient Budgeting of Deltas
3. Nutrient Budgeting for Muddy Coastal Waters
4. Global Climate Hazards and Vulnerability
5. Human Perspectives

International participants included scientists and researchers from Australia, China, Japan, Germany, the United States, and from different universities and institutions in India. The names of the participants are provided as an annexure to this document.

The themes/ concept of the workshop is described as a graphic in Figure 1. This sequence served as the basis to understand deltas from various perspectives and to bridge them under a common scientific and social science platform. This is in keeping with the increased demand towards treating deltas as socio-ecological systems where people interact with each other and the environment with science providing useful information for management.

Figure 1: Workshop Components



2. Assessing Existing Knowledge

By several key criteria, Deltas are now widely perceived to be in crisis. In a recent major study published in Nature Geoscience in 2009[4], it was found that of the 33 major deltas studied, 24 were sinking. Possibly the worst affected is the Chao Phraya, the river that flows through Bangkok. In some years, parts of the delta are believed to have sunk by 15cm relative to sea level, significantly more than the global rate of sea level rise as a consequence of climate change (1.8-3.0mm per year). Researchers report that the flow of sediment down to the Chao Phraya delta has been almost entirely blocked - due to withdrawal of water for irrigation, damming the river, and directing the main flow through just a few channels.

At the global level, based on seventeen drivers, the strongest signals in the coastal zone were from pollution and climate change. With respect to vulnerabilities in delta regions, currently signals from anthropogenic sources are found to be overriding those from climate change and many of these signals are from South Asia and South East Asia.

Figure 2: Heavily Populated Delta Regions that are Vulnerable to Sea Level Rise[5]

[4] Syvitski, J.P.M. Kettner, A.J., Overeem, I., Hutton, E.W.H. Hannon, M.T. Brakenridge, G.R., Day, J., Vörösmarty, C., Saito, Y., Giosan, L. and Nicholls, R.J. (2009) Sinking deltas due to human activities. Nature Geoscience, DOI:10.1038/ngeo629

[5] www.idrc.ca/openebooks/262-7/f0052-01.gif

2.1 ENVIRONMENTAL EFFECTS OF HYDROLOGICAL ALTERATIONS

Deltas are extremely important units of the coast, and their associated river and marine systems. They are key integrators and indicators of processes in entire watersheds, and key filters and transformers of materials and energy for the marine environment. They are important regions for humanity in their own right, providing ecosystem goods and services, and they are highly sensitive indicators of change. Global climatic changes during this century are likely to bring about dramatic changes in the coastal regions of the world. In recent years, much thought has been directed towards the consequences of such changes on the continental landscapes. If a major marine transgression initiates because of global warming the area of maximum impingement will be at the coastline.

The likely effects are several: ranging from changing selection pressure on all terrestrial coastal ecosystems as the area of habitat diminishes to the regional changes in the effects of geological processes of erosion or transportation and radical alteration of the coastal geomorphology. The predicted global rise in sea level is estimated to be between 0.18 to 0.59 m in this century[6]. This is likely to result in extensive coastal flooding and heavy economic losses with many of the world's major cities located in vulnerable coastal areas. For example, in the United States of America, a lot of this interest is associated with coastal Louisiana described as the most vulnerable area in the United States. While forecasts that up to 90% of the Mississippi River Plain will be lost by the year 2100 may be excessive, they may not be unrealistic[7].

The Missisippi in the US and the Chao Praya in Thailand are but two examples of the problems being faced by deltas all over the world. The biggest problem is population increase in coastal areas which directly contributes to coastal stress. Deltaic coastal areas are economically important and hence are of high concern to governments and various agencies especially with respect to control and management of resources.

The magnitude and extent of dam construction and associated water diversion, exploitation of groundwater aquifers, stream channelization, and inter-basin water transfer in the world today are so large that these hydrological alterations have global–scale environmental effects[8].

Key facts about deltas

- Deltas are extremely important units of the coast, and their associated river and marine systems. They are key integrators and indicators of processes in entire watersheds, and key filters and transformers of materials and energy for the marine environment.
- They are important regions for humanity in their own right, providing ecosystem goods and services, and they are highly sensitive indicators of change.
- Global climate change in combination with human activities will directly affect deltas potentially producing catastrophic change on a decadal scale. If /when collapse occurs – the effects are likely to be catastrophic
- Considering that we are living in times of real and growing energy scarcity, deltaic ecosystem services provide an enormous subsidy for the global economy.
- Recent studies of deltas all over the world have clearly indicated increasing vulnerability to flooding due to sinking of deltas attributed to a variety of reasons such as sediment compaction due to removal of gas, oil and water from the delta's underlying sediments, upstream trapping of sediments in dams and reservoirs as well as floodplain engineering
- Deltas being areas of intensive agriculture and settlements also see large amounts of nutrient inputs which reach coastal waters resulting in eutrophication and pollution related problems.

Other major impacts on deltas include

- Sea level rise
- Subsidence of delta regions
- Degradation/loss of deltaic coastal ecosystems including coastal wetlands and estuaries
- Fresh water flow and decreased sediment yield

6 IPCC, 2007: Climate Change 2007: Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, Martin L., Canziani, Osvaldo F., Palutikof, Jean P., van der Linden, Paul J., and Hanson, Clair E. (eds.)]. Cambridge University Press, Cambridge, United Kingdom, 1000 pp.

7 http://cires.colorado.edu/science/groups/wessman/projects/wdn/about/

8 Rosenberg et al., 2000; Environmental Effects of Hydrological Alterations: A Special Issue Devoted to Hydrological Alterations; Bioscience Vol. 50 (9): 746-751

2.2 DELTAS AND SEA LEVEL RISE

As stated by Overeem and Syvitsky (2009)[9] Deltas are unfortunately also fragile geomorphic features, and can change dramatically with modest modifications in the controlling environmental conditions. The authors report that already, thirty-three major deltas collectively include significant area (~26,000) below local mean sea level and another ~70,000 km^2 of vulnerable area below 2m. This vulnerable area may increase by 50% under projected 21st century eustatic sea level rise. In response to rising sea levels and/or diminishing fluvial sediment discharge, most deltas would naturally reduce their size under wave and current interaction and migrate to shallow parts of the basin by switching and/or inundation[9]. Sea-level change related to global warming increases delta instability. For a given deltaic coast, changes in its elevation relative to sea level depend on three factors (Syvitski et al., in review):

1) Changes to the volume of the global ocean (Eustasy). This is influenced by fluctuations in the storage of terrestrial water (e.g. glaciers, ice sheets, groundwater, lakes, and reservoirs), and fluctuations in temperature of the ocean's surface waters (Warrick & Oerlemans 1990[10], Bindoff et al. 2007[11]).

2) Vertical movements of the land surface, as influenced by hydro-isostasy related to sea level fluctuation, loading due to the weight of delta deposits, glacio-isostasy related to the growth or shrinkage of nearby ice masses, tectonics, and deep-seated thermal subsidence (Syvitski 2008[12]). Isostatic changes can cause deltas to subside at rates of 1-5 mm/y.

3) Changes to the sedimentary volume of the delta, through natural compaction (3 mm/y), accelerated compaction (150 mm/y), and aggradation or sediment deposition onto the delta's surface (50 mm/y). Aggradation depends on both the rate sediment is delivered to a delta, and the amount of sediment retained on the delta during its transport across the delta surface.

Coastal zones, especially mega deltas in Asia and Africa, low-lying coastal urban areas and atolls are also particularly vulnerable to the impacts of sea-level rise, storm surges, and increases in the intensity of cyclones in certain regions. These increases in exposure to the risks of climate change are juxtaposed on the already high (and growing) vulnerability of coastal areas, which are home to 23% of the world's population and have population densities three times the global average[13]. The rise of sea level has caused more frequent and severe coastal flooding resulting in loss of coastlines, coastal lands, wetlands and mangroves. The increased severity in floods is projected to bring serious impacts to low-lying areas with high population density. Severe flood may cause large scale population displacement; resulting in socio economic instability and resource insecurity.

Fig. 3: Relative vulnerability of coastal deltas as shown by the indicative population potentially displaced by current sea-level trends to 2050 (Extreme = >1 million; High = 1 million to 50,000; Medium = 50,000 to 5,000; following Ericson et al., 2006)

2.3 MEGADELTAS OF ASIA

There are 11 megadeltas (Table 1) with an area greater than 10,000 km^2 in the coastal zone of Asia that are continuously being formed by rivers originating from the Tibetan Plateau

9 Overeem, I. & Syvitski, J.P.M. (2009): Dynamics and Vulnerability of Delta Systems. LOICZ Reports & Studies No. 35. GKSS Research Center, Geesthacht, 54 pages.

10 Warrick, R.A. & Oerlemans, J. (1990): Sea level rise. Cambridge University Press, Cambridge.

TABLE 1: MEGADELTAS OF ASIA

Features	Lena	Huanghe-Huaihe	Changjiang	Zhujiang	Red River	Mekong	Chao Phraya	Irrawaddy	Ganges-Brahmaputra	Indus	Shatt-el-Arab (Arvand Rud)
Area (103km^2)	43.6	36.3	66.9	10	16	62.5	18	20.6	100	29.5	18.5
Water discharge (109m^3/yr)	520	33.3	905	326	120	470	30	430	1330	185	46
Sediment load (106 t/yr)	18	849	433	76	130	160	11	260	1969	400	100
Delta growth (km^2/yr)	--	21.0	16.0	11.0	3.6	1.2		10.0	5.5 to 16.0	PD30	
Climate zone	Boreal	Temperate	Sub-tropical	Sub-tropical	Tropical	Tropical	Tropical	Tropical	Tropical	Semi-arid	Arid
Mangroves (103 km^2)	None	None	None	None		5.2	2.4	4.2	10	1.6	None
Population (106) in 2000	0.000079	24.9 (00)	76 (03)	42.3 (03)	13.3	15.6	11.5	10.6	130	3.0	0.4
Population increase by 2015	None	18	-	176	21	21	44	15	28	45	--
GDP (US$109)		58.8 (00)	274.4 (03)	240.8 (03)	9.2 (04)	7.8 (04)	--	--	--	--	--
Megacity	None	Tianjin	Shanghai	Guangzhou	--	--	Bangkok	--	Dhaka	Karachi	--
Ground subsidence(m)	None	2.6 to 2.8	2.0 to 2.6	X	XX	--	0.2 to 1.6	--	0.6 to 1.9 mm/a		--
SLR (cm) in 2050	10 to 90 (2100)	70 to 90	50 to 70	40 to 60	--	--	--	--	--	20 to 50	--
Salt-water intrusion (km)	--	--	100	--	30 to 50	60 to 70	--	--	100	80	--
Natural hazards	--	FD	CS, SWI, FD	CS, FD, SWI	CS, FD, SWI	SWI	--	--	CS, FD, SWI	CS, SWI	--
Area inundated by SLR (103 km^2). Figure in brackets indicate amount SLR.	--	21.3 (0.3m)	54.5 (0.3m)	5.5 (0.3m)	5 (1m)	20 (1m)	--	--	--	--	--
Coastal protection	No	Protected	Protected	Protected		Protected		Protected	Protected	Partial	Partial protection

PD: Progradation of coast; CS: Tropical cyclone and storm surge; FD: Flooding; SLR: Sea-level rise; SWI: Salt water intrusion; DG: Delta growth in area; XX: Strong ground subsidence; X: Slight ground subsidence; --: No data available

(Milliman and Meade, 1983[14]; Penland and Kulp, 2005[15]) These megadeltas are vital to Asia because these are home to millions of people, especially the seven megacities that are located in these deltas (Nicholls, 1995[16]; Woodroffe et al., 2006[17]).

The scientific value of global deltas include:

1. Understanding of deltas individually and in comparison.
2. Use change in deltas across regions or the globe as a natural indicator of broad scale phenomena, such as climate change and variability, and human impact on watershed and delta hydrology.
3. Improve understanding of deltas as components of the white water to blue water system, so that system models can be developed for forward and reverse prediction.

ILLUSTRATIVE REGIONAL IMPACTS OF CLIMATE CHANGE ON DELTAS AND COASTS OF ASIA

- Coastal areas, especially heavily populated mega delta regions in South, East and South-East Asia, will be at greatest risk of increased flooding from the sea and, in some mega deltas, flooding from rivers.
- By 2050, more than one million people may be directly affected by sea-level rise in each of the Ganges-Brahmaputra-Meghna deltas in Bangladesh and the Mekong delta in Viet Nam.
- Endemic morbidity and mortality due to diarrhoeal disease primarily associated with floods and droughts are expected to rise in East, South and South-East Asia according to projected changes in the hydrological cycle.
- Climate change is projected to compound the pressures on natural resources and the environment associated with rapid urbanisation, industrialisation and economic development. Up to 50% of Asia's total biodiversity is at risk.
- 24% to 30% of coral reefs may be lost in the next 10 to 30 years.

In the mega deltas such as Kolkata, Dhaka and Shanghai that are undergoing rapid urbanization. Millions of people are badly affected in terms of destruction of lives, properties, crops, livelihood means and infrastructures, incurring huge economic losses. A recent study was undertaken on Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes of the world's large port cities to coastal flooding due to storm surge and damage due to high winds. This assessment investigates how climate change is likely to impact each port city's exposure to coastal flooding by the 2070s, alongside subsidence and population growth and urbanisation. The study provides a much more comprehensive analysis than earlier assessments, focusing on the 136 port cities around the world that have more than one million inhabitants in 2005. The analysis demonstrates that a large number of people are already exposed to coastal flooding in large port

11 Bindoff, N.L.; Willebrand, J.; Artale, V.; Cazenave, A.; Gregory, J.; Gulev, S.; Hanawa, K.; Le Quéré, C.; Levitus, S.; Nojiri, Y.; Shum, C.K.; Talley, L.D. & Unnikrishnan, A. (2007): Observations: oceanic climate change and sea level. In: Solomon, S.; Qin, D.; Manning, M.; Chen, Z.; Marquis, M.; Averyt, K.B.; Tignor, M. & Miller, H.L. (eds.): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 385-432.

12 Syvitski, J.P.M. (2008): Deltas at Risk. Sustainability Science (3): 23-32.

13 OECD (2009), Policy Guidance on Integrating climate change adaptation into development co-operation – ISBN-978-92-64-05476-9 © OECD 2009

14 Milliman, J.D. and R.H. Meade, 1983: World-wide delivery of river sediment to the oceans. J. Geol., 90, 1-21.

15 Penland, S. and M.A. Kulp, 2005: Deltas. Encyclopedia of Coastal Science, M.L. Schwartz, Ed., Springer, Dordrecht, 362-368.

16 Nicholls, R.J., 1995: Coastal mega-cities and climate change. GeoJournal, 37, 369-379.

17 Woodroffe, C.D., R.J. Nicholls, Y. Saito, Z. Chen and S.L. Goodbred, 2006: Landscape variability and the response of Asian megadeltas to environmental change. Global Change and Integrated Coastal Management: The Asia-Pacific Region, N. Harvey, Ed., Springer, 277-314.

18 Cruz, R.V., H. Harasawa, M. Lal, S. Wu, Y. Anokhin, B. Punsalmaa, Y. Honda, M. Jafari, C. Li and N. Huu Ninh, 2007: Asia. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 469-506.

19 OECD Environment Working Paper "Screening Study: Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes. Interim Analysis: Exposure Estimates", ENV/WKP(2007)1, OECD 2007. The full report can be accessed from: www.oecd.org/env/workingpapers.

cities. Across all cities, about 40 million people (0.6% of the global population or roughly 1 in 10 of the total port city population in the cities considered here) are exposed to a 1 in 100 year coastal flood event. For present-day conditions (2005), the top ten cities in terms of exposed population are estimated to be Mumbai, Guangzhou, Shanghai, Ho Chi Minh City, Kolkata etc[19].

In a sample of 40 deltas distributed worldwide, Ericson et al. (2005) reported that approximately 20% are experiencing accelerated land surface subsidence and 70% show decreased accretion rates due to a decline in fluvial sediment supply. An analysis of satellite images of fourteen megadeltas (Danube, Ganges-Brahmaputra, Indus, Mahanadi, Mangoky, McKenzie, Mississippi, Niger, Nile, Shatt el Arab, Volga, Huanghe, Yukon, and Zambezi) indicated that a total of 15,845 km^2 of wetlands have been irreversibly converted to open water since 1990 and that most of the wetland losses were attributed to human activity (Coleman et al., 2005) . According to this analysis, if a similar trend is present in forty other world deltas, a total wetland loss would be on the order of 364,000 km^2 over the past 15 to 20 years .

Various issues and concerns in the Asian megadeltas were addressed as one of the major themes (IV) in this workshop and is detailed in Chapter 6 of this report.

2.4 MANAGEMENT OF DELTAS

Sustainable development has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987 . But in practice, what does this mean for a delta system? Day et al. (1997) define sustainability for deltas from three different points of view, geomorphic, ecological, and economic.

Besides natural science issues, the other key concern is governance, which can be construed as resting on the three pillars of:

1. market instruments
2. governmental decisions and
3. civil society

This is important being the frame in which management occurs and indicates the scale at which action has to be taken. In the Black Sea region, for example, despite the steep reduction in nutrients in the water, eutrophication episodes were still there because the sediments have a 'memory' of nutrients. Phosphorus gets released from sediment and cyanobacteria with their ability to fix atmospheric nitrogen bring in new nitrogen into the system. These keep the system going resulting in algal blooms and eutrophication which have nothing to do with direct coastal pollution. The reasoning behind such events is difficult to explain to politicians and general society because the impacts of actions such as bans on certain activities are not immediately visible .

It is therefore increasingly important to think in terms of socio-ecological systems, which can be described simply as people interacting with their environment. Science can provide useful information in management of various issues. Examining what has been happening over a period of time indicates a paradigm shift in the thinking of the science itself. A number of small efforts are going on to translate science from the global community for use by the local community. Ways to translate global models into regional information and then use it at the local level are required but the links are missing in many places. There is also a change in the user community which is looking at the issues in a different manner and hence asking different questions that are looking to answer adaptation requirements. In order to understand the changes occurring in the deltas, it is essential to develop a basic understanding of the various types, formation and characteristics of deltas and is described in the following section.

[20] Ericson, J. P., C. J. Vorosmarty, S. L. Dingman, L. G. Ward and M. Meybeck, 2005. Effective sea-level rise and deltas: causes of change and human dimension implications. Global and Planetary Change 50:63-82.

[21] Coleman, J. H., O. K. Huh, D. Braud, and H.H., Roberts, 2005. Major world delta variability and wetland loss. Gulf Coast Association of Geological Societies, 55:102-131.

[22] Burkett, V. 2008. Megadeltas and Climate Change. Basins and Coasts, 2/1, 16-19. http://www.imcafs.org/

[23] WCED (1987): Our common future. Oxford University Press, Oxford.

[24] Day, J.W.; Martin, J.F.; Cardoch, L. & Templet, P.H. (1997): System functioning as a basis for sustainable management of deltaic ecosystems. Coastal Management (25): 115-153.

[25] Special lecture by H.H. Kremer at the Deltas Workshop, Chennai December 2009

Reporting of Thematic Presentations

3. Theme I: Types, Formation and Characteristics of Deltas

3.1 FORMATION AND CLASSIFICATION OF DELTAS

A delta can be described as a complex coastal topographic feature formed by seaward shoreline migration . The really large rivers around the world are seen to be concentrated in the tropical regions bringing a lot of sediment down to the sea. The rivers interact in various ways with the coast.

Deltas can be classified as dominated by rivers (Mississippi), tides (Sunderban), or waves (Sao Francisco). This classification could be applied to Australia also. The Australian coast could be divided into four regions and the systems identified as wave dominated estuaries, tide dominated estuaries, wave dominated deltas and tide dominated deltas. Sediment coring and dating procedures indicate how the systems developed as wave dominated or tide dominated. Northern Australia has a monsoonal climate regime with clear wet and dry seasons and also has the third largest tidal range in the world. In this area, during the wet season, the river dominates and during the dry season, the tide dominates. Reconstruction using pollen records gives an idea about the development and spread of mangroves, extensive about 6000 years ago when the seas stabilized. Rhizophora forms were seen to decrease with the increase in other types and as sediment levels built up resulting in seasonal inundation, the mangroves were replaced by grasses and sedges with mangrove forms now confined to the margins.

[26] Saito, Y. (2001) Deltas in Southeast and East Asia: Their evolution and current problems. In Mimura, N. and Yokoki, H., eds., Global Change and Asia Pacific Coasts. Proceedings of APN/SURVAS/LOICZ Joint Conference on Coastal Impacts of Climate Change and Adaptation in the Asia-Pacific Region, APN, Kobe, Japan, November 14-16, 2000, p. 185-191.

[27] Woodroffe, C. "A geomorphological framework for the classification of deltas and estuaries", From the presentation made at the Deltas Workshop, Chennai December 2009

Fig 4: Formation of Deltas
Source: Woodroffe, 2009

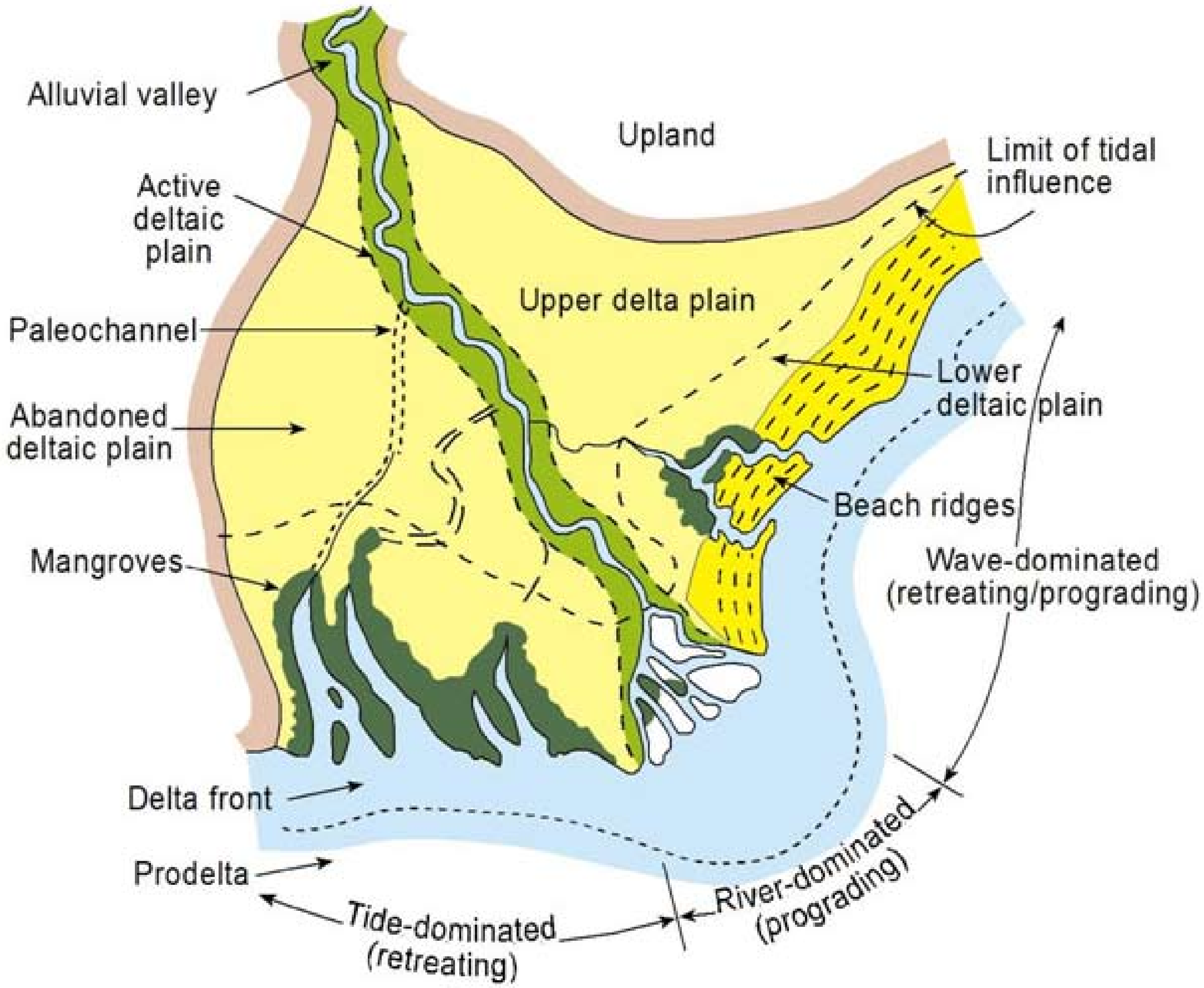


Figure 4 shows a large river coming down an active floodplain surrounded by floodplains that are not active any more or receiving sediment or runoff from the river during the wet season. The river itself might be prograding (e.g. Meghna, forming Chars) but much of the active delta is abandoned and currently dominated either by wave processes or tide processes. The wave dominated potion is characterized by sand ridges because the waves are collecting and redistributing the sand and closing river mouths. The tide dominated portion is characterized by mangroves.

There are a few differences between deltas in Asia and those in Australia, the most important being the lower sediment supply and the lower population density in Australia. On the other hand, the monsoonal northern region of Australia contains coastal plains like those of South Asia. Overall, it may be concluded that the morphology of a river mouth reflects the relative balance of river, wave and tide and wave, tide and river influence can vary within a delta, spatially and temporally which results in various formations along the coast.

3.2 THE DELTAS OF SOUTH EAST ASIA

Deltas face dual pressures due to global warming and human interference. There has been considerable reduction in the amount of sediment reaching the coast. At this time, it is useful to examine how the estuarine regions would change in the near future. An "Ecohealth" model has been proposed to examine the changes resulting in the increased acidification of estuaries by comparing the Yangtze and the Nile. The Yangtze and the Nile both have reduced sediment loads reaching the estuary but while the waters of former still remain turbid, the waters of the Nile are clear with little suspended sediment. The model looks at the acidification of oceans and estuaries and believes it is driven by temperature changes and various human activities. The model includes both a water phase and sediment phase and looks at the various processes that are affected by acidification.

Key issues as stated in ECSS special issue - EMECS8 Harmonizing catchment and estuary.
Chen, Z., Yanagi, T. and Wolanski, E. (eds), 2009

- …Can these modified estuaries continue to absorb the loads of nutrients and heavy metals that are ever increasing as a result of human influences? ……
- …How will global warming, and/or sea level rise, and/or ocean acidification, and/or introduced species change the ecology of these estuaries and the coastal waters? …….
- …Will these estuaries and coastal waters keep providing vital ecosystem services including food to an ever increasing human population?.........'

Signals from the Yangtze indicate increasing acidification. Measurements of seawater parameters indicate that with rise in temperature, the salinity and nutrients were increasing but the dissolved oxygen levels were decreasing. The river was becoming hypoxic at the mouth indicating overloading of nutrients from the catchment and consequent eutrophication. The diatom diversity and population was steadily getting reduced but there was an increasing trend in the number of phytoplankton and zooplankton species and the increased presence of tolerant species in the estuary. With the water storage capacity of the upper Yangtze basin steadily increasing in the last fifty years, a reduction in the sediment load is seen. Values of silicate were steadily going down and this could be correlated with the reduction in diatoms as diatoms use silicate in their cell walls. The overall conclusion is the change in the C-N-P ratios that promotes the growth of toxic algae and red tides in the East China Sea. The water continues to be turbid because of the re-suspension.

In the case of the Nile delta, studies were carried out before and after the construction of the Aswan dam. Similar conclusions were drawn with regard to the drop in the diatom population and the increase in toxic phytoplankton that do not require silica for growth. Changing agricultural practices have resulted in higher amounts of Nitrogen and Phosphorus reaching the lagoons. Industrialization and domestic sources have contributed to increased load of heavy metals in the surface sediments of the lagoon. Concern is over the increased rainfall due to global warming that could result in the displacement of the heavy metals towards the coastal areas where they could do more harm. The ecopulse model had many components that need to be elaborated especially at the regional scale.

The western Pacific area is a busy system for fluvial sediments. The Mekong originates from the Tibetan Plateau, runs through China, Myanmar, Laos, Thailand, Cambodia, and finally enters the South China Sea in Vietnam. It is the third longest river in Asia with the third largest delta plain in the world (after Amazon and Ganges-Brahmaputra) and each year, it delivers 160 million tonnes of sediments into the ocean. The Mekong river mouth faces a very flat shelf. Earlier studies have indicated that the Mekong River Delta prograded 250 km towards the South China Sea in the last 5500 years. The deltaic architecture is well defined by shelf/pro-delta facies, delta front facies, and the sub to intertidal flat facies. This has not been a continuous feature and there has been a change from tide dominated to wave and tide dominated system about 3000 years ago. For investigating the subaqueous part of the Mekong River Delta, in 2006 and 2007, two geophysical cruises in the nearshore area were conducted with the collection of collected more than one thousand km of seismic tracklines and dozens of gravity cores. The water is seen to be very turbid even during winter. Based on the area and thickness of the subaqueous delta front, it is calculated that about 80 percent of Mekong sediments have been trapped within the delta plain in the last 3000 years. While generally the sediments are made up of silt, the grain size gradually decreases from a sandy-silt clay mix to clayey silt from the east coast to the west coast. The monsoon plays an important role in water/ sediment discharge, mixing in the estuary, and sediment transport in the coastal area. Preliminary conclusions from the study indicate that up to 20m thick subaqueous delta is found outside the Mekong River with a morphological asymmetry. Mineralogical data indicate that this subaqueous delta is mainly made up of Mekong sediments while ^{210}Pb, 14C, and 13C data show a non-steady accumulation process of 'old' sediments with a mixed marine/terrestrial source.

In the case of the Yellow River as in the Mekong, re-suspension seems to be controlled mainly by the monsoon with more re-suspension when the northerly wind prevails. Wave action is one of the most significant causes of coastal and near-shore erosion. The Yellow River Delta has mid-latitude climate with the East Asian monsoon while the Mekong experiences tropical climate and the South East Asian monsoon regime. The East Asian region experiences four seasons where there are strong northerly winds in the winter and southerly winds with occasional typhoon attack in summer. The method used to study occurrence of sediment re-suspension was by running a numerical wave model for the Bohai Sea (Yellow River delta) and the South China Sea (Mekong delta). Seasonal variation in the re-suspension was seen occurring more frequently during November (winter monsoon) in the Yellow River and least during July (summer monsoon). Spatial variability was also seen with strong bottom stress occurring more at Bohai Bay (north) than at Laizhou Bay (south) in summer. In the case of the Mekong, re-suspension was likely to occur along the eastern side of the Gulf of Thailand during the south west monsoon while it is likely to occur off the Mekong delta during the north east monsoon.

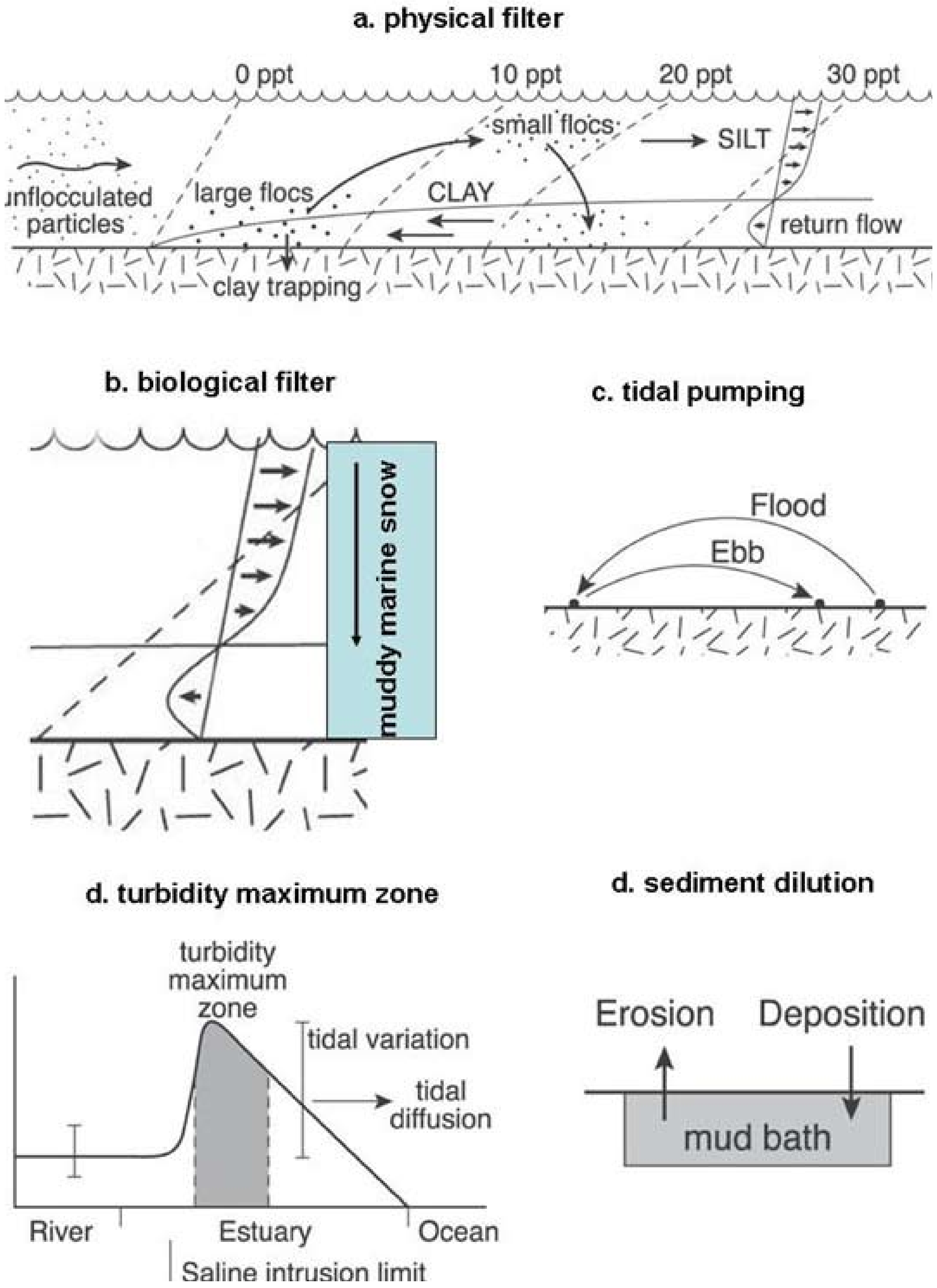
4. Theme 2 Biogeochemistry and Nutrient Budgeting of Deltas

4.1. THE BIOLOGY OF MUD

The dynamics of fine sediments depends not only on the physical characteristics such as waves and tides but also on the biology. Mud is of interest to engineers because of its importance in navigation, it hides objects (e.g. mines), it can be a pollutant by itself degrading the environment, and PCBs, heavy metals and nutrients adhere to it. When the density of mud is of the order of 1.3tonnesm^{-3}, dredging is avoided as this results in the formation of a plume that is visible for quite a distance. When dredged spoil is dumped at sea, it is a dense fluid, unconsolidated, settling at 1m/s, hitting the bottom, and spreading laterally with an internal bore at the leading edge. Mud decreases the amount of light entering the water and hence causes reduction in primary productivity which results in the control of life in the water column. It results in the smothering of benthos, drowns zooplankton and prevents mussel spawn from settling. Deforestation of coastal areas has resulted in sandy beaches becoming muddy as in the case of Cairns in Australia which used to be sandy and has now become muddy because of siltation.

A number of models have been proposed for mud dynamics but they do not work well in the field because they do not consider biological aspects. There are different processes in the biology of mud. Figure 5 shows the mud dynamics in estuaries. Settling velocity, for example, can differ by a factor of ten between laboratory and field. Forces such as bioturbation and pelletization on muddy marine snow decrease settling velocity while biofilms from microphytobenthos and macroalgae increase the settling velocity. Grazing on biofilms also plays a role in this. The rate of mud resuspension by tides and waves has been modeled as a function mainly of the water velocity in engineering models because the information generated is based on experiments with mud in the lab which does not behave the same way in the field. Dewatering or consolidation of mud is controlled by the formation of tiny flocs and microchannels which push the water out. Turbulence and organic matter have been shown to slow down dewatering. Higher density of plankton has been found to result in faster consolidation of mud. Patchiness at the surface is controlled by what is happening at the bottom. The flux of nutrients between the sediment and water column has been found to be controlled by bacteria which determine the direction of net flux. The importance of mud in the nutrient balance was studied in Subic Bay in the Philippines when it was clearly shown that the partition coefficient controlling the partitioning between particulate and dissolved forms of phosphorus was controlled by mud in suspension. A new LOICZ budget has been formulated for estuaries with muddy waters.

Fig 5: Mud Dynamics in Estuaries [28]



[28] Wolanski, E. "The importance of the biology in estuarine fine sediment dynamics". From the presentation made at the Deltas Workshop, Chennai, December 2009.

Thus, mud has to be viewed not a messy fluid, but as a living body as it plays a major role in controlling the settling of mud flocs and the resuspension of settled mud, the consolidation (dewatering) of mud, patchiness and nutrient dynamics. These are areas that need future investigation.

4.1.2 CARBON BUDGET FOR INDIAN MANGROVES

Mangroves, salt marsh and seagrass are important coastal vegetation and contribute to the organic carbon burial in the global coast. Considering the extensive losses in coastal vegetation worldwide, it would mean a reduction in carbon burial if these systems work well. Exchange of carbon between coastal vegetation and ocean is increasingly recognized as potential component in the ocean carbon budget. Bouillon et al. (2008) made a reassessment of global mangrove primary production from literature and estimated it at ~218 ± 72 Tg C a^{-1}. According to them, despite using the best available estimates of various carbon sinks (organic carbon export, sediment burial, and mineralization), it appears that >50% of the carbon fixed by mangrove vegetation is unaccounted for. They estimated this unaccounted carbon sink at ~112 ± 85 Tg C a^{-1}, equivalent in magnitude to ~30–40% of the global riverine organic carbon input to the coastal zone.

India has 3% of the global mangroves and 5% of Asian mangroves but the role of mangroves in carbon budget is not understood due to dearth of data. India has 4445km^2 of mangroves and the annual organic carbon burial is estimated at = 0.617855 Tg C. 1698 km^2 of salt marsh vegetation exist along the Indian coast and their annual carbon burial rate is estimated at 0.256398 Tg C. Seagrasses cover 1391 km^2 and contribute to the burial of 0.115453 Tg C annually. Examination of soil carbon in relation to depth in Vellar estuary (Cauvery delta, Tamil Nadu, India) indicated that burial rates were much higher in the case of luxuriant mangroves. The carbon stock in the sediment was found to increase with age as shown in field studies in artificially developed mangrove ecosystems. As the total carbon in the soil increases, the number and biodiversity of cyanobacterial species also increases. There is need to know about the role of insects which feed extensively on mangrove leaves, the role of natural and anthropogenic stress factors as well as the role of climate change on carbon burial. A clear difference in the particulate organic carbon in the water regime may be seen in Rhizophora lined creek, Avicennia lined creek and open waters. Avicennia lined areas had higher organic C content compared with Rhizophora lined waters, which in turn had some twenty times as much organic C compared with open water areas. Diel and seasonal variations can also be observed.

It must be pointed out that more data based on large numbers of samples throughout coastal India are warranted. These include data on tidal export of DIC and CO_2 efflux from sediment and waters.

An estimate of the Carbon budget in mangrove forest ecosystems of India is given in Table 2 below:
TABLE 2: CARBON BUDGET FOR MANGROVES IN INDIA

Component	Net Primary Production (%)	Component	Fate of mangrove production %
Litter fall	31.2	Burial in sediment	8.7
Wood	31.2	CO2 efflux	19.3
Root	37.6	POC export	9.7
		DOC export	11.0
		Mineralization of carbon (DIC)	51.3
Total	**100**	**Total**	**100**
Annual net primary production of mangroves in India is 6.05604 trillion grams carbon. Indian mangroves contribute to 2.8% of global mangrove primary production of 218 trillion grams of carbon			

[29] Bouillon, S., et al. (2008), Mangrove production and carbon sinks: A revision of global budget estimates, Global Biogeochem. Cycles, 22, GB2013, doi:10.1029/2007GB003052.

[30] Kathiresan, K, Carbon Cycling in Mangrove Ecosystems. From the presentation made at the Deltas Workshop, Chennai, December 2009.

4.1.3 CARBON SEQUESTRATION BY WEATHERING PROCESSES

There are processes in rivers that are important to climate change. Rivers have two major components: chemical and physical. Both are due to the weathering processes but are affected by many changes over time. The chemical balance of a river system can be viewed as the balance between input and output. Because of the number of dams on each river system, it is already disturbed and contaminated by the time it reaches the delta. Any impact on sediment has its effect on the productivity and the many chemical and biological processes in the delta area.

Water gets its chemical properties by the primary weathering process and CO_2 is essential whether the mineral is silicate or non-silicate. Weathering can be considered to be a process of scavenging atmospheric CO_2. Using this concept, the amount of CO_2 required for the weathering of a silicate and a non silicate mineral can be estimated. The Chemical Index of Alteration (CIA) appears to be an important factor but the order of relative importance is not known because the runoff from the rivers is scattered over a wide scale of magnitude. Bicarbonate is an index of alkalinity and calcium-magnesium is supposed to be the main contributor of alkalinity. The tendency is to look at calcium and magnesium as coming from a bicarbonate weathering but this is not always true. Sampling by students over the last thirty years in the Godavari along with published data shows extensive temporal and seasonal variability in chemical weathering, carbonate weathering as well as variation from the catchment to the delta region. Similar exercises were carried out in the Narmada and Tapti which showed a progressive consumption in pCO_2 from the catchment to the delta for carbonate weathering and silicate weathering. Plotting the pCO_2 against run-off also shows reasonable correlation just as the basin area with respect to pCO_2 consumption. The bicarbonate alkalinity observed in most river systems is in the range of 150-200ppm. The pCO_2 should have been at least two orders of magnitude higher. It is also evident from data that the pCO_2 cannot be accounted for by looking at total alkalinity only based on carbon dioxide – bicarbonate system of calcium and magnesium. Given the range of climatological and ecological variations in the Indian subcontinent, it appears that bicarbonate release due to silicate weathering is important in the CO_2 consumption pattern. Comparing river systems of the world, it was found that Narmada had a very high consumption of CO_2 in silicate weathering. This is because Narmada is located in the basaltic area which is highly weatherable. Hence Narmada consumes a lot of CO_2. The role of weathering and the consumption of CO_2 is a concept of importance in calculating future climate scenario conditions.

4.1.4 SEDIMENT FLUX TO THE COAST

The Ganges-Brahmaputra-Meghna system is a complex combined system in the north eastern part of the Indian subcontinent. The flow in the Ganges ranges from 1000 to 80,000 cumecs; in the Brahmaptura, the flow ranges from 2400 to 102,000 cumecs while the Meghna makes a relatively small contribution of 500 to 30,000 cumecs. The sediment transport varies from 286 million tonnes in the Ganges to 600 million tonnes in the Brahmaputra to 1 million tonnes in the case of the Meghna; roughly about 1 billion tonnes altogether. These are the systems that are building the Bengal fan. The coastal dynamics is highly dependent on this sediment flux. Currently, the GBM system is calculated to be carrying a load of 6.24 x 106 tonnes C/year, 8.5x105 tonnes N/year and 8.4x104 tonnes/year.

Sedimentation in the reservoirs of dams shortens the useful life of the dams. The larger sediments get deposited in the upper reaches. A number of dams and reservoirs are being planned and constructed in the riparian countries of India, China and Bhutan. These dams and reservoirs are important repositories of large amount of sediments which otherwise would have been carried with the flowing waters and thus the construction of these dams and reservoirs has, to a large extent, altered the amount of sediment load reaching the delta. This extensively influences sediment supplies and transport. The sediment profile has been morphologically, chemically and mineralogically changing over time. This region is also seismologically active witnessing frequent landslides and floods as well. The region is also expected to see an increase in the per day rainfall according to the IPCC reports.
It is necessary to look at the six major rivers rising in the Himalayas – the Indus, Ganges, Brahmaputra, Mekong, Yangtze and Yellow River – to examine their flow data and discharge into the sea. Each year the rivers flood leaves behind fresh layers of sediments and qualitative assessments suggest changing trends of sediment deposition. Shifting of the eroding bank has also been observed. The concern is because of the cascading effect of the multiple interventions on the sediment flux at the coast.

4.1.5 NUTRIENT TRANSPORT AND BUDGETS

Chilika lake in Orissa, India, is a shallow and large partially enclosed bar built lake ecosystem in the state of Orissa, India. The system is a unique assemblage of marine, brackish and fresh water ecosystem with predominantly estuarine characteristics. It is connected to Bay of Bengal via a mouth at the northeastern end and also at the southern end through a canal from Rambha Bay to the mouth of Rushikulya estuary. Biogeochemical processes and budgets of carbon, nitrogen and phosphorus were constructed through seasonal observations and modeling through the use of LOICZ biogeochemical budget model which is a steady state box model. During monsoon, the fresh water discharge from the northeastern rivers (tributaries of the Mahanadi) were strongest and contributed nearly 68% (74.7 x 106 m^3 d^{-1}) of flow into the lake, whereas, the rest nearly 32% (32.8 x 106 m^3 d^{-1}) came from the rivers of western catchments. During monsoon the residual flux (i.e. total fresh water input) was calculated to be 62% of the mixing flux indicating its dominance in the lake. The residence time of water in the lake was 1 week during monsoon and 3 months during premonsoon.

During premonsoon the measured N_2O flux implied that under high residence time of lake water, nitrification would be favoured in the system resulting in efflux to the atmosphere before its runoff to the coastal ocean. As in the case of DIN, the residence time of DIP in the lake is found to be longer than the residence time of water. This probably allows effective biological utilization of DIP for primary productivity in the lake making the system autotrophic during premonsoon. During monsoon, the presence of high level of SPM affects the primary production and shifts the system more towards heterotrophic under influence of riverine organic matter.

During premonsoon under poor riverine discharge conditions, mineralization slows down resulting in low non-conservative sources to the coastal ocean. The net ecosystem metabolism (NEM) during monsoon was about -3.15 mmol m^{-2} d^{-1}, which was significant to the non-conservative behaviour of nutrients (DIN and DIP). In contrast, during premonsoon the NEM was positive at 0.12 mmol m^{-2} d^{-1}. This implies that the system is autotrophic, though it is significantly lower unlike monsoonal heterotrophy.

Overall, the system is seen to be highly heterotrophic during monsoon, influenced by riverine organic carbon in the lake mineralization process. Although high residence time of water and nutrients favors primary production, the influence of riverine organic carbon possibly shifts the system from net autotrophy to heterotrophy. It appears that Chilika lake is an ecosystem where heterotrophic activity of the system is highly dominant process contributed to emission of CO_2 fluxes rather than physical ventilation of riverine CO_2 in the system.

The river Cauvery forms a large delta in Tamil Nadu, India. Changing land use patterns, discharges from agricultural operations as well as from human settlements are known to influence dissolved nutrient concentrations in riverine systems. Surface and subsurface sediments and water samples were studied downstream of the Cauvery River (Tamil Nadu, India) for nutrients, stable isotopes, RREs and metals signatures. Studies in Pichavaram mangroves indicated that sediments from vegetative regions contained higher concentrations of organic carbon than estuarine regions reflecting high rates of organic carbon retention. Among the rare earth elements (RRE), the Light RRE (LREEs) were more enriched than the Heavy rare earth elements (HREEs) and the Eu anomaly was relatively weak. The variation in the enrichment of HREEs was controlled by the salinity gradient and inputs from estuarine zones. The variation in the enrichment of HREEs was controlled by the salinity gradient and inputs from estuarine zones. The enrichment factor substantiates that most of the REEs have weathering sources and are altered in the complex biogeochemical processes operating here. In general, the interior channels and high-salinity zones were more enriched with HREEs than LREEs and it may be concluded that the mangroves contribute around 70%–80% of the LREEs) and 20%–30% of HREEs to the adjacent sea.

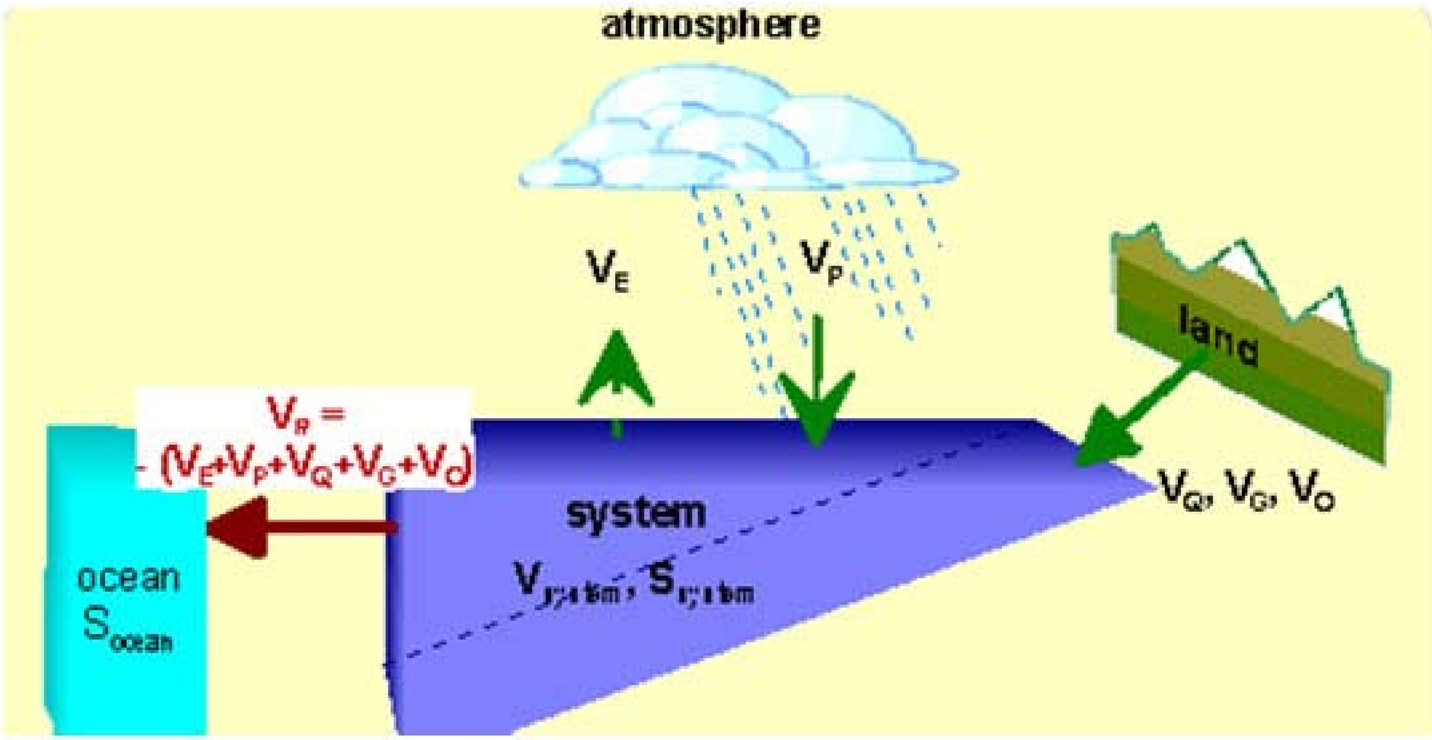
Carbon burial in sediments is also influenced by land use patterns. Organic carbon, total nitrogen and unsupported 210Pb activity in core sediments were measured to quantify the burial or organic carbon and the relative importance of allochthonous and autochthonous contributions during the past hundred years in the Pichavaram mangroves also in the Cauvery delta. This area receives copious inflow of freshwater during the Northeast monsoon (October-January) through the Coleroon and Uppanar rivers. They also bring in eroded soils and organic matter from land derived sources to the mangrove region. Studies showed that OC burial rate average 1.83 mol C m^{-2} yr^{-1} with the highest rate in the Rhizophora zone and lowest in the Avicennia zone. This burial rate is consequent to a highly seasonal supply of riverine sediment deposition, high productivity and organic matter from land derived sources.

With high levels of direct sewage discharges as well as agricultural and industrial effluents, it is not surprising to see the high bacterial pollution especially in the sediments underlying the water along the coast. Seasonal samples from fifteen sites along the Tamil Nadu coast were subjected to bacteriological analysis (Total Viable Count, Total Coliform count, Total Streptococci count, Total vibrios count and five different types of pathogenic bacteria counts). The values in both sediments were observed to be highest during monsoon, lesser during summer and lowest during postmonsoon.

5. Theme 3
Nutrient Budgeting for Muddy Coastal Waters

The LOICZ biogeochemical model is a useful tool to understand where the nutrients go when reaching an estuary, are they flushed to sea or are they causing eutrophication of the estuary or coastal waters. The model, summarized in Figure 6, is simple to use, yet realistic.

Figure 6. The LOICZ biochemical model tracks water and nutrients as they travel through the estuary



It can answer questions important to management, such as

- what is the residence time of water in the estuary and thus how sensitive is the estuary to human effects?
- how much of the nutrients are filtered in the estuary in its present state, and what is the health of the estuary?
- what is the effect on the estuary of withdrawing water for irrigation or changing the hydrology of the river by constructing dams?
- what is the effect of increasing (or reducing) nutrient discharge (i.e. from sewage, aquaculture, fertilizers from agriculture, or sewage treatment plants) on the health of the estuary?

To use the model, some field data are needed on the inflows and outflows of water and nutrients from the estuary. Such data are relatively easy and inexpensive to obtain.

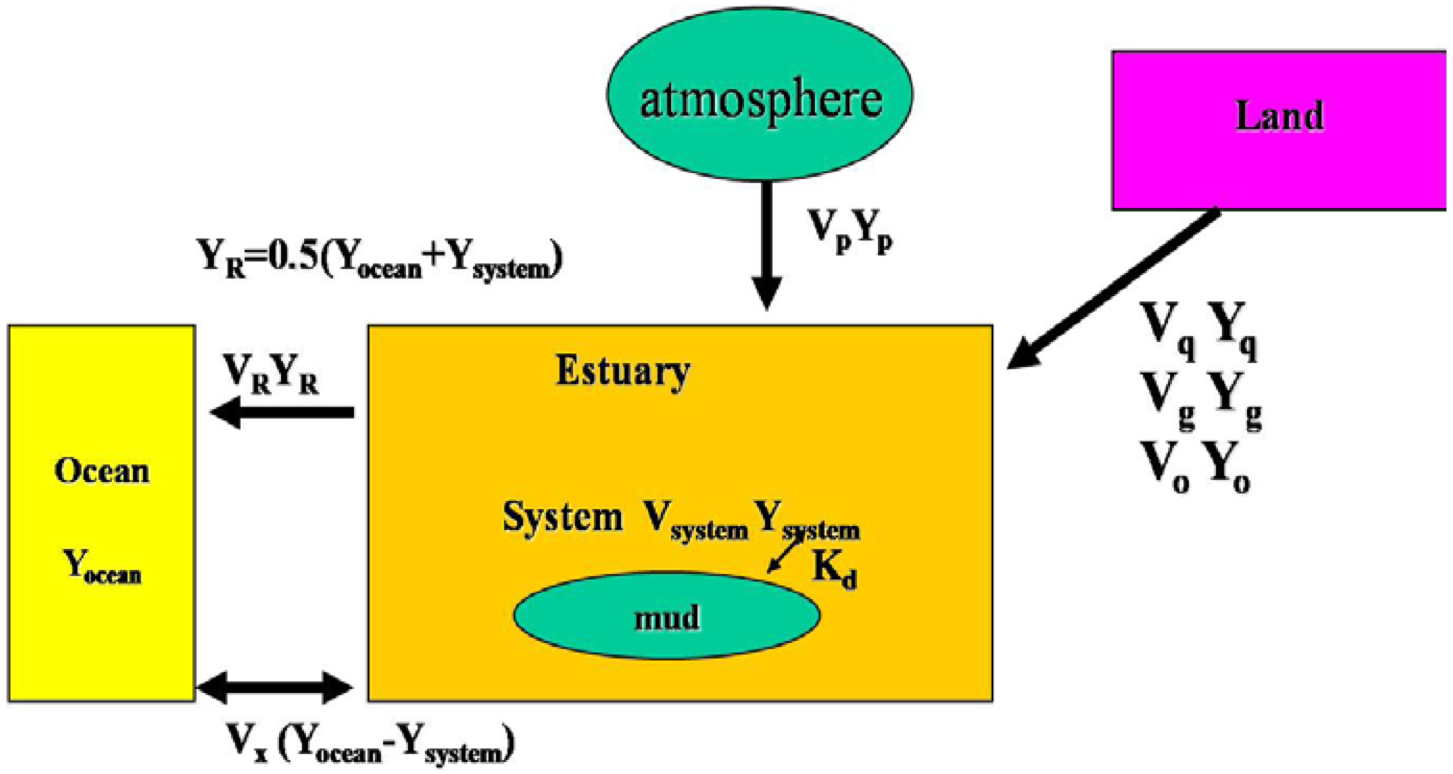
The model has problems however in turbid estuaries, i.e. where the suspended fine sediment (mud) concentration (SSC) is high. The problem is not with the reduction of light available for photosynthesis, since this is already incorporated in the model by assimilating field data on the status of nutrients and chlorophyll-a, instead the problem is due to the fine sediment absorbing dissolved nutrients in particulate forms in the turbidity maximum zone of tidal estuaries (thus behaving like a sponge inhibiting eutrophication) or desorbing nutrients in quasi tideless coastal lagoons (thus facilitating eutrophication).

Figure 7. The new LOICZ biochemical model for turbid estuaries considers not only inflows and outflows in the estuary, it also incorporates the partitioning of nutrients between dissolved and particulate phases in the estuary.

During this thematic session, Prof. Wolanski coordinated the group work on the revised LOICZ model for water and nutrient budgeting, incorporating "mud" for the following coastal ecosystems of India:

1. Hooghly Estuary (Ganges Delta)
2. Bhitarkanika (Mangroves in the Mahanadi Delta)
3. Chilika Lake (Lagoon in the Mahanadi Delta)
4. Pichavaram (Mangroves in the Cauvery Delta)
5. Vembanad Lake (Backwaters of Kerala)

The new LOICZ model for turbid estuaries, produced by Eric Wolanski and Dennis Swaney, incorporates this process through a partitioning coefficient Kd, which can also be readily calculated from a few additional field data.



6. Theme 4 Global Climate Hazards and Vulnerability

6.1 VULNERABILITIES OF MEGADELTAS IN SOUTHEAST ASIA

Megadeltas of Asia were featured for the first time in the 2007 IPCC report. The Asia-Pacific region is known for its large deltas such as the Ganga-Brahmaputra-Meghna, Chao Praya, Indus, Ayerwady, Mekong and Yangtze among others. They are characterized by high population density especially in the coastal zone with a number of megacities located on the coast. Asia's rivers carry some 30% of the water discharge and 70% of the sediments. Most of the oil deposits in South East Asia are from deltaic sediments. The presence of large deltas in Asia can be attributed to three important factors: large rivers with sources in the Himalaya and the Tibetan plateau bringing down large quantities of sediment, high precipitation due to monsoonal climate and stable or slightly falling sea levels. The island of Borneo is of special importance as the amount of sediment transported by the rivers here is much higher than the combined discharge of some large rivers than the combined discharge of some large rivers .

Deltas throughout the world are at risk due to three main reasons: sinking, shrinking and ecosystem collapse. Focusing on coastal erosion, the controlling factors for shoreline change are sediment supply and sea level rise. Wave conditions and construction also play a role. Sediment supply to the river mouth may result in deposition at the mouth or may be away from the mouth. If the shoreline is to be stable, the sediment supply and removal must be in equilibrium. In the case of rising sea levels, more sediment is needed to fill the accommodation space in the shoreline. Thus sediment supply and sea level rise are important factors in shoreline migration. The six large rivers in Asia have tremendously reduced sediment discharges now, down from 2200 million tonnes per year to 500 million tonnes, attributed to human activities such as dam construction, irrigation and sand mining in the basins.

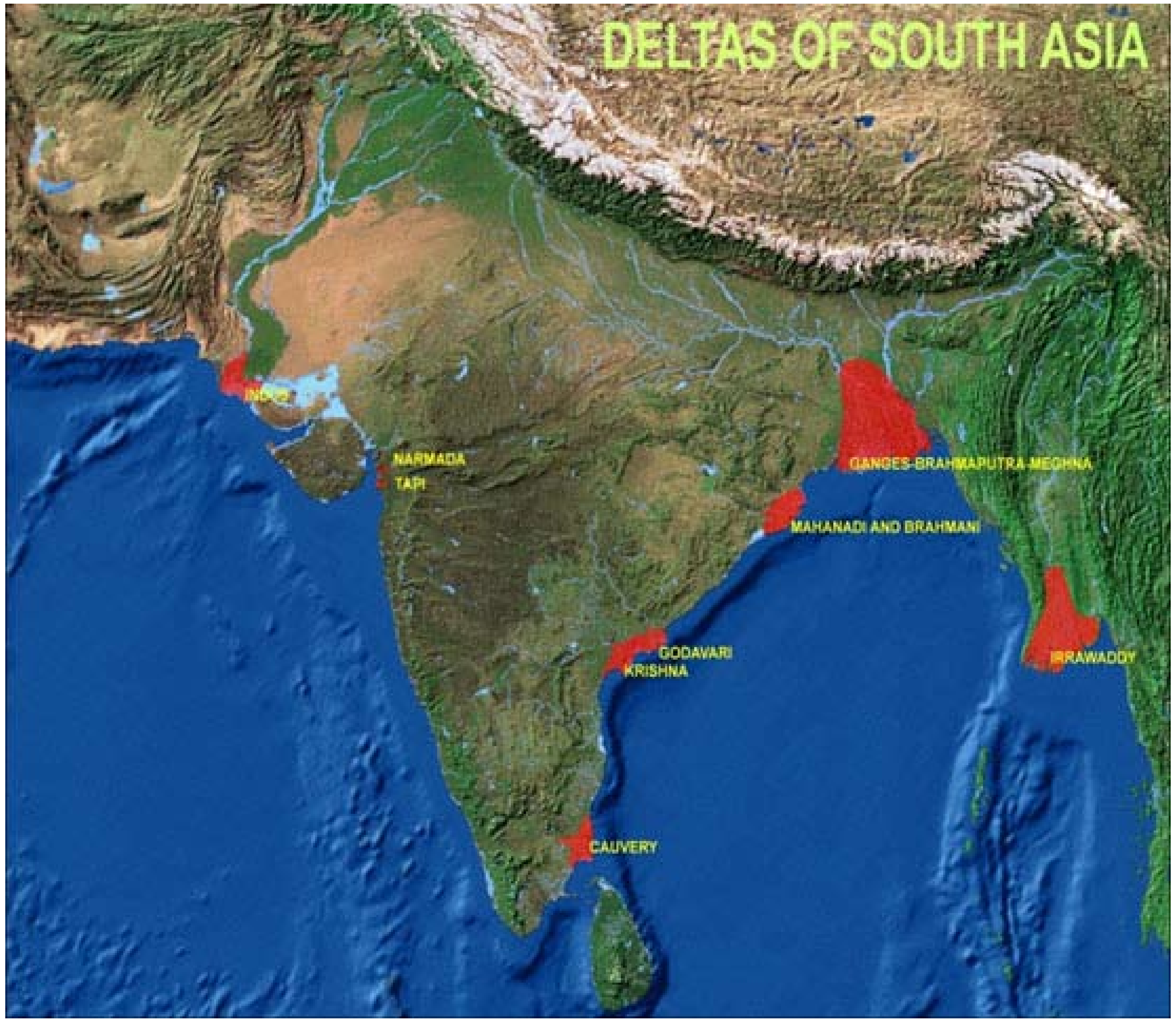
In the case of the Yellow River, the sediment was mostly from the Loess platform which was once covered by forest. After the area was deforested, soil erosion resulted in large amounts of sediment in the river. This resulted in the progradation of the delta. The discharge, however,

Milliman, John D. , Katherine L. Farnsworth and Christina S. Albertin, "Flux and fate of fluvial sediments leaving large islands in the East Indies", Journal of Sea Research, Volume 41, Issues 1-2, March 1999, Pages 97-107. doi:10.1016/S1385-1101(98)00040-9 has declined considerably because of construction of a large number of dams. Currently only about 150 million tonnes per year, a tenth of the earlier discharge, reaches the shore. The shoreline is prograding in some sections, especially in the south. In the north, sediment loss has resulted not only in erosion of the shoreline but also of the near shore areas. There is a change in the shoreline morphology from convex to concave. The amount of sediment that is discharged today is not sufficient to maintain the shoreline.

The Pearl River delta in China is also at high risk. In addition to dam construction, sand mining in the river is of concern. The amount of sand removed is much higher than the amount brought in by the river. Hence not enough sediment reaches the coast. There has been an increase in the salinity in the river.

In the case of the Chao Praya, there are a number of aquaculture farms in the mangrove areas which have now become limited in distribution. In addition to these are the salt factories, prawn and fish farms. While over some 6000 years, the shoreline is believed to have prograded about 100 km, it is retreating rapidly in the last fifty years. The major reason is believed to be land subsidence due to groundwater pumping in the coastal and river-mouth areas of the Chao Phraya amounting to 20 to 30 cm between 1978 and 1987. This means that relative sea level rose at a rate of 2 to 3 m/100 y, which is higher than the predicted rate of sea-level rise in the 21st century from global warming. While in the city area, groundwater extraction is prohibited, it is still done in the countryside.

A recent visit to areas in Bangkok, Thailand, indicated that the colour of the mangroves has changed from



green to brown. The reasons could be an increase in salinity, increase in sea level (because they cannot survive below MSL) resulting in the move from upper part of the intertidal zone to the middle part. In some areas of Bangkok, only electric poles are seen as indications of once occupied areas. The overall impact of sea level rise is extensive inundation and submergence, increase of wave power, decrease of sediment discharge from rivers and increase of sediment supply from coastal cliffs. Various methods of coastal protection are being tried. Being a muddy coast, groins and breakwaters are of no use and hence soft engineering solutions and others such as mangrove plantations are being attempted.

6.2 MEGADELTAS OF SOUTH ASIA

Mega deltas in South Asia include the Ganges-Brahmaputra, Indus and Ayeyarwady. There are also many deltas in the Indian sub-continent, especially along the east coast of India. They are influenced by the monsoon, and carry high sediment loads with a strongly seasonal discharge. They have large coastal tide ranges and the sediments are dominated by silt-sand. The major problems facing the deltas in this region are relative sea level rise (due to delta subsidence), decrease of sediment supply (due to dams and sand mining), ecosystem degradation and habitat loss (deforestation of mangroves and coastal forests, reclamation of wetlands (e.g. aquaculture, settlements) and shoreline change (erosion/accretion due to construction of groins/ ports/ harbours and wave conditions such as storm surges). The Ganges-Brahmaputra-Meghna is well known for the largest stand of halophytic mangroves. The delta is well-known for major river and rain floods which can submerge large parts (>60%) of the delta during the wet season and the deadly storm surges produced by the landfall of cyclones in the Bay of Bengal. The high population density of the Low Elevation Coastal Zone makes a large part of the delta vulnerable to sea level rise and its consequences. In the case of the Godavari River, there is clear evidence that dams across the river and its tributaries have reduced the flow of sediment to the coast. Sediment supply decreases have resulted in sustained shoreline erosion / continued subsidence. In addition, cyclonic storm surges result in episodic erosion along the coast. In the case of the Indus in Pakistan, dams and barrages on the river have reduced the freshwater and sediment flow and this has resulted in increased saltwater intrusion into the delta, loss of estuarine flora and fauna and reduction in the area covered by mangroves. The overall delta area has also shrunk.

The density of population in the different Asian deltas ranges from a high 1220 km^{-2} in the Ganges delta to 849 km-2 in the Godavari delta to about 102 km^{-2} in the Indus delta. While the projected growth rate is about 28% in the Ganges delta, it is expected to be 46% in the Indus delta. Overall, destruction of wetland habitats has diminished water quality, decreased biological production, and reduced biodiversity. It is also important to note that changes in the management regimes can also affect the status of the delta. For example, the declaration of an area as a biosphere reserve (e.g. Sunderban) makes it likely to be better managed and protected.

To summarize, in the case of Asian deltas, it seems likely that there will be a move from river dominated to wave dominated regimes characterized by extensive beach, beach ridges, and dune formation as seen in Godavari and Indus, mainly due to shortage of sediment reaching the coast. Extension of salt wedge inland may increase – this is already reported in the Ganges delta. Increased coastal flooding from storm surges as well as flooding due to intense rainfall in delta and flooding due to rivers breaking out from embankments may be expected in the future. It is clear that what is required urgently is risk and vulnerability mapping (floods, subsidence risk, erosion, loss of ecologically sensitive ecosystems), adoption of hazard zone approach in coastal management, research into delta health and the interaction between the health of deltas and well being of humans and the social versus physical stresses on deltas.

6.3 SHORELINE CHANGES

Shoreline variations are caused by both natural processes and human activities. Natural processes include tides, waves, currents and storms and major geological events such as tsunami. Human activities affecting the shoreline are construction of ports and coastal structures, land reclamation, and land use practices. Shoreline accretion results in more usable land, while shoreline erosion has been reported to cause potential problems to the infrastructure, community and ecosystems along the coast. Therefore, accurate demarcation and monitoring of shoreline variations (long-term and short-term) are necessary for a scientific understanding of coastal processes and for assessing the nature of impact - natural or human mediated, for devising effective coastal management strategies in future.

ORISSA: The Mahanadi deltaic region in Orissa is known for mangrove swamps, tidal flats, beaches, sand dunes and spits. The region is also subject to tropical cyclones, monsoons and floods. Studies using remote sensing and field data of shoreline changes along the Gahirmatha coast have indicated erosion and accretion in various places. It was observed that the shoreline retreated all along the coast between Ekakula (219 m) to Pentha (947 m) during 1972 to 1999 while Hansua river mouth had 470 m accretion. Since the sediment supply from the south is arrested by various breakwater structures that have been constructed, the morphology of the coast is controlled by the sediment brought by the rivers of that region and the reworking and redistribution of sediments available in this area. The changes in the orientation prevent continuity in the littoral drift after the Ekakula spit. Palmyra sandy shoal formations indicate that this region acts as a sink for the sediments brought from south. Considering that this coast is an important breeding ground for Olive Ridley turtles, shoreline changes have increased their vulnerability during cyclones and storm surges.

The paleo-geomorphic evolution of the Mahanadi delta region was studied through various published maps of historic, geographic, geologic and geomorphic information. During the upper Pleistocene – Holocene period extensive deltaic sedimentation from Mahanadi river system led to the development of the modern Mahanadi delta. Detailed examination of the borehole cuttings retrieved from several boreholes provided information on sea level-fluctuation, paleo-strandlines, paleo-depositional environments and paleo-geography. The observations of the study reveal that the coastline regression started during Pleistocene (25 km) followed by transgression (5 km) till Late-Up-Pleistocene. During the end of Pleistocene, the regression was found to be vigorous to the extent of 10 km away from the present shoreline. This aggressive regression was followed by a period of slow transgression till early Holocene.

ANDHRA PRADESH: The littoral-drift regime along the 290 km coastal stretch between Narsapur and Vishakhapatnam, north-eastern coast of Andhra Pradesh (A.P.), India, has been investigated by analyzing coastal drift indicators and landform change detection study based on multi-date, multi-temporal satellite images. Along two distinct coastal segments, the Godavari delta coast and Uppada-Vishakhapatnam open coast, twenty littoral cells were identified. The results of these three independent techniques revealed that multi-date, multi-temporal satellite images help in understanding the cellular nature of littoral drift along the coast. Although the shore drift is bi-directional and seasonal, the overall net littoral drift moves from SW towards NE along the eastern coast of India, and littoral-drift characteristics along the northeast Andhra Pradesh coast indicate that littoral drift regime is well adjusted to the present ambient wave climate.

GUJARAT: A recent study has indicated that nearly 74.24% of the coastline is eroding, of which 35.47% can be described as low erosion; 16.08% with moderate erosion and 22.59 % as severely eroded areas. The study used an improved method based on remote sensing technology coupled with limited DGPS surveys and integrated in GIS to collect historical shoreline information. Base maps were prepared on 1:50,000 scale using Survey of India/US Army toposheets and onscreen digitization of coastline were carried out using various satellite images on 1:15,000 scales and stored as four different layers in GIS environment for the years 1980, 1990, 2000 and 2009. The multi-date shorelines served as input into the USGS digital shoreline analysis model to cast various transects (261 reference stations) along the coastline of Gujarat. A distance of 5-10 km intervals was assigned to calculate the erosion/accretion statistics in ArcGIS 9.3 software. The results obtained were classified as low (0 to -10m), moderate (-10 to -30m) and severe erosion (-30 to -125m) respectively. For accretion, only two basic classification scales were used as accretion areas (0 to +30m) and high accretion zones (+30 to +180m).

6.4 SEDIMENT CORE STUDIES

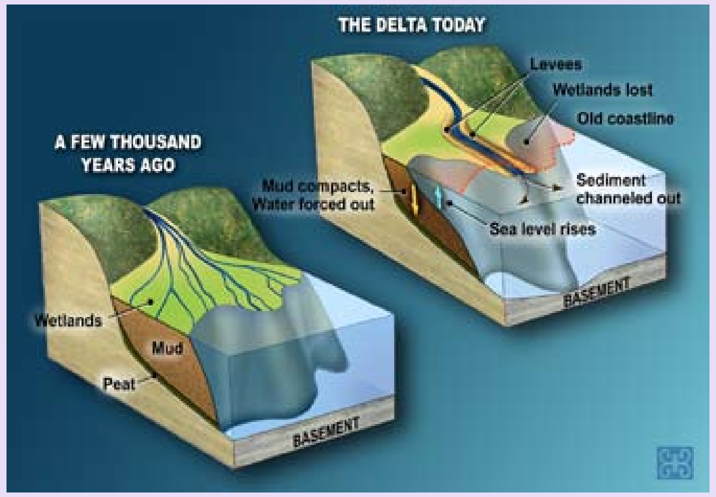
Knowledge about events and impacts is important for coastal management and land- use planning under current global change phenomena. For this an understanding of the sedimentological processes, determining periods of dune formation and deposition of sediments from tsunami and/or storm surges and studying impact of coastal processes on the ecological evolution of a region is required. This was examined in two studies in India, one in the Andaman Islands and the other near Cuddalore in the Cauvery delta on the mainland. In the former, palynological investigations helped in identification of the progression of species. Analysis of sediment core indicated possibilities of a storm event depositing sand with fine silt being deposited through cracks which possibly developed due to an earthquake.

Aeolian sediments in dry land and coastal areas have great potential for paleo-environmental studies. Investigation of coastal dunes provides information about sea level fluctuations. Dunes were examined in the northern and southern part of the Cauvery delta using optically stimulated luminescence dating. Comparing the studies of sea level fluctuations with results obtained, it appeared that the dunes reflect sea level high stand at 4 ka and a low stand during the Little Ice Age. A prominent feature of the investigated sections in the northern part was soil-like horizon containing numerous artifacts. The periods of sand movement were found to coincide with periods of reduced precipitation in south east India. The investigated dunes in the northern part of the Cauvery Delta reflect the sensitivity of that area against changes in climate and human impact resulting in increased sand movement. In the southern part of the Cauvery delta (Vedaranyam), paleo beach ridges were found inland which reveals sediment accretion and regression of sea to the present day coast.

The 2004 Indian Ocean tsunami resulted in a number of studies examining sediment cores for paleo-tsunami evidences. In the case of Tamil Nadu, tsunami deposits from 2004 have been characterized. Keeping the geomorphology and 2004 tsunami sediment characteristics as the key, excavations were made for candidates on the Cauvery river delta and such candidates have been found at four sites within 2 km from the modern beach. Pre-2004 sheets were traced across the mudflats near the place where the 2004 tsunami inundation was higher. Using sedimentology, micropaleontology and field characteristics, the possibilities of storm surges and other coastal processes have been ruled out for the origin of these deposits and they have been identified as probable candidates of ancient tsunamis.

Reconstructing coastal changes over long periods of time helps in understanding the pattern of evolution of shorelines. Wetlands such as coastal lagoons and mangroves which act as a buffer zone between the land and ocean have high sediment accretion rates and stabilized vegetation. The geochemical compositions of the sediments including carbonates, organic materials can be used for climate proxies. This concept has been used to examine the geochemical evolution of Holocene sediment in the Muthupet lagoon, and the impacts of different sedimentary environments on the chemical composition of the sediments. Muthupet is the southernmost end of the Cauvery delta in Tamil Nadu, India. Certain areas in Muthupet lagoon and mud flats on its northern flank are prone to floods during the monsoon season. Sediment texture studies of the study area indicate the dominance of clay particles flocculated by the grid pattern of mangroves. Si/Al ratio (~2.63) indicates the abundance of detrital clay in these lagoon sediments. A sediment core was collected from the middle of the lagoon and the down core variations of geochemical parameters and their ratios were employed to reveal the characteristics of Holocene climate and associated environmental implications of the area. The variations observed in the chemical parameters of down core sediments of the Holocene strata indicate the existence of humid and arid climatic conditions. The occurrence of major events at various periods was also indicated. It is expected that Oxygen isotopic and ^{210}Pb studies of these sediments may throw more light on the period of deposition and the major events that occurred during this period.

Picture 5: Uses of Deltas: PROTECTED WETLANDS
(Picture of Pichavaram Mangroves, South India)
Photo Courtesy: B. Senthilkumar, IOM



7. Theme 5 Human Perspectives

7.1 OVERVIEW

Deltas are home to large populations and are important centres of agricultural production while coastal areas have fishing as an important livelihood. Agriculture is intensive with irrigation channels drawn from the river systems that make up the delta. The deltaic coasts in Asia are often fringed with mangroves and also have seagrass and coral reef ecosystems off shore in many places. Hence they offer excellent habitat for fish and shellfish and therefore, a sizeable fishing population, mostly artisanal, often using traditional craft and gear is present. In some places, the populations in a hamlet or village may pursue fishing or agriculture exclusively, in others, there may be a mix of such populations.

Deltas in the tropics are also subject to hydro-meteorological hazards in terms of floods, droughts and cyclones. The 2004 Indian Ocean tsunami affected almost the entire coast of Tamil Nadu, with the worst affected district being Nagapattinam. Natural ecosystems such as mangroves offer protection but it is also disaster preparedness by the people that enables quick response to a disaster situation.

A number of studies have been carried out to ascertain the vulnerabilities of coastal communities after the 1999 super cyclone that hit Orissa and the 2004 Indian Ocean tsunami. A number of adaptation and mitigation plans have also been put into place in Tamil Nadu and Orissa.

7.1.1 VULNERABILITY OF AGRICULTURE AND FISHERIES SECTORS

The predominant livelihood of people in Nagapattinam district, at the tail end of the Cauvery delta, is agriculture. Being at the tail end, it takes time for the water to flow through the river and reach the fields. However, erratic rainfall in the catchment as well as in the delta, upstream dams that retain water and the interstate dispute on water sharing have resulted in the area suffering frequent hydrological drought. An analysis in 2005 that looked into the impact of the tsunami on the agriculture in Nagapattinam found that the tsunami was just another disaster and that the agriculture sector was highly vulnerable because of the large number of small farmers with small holdings. In the case of fisheries, the huge humanitarian response after the 2004 tsunami had resulted in changing the face of the fisheries with traditional catamarans being replaced extensively by Fibre Reinforced Plastic (FRP) boats as well as an increase in the number of boats and consequent increased pressure on resources.

Vulnerability analysis of the agrarian and fisheries sectors in the Cauvery delta was done for the districts of Nagapattinam and Cuddalore in Tamil Nadu. Both districts are subject to frequent natural hazards such as floods and cyclones. In addition, The Window of Vulnerability (WOV), a time frame within which defensive measures are reduced, compromised or lacking was examined in a group of villages where the dominant livelihood was agriculture or fisheries. This study used the inverse of the number of days the study respondents were able to get work as a measure of the WOV. It was found that agriculture provided greater employment in both districts and employment in the fisheries sector was found unpredictable. Vulnerability in agriculture was mainly caused by non-availability / erratic supply of Cauvery water while in fisheries it was capitalization of fisheries, post-tsunami increase in the number of craft, closed season and changing patterns of sea ingress.

Nagapattinam is traversed by fourteen river systems from which channels for irrigation and drainage have been cut. A study on the status of the irrigation systems structured around fourteen Tail-End Regulators was carried out in 2007. It was found that both drainage and irrigation channels were extensively damaged and in disuse because of lack of water in the irrigation channels due to multiple reasons listed earlier. This was a major cause of flooding and drought that the farming community faced. Taking into consideration the fact that it was not mere repairs of the defective agri-infrastructure created but long- term maintenance that would be a sustainable solution to the frequent flooding or droughts that the farming communities faced, a set of interventions were planned and executed as a "Participatory Agri- infrastructure maintenance" model including, both, the local panchayat and the actual users, as active participants in the model. A number of challenges were faced in the institutionalization of the process which was carried out by intensive social mobilization that took much more time and effort than anticipated. The programme promoted the building up of water user associations and the involvement of the government line departments (PWD, agriculture) as well as the Panchayati Raj Institutions which form the local governance. The programme resulted in saving from flooding of over 3000 acres in three TER systems apart from enabling cultivation of additional acreage. Participatory action brought costs down apart from allowing micro level management. It is clear that sustainability lies in finding local solutions to local problems but aligning with the larger framework.

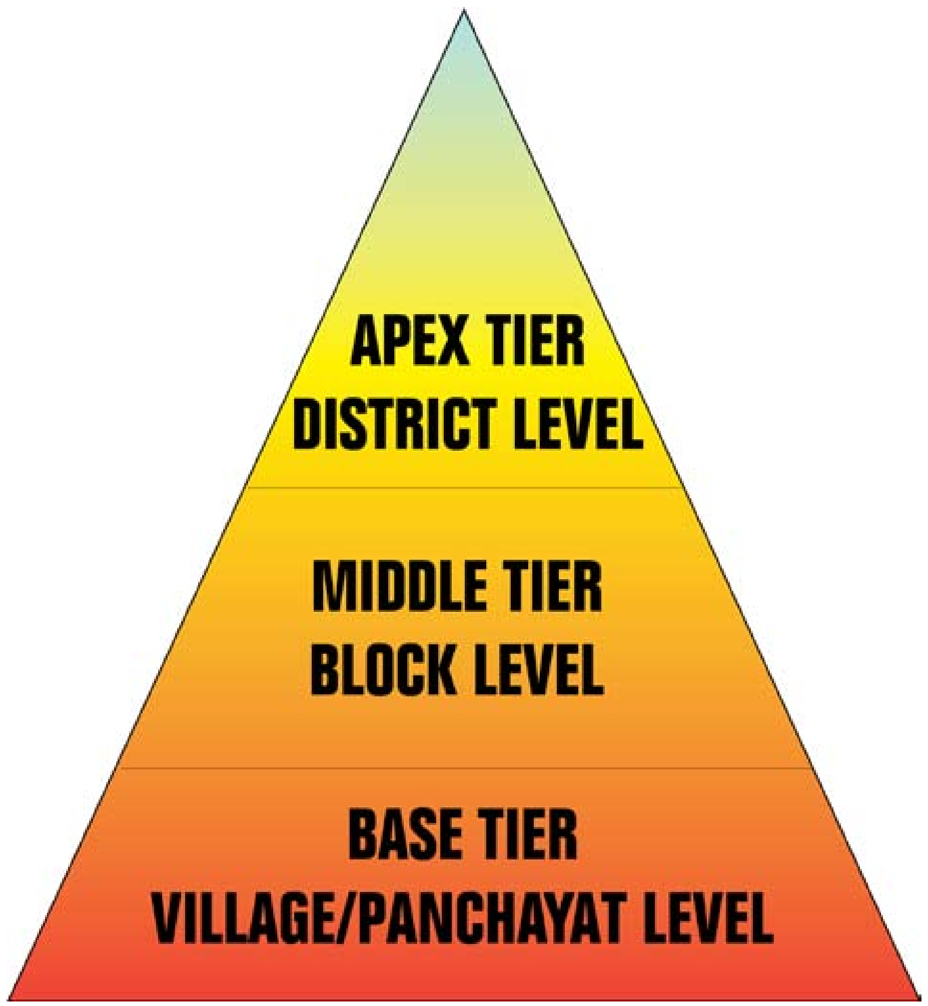
Groundwater salinity in deltaic regions is an increasing problem. Agriculture activities, geological formation and local environmental conditions control the groundwater quality in any area. Studies in Cauvery delta indicate that because of intensive agricultural practices, there is high demand for groundwater for irrigation and deterioration in the groundwater quality. Groundwater quality is found to be controlled by rainfall / river recharge. In the eastern region of the delta, building up of solutes was observed and this is likely to force changes in the cropping pattern. To overcome this problem of groundwater salinity, it is essential to maintain flow in the drainage channels or by means of substantial rainfall recharge systems.

7.1.2 PROTECTIVE NATURAL ECO SYSTEMS

The relative vulnerability of 262 villages of the Mahanadi delta lying within a 10 km distance from the coast of the Kendrapada district, Orissa, were compared by estimating the village wise probability of facing human fatality due to severe storms. Probability estimates using a cyclone impact (human deaths) function which included a wide range of factors including the presence of mangrove forest were used to control for the exposure and adaptive capacity of the villages. Villages established after clearing the forest in mangrove habitat areas and those with more marginal workers were found to face a very high death risk and thus, need complete evacuation before a high intensity cyclone. In contrast, villages situated in the leeward side of existing mangrove forest or near a major river appear to be facing a much lower risk of deaths. The results have important implications for conservation of mangrove forests in cyclone prone areas and also in the design of development policies for villages established in the mangrove habitat. Since during cyclones, evacuation, rescue and rehabilitation works are undertaken at the village level, identification of the relative vulnerability of the villages helps the policy makers in prioritizing the rescue and relief works.

7.1.3 THE BOTTOM-UP APPROACH

Cuddalore district in Tamil Nadu at the northern edge of the Cauvery delta, is vulnerable to cyclones and flooding of rivers during the North-East monsoon period every year. The population density is about 630 km^{-1} (2001 census). In November 2000, the district was hit by a cyclone and it became necessary to evacuate people. However, people cannot be forcibly moved and they have to be persuaded. Disaster management has been perceived as the job of the government mainly because of the top down approach. In Cuddalore, even



before the cyclone, the administration tried to work towards a bottom up approach as shown in the graphic below:

An unstructured participatory approach was followed at the base (village/panchayat level) and information generated from past memory of people regarding types of hazards, demarcation of vulnerable locations/ zones, choice of mitigation methods, identification of temporary shelters, and fixing of roles and responsibilities during different phases of the disaster. This approach led to the acceptance by the people of the action plans to be put in place. At the middle tier/block level, it was putting together information about all the areas under that level, a consolidation of information regarding various resources that could be mobilized. At the district level (apex tier), the focus was on identification and execution of risk reduction activities including mobilization of equipments, finalization of standard operating procedures, and the organization of rescue, relief, rehabilitation and restoration activities. Lessons learnt from the exercise include the need for involvement of all sections of the society, from planning to execution in the disaster management plan and that pre-disaster preparedness ensures reduction of risk to life and property. Dissemination of accurate information about expected hazard helps in better community mobilization and evacuation efforts and it is necessary to be clear in roles and responsibilities of stakeholders to ensure efficiency and effective utilization of available resources.

In the Sunderban delta, changing frequency and intensity of coastal flooding are seen. The coping capacity of inhabitants in this area is low. With long term climate change effects having to be considered, it is clear that the old paradigm of disaster management has to give way to the new paradigm of adaptation. Disaster management is mostly reactive and the expenditure is on relief (food and clothing), evacuation and housing in temporary shelters, compensation for loss of life, assets etc with government agencies, NGO, family and society providing the support. Sagar Island in the Sunderban is a large island with a population of over 185,000. The main livelihoods are agriculture, aquaculture, prawn seed collection and capture fisheries. The agricultural land is low lying and subject to high salinity, flooding, erosion and little irrigation. Analysis indicates that government support compensated only for about 17% of the damages. Hence, for a long term solution, it was found advisable to go for adaptation strategies. An adaptation framework of building cyclone resistant houses and embankments requires high capital expenditure as well as maintenance expenditure but results in long term adaptive capacity creation in lieu of recurring ad hoc disaster relief expenditure and promotion of sustainable development.

As previously stated, deltas should be considered, in terms of processes and management, as a part of a more complex River-Delta-Coast System. It is important to recognize that deltas are equilibrium landforms, but they are also landforms that are dynamic: they respond to changes in water and sediment fluxes, and are characterized by an ability to evolve through time. However, although our knowledge of individual components, or sub-systems, is in many cases adequate, if not good, it tends to be formulated in a way that makes it difficult to identify true inter-relationships between variables. For example, deltas are to varying degrees subsidized by the wider catchment, whilst increasingly they provide a number of tangible benefits (both locally and globally).
It appears thus of major importance that a major step forward should be to reconsider the way definitions are formulated both for all parts of the river-delta-sea systems, in a manner that helps the better understanding of the natural and human induced processes in those systems. Pressures (both anthropogenous as well as natural, at smaller as well as wider scales) should also be identified for the river-delta-sea systems, both for the system as a whole and for all its components. This goal is of uppermost importance when trying to identify critical issues affecting the systems` state of sustainability.

Management plans that try to reach sustainability in deltaic areas should also try to answer the following questions:

- How capable is the system in terms of sustaining development or other anthropogenic changes?
- How much non-natural activity can the system sustain without adverse effects?
- How much of a change from the natural condition are we willing to allow?

To address these distinct attributes, it is necessary to identify inter-relationships between the socio-economic processes and the physical-biological system, as well as connections within the various parts of the system, in order to determine the effects of any disturbance, or the implications of changes in key variables.

Picture 6: Uses of Deltas: Agriculture
Image courtesy: Purvaja Ramachandran, IOM, Anna University Chennai

8. Management of Deltas

During the workshop, the following management principles and objectives were proposed:

- The primary objective of delta management is to maintain a sustainable delta, by establishing a balance between the socio-economic and the natural systems;
- Delta management must be flexible and adaptive, in order to accommodate specific needs of individual deltas.
- i.e.,different management approaches are required betweenareas of deltas that are designated as biosphere reserves and highly populated deltas (e.g. Asian deltas)- where intensive economic activities are already in place..
- Management options should deal with the multiple uses of deltas and try to reach sustainability in order to evolve non-conflicting levels for each of the uses.
- Significant stakeholder involvement and inclusion of policy makers, representatives from the local population must be considered while formulating a management plan for each of the deltas

- Due to its very unique characteristics (River-Delta-Coast systems), Delta Management also needs to address:
  - Interstate and transnational issues
  - Science coordination – as research is done by multidisciplinary teams and
  - Communication of science to policy makers

Picture 7: Management of deltas: Sustainable delta: Creation of a balance between socio-economic and natural systems Source: http://dantruong.ws

Uses of Deltas: Irrigation
Source:

http://upload.wikimedia.org

9. Knowledge Gaps

At the present there is a fragmentation of knowledge in different disciplinary compartments. These gaps and questions still to be answered and are presented below:

- Better understanding of the interaction between natural science and social science aspects of delta management
- Reduction of freshwater flow into the deltas and its impact on coastal ecosystems
- A detailed and precise knowledge on subsidence (due to tectonics and sediment loading, sediment compaction, as well as due to extraction of oil and water) and sea level change (eustatic, global warming, subsidence etc.).
- Improved knowledge of sediment and nutrient dynamics and budgets, throughout the system, which may require standardized data collection
- Essential structural and functional elements needed to ensure continued ecosystem services
- Impact of rising sea levels on deltaic and other estuarine complexes
- Communication between scientists, policy makers, stakeholders and general public

Delta Workshop 2009- Communication between Scientists, policy makers and stakeholders during the meeting

10. Conclusions and the way forward

The workshop was seen as a successful attempt to bring the various aspects of studies on deltas – physical description, nutrient biogeochemistry of deltas, vulnerability to hazards and the socio-economics of delta inhabitants. This workshop also focused largely on the increasing pollution due to excess nutrients in coastal systems. A nutrient budget model for a variety of coastal ecosystems was developed based existing nutrient database in these systems which will then be effectively used to combat the nutrient loading. It has been re-emphasized in this workshop that excess nutrients cause grave pollution problems to coastal waters, estuaries and deltas in the developing countries, particularly due to

- agricultural sources,
- changing land use
- N and P pollution through point and non-point sources and
- lack of habitat protection

The last session on human dimensions especially is likely to help in moving the discussion strongly on issues of mitigation and adaptation in the wider context of global change which includes climate change, globalization and economic fluxes. The overall outcome of the workshop was a circle that showed directions in which future discussions on changing deltas should emerge.

It is necessary to develop an approach to develop typology on geomorphological characteristics of deltas to help us understand them better. The health of systems needs to be looked at as well as looking at various scales – from the catchment to the socio-political and the seasonaility of processes. Human perturbations need to be taken into account while studying the changes in deltas. Studies on rare earth minerals as well as on pathogens also need to be studied in detail. A number of generalizations are being made on the basis of small databases and this aspect needs to be looked at seriously.

Past records are difficult to get at – especially for water and sediment flows in river systems and hence the difficulty in getting a good picture of the past to enable better understanding of the present. This is essential to enable development of the ability to translate what happened in the past to see what will happen in the future. It may be easier to choose non-controversial deltas for modeling because discharge data can be confidential. Also, it is better to avoid trans-boundary river systems because upstream data are weak or not available at all and it is essential to have detailed and complete data for upstream processes.

Deltas are seen vulnerable to a series of stresses and impacts. What emerged is the need to communicate on common understanding as many of the activities and issues are cross-cutting in nature. Deltas need to be seen in the future as socio-ecological systems and high focus on the human interactions in deltas is needed. It is only by doing so, that we can expect wider social and political support for the conservation and maintenance of deltaic wetlands, although this will require improvements in communication and transparency.

Keynote Addresses and Oral Presentations made during the December 2009 Workshop

1. TYPES, FORMATION AND CHARACTERISTICS OF DELTAS

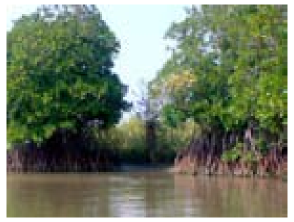
Global Change and Coastal Systems: Challenges at the science policy interface	**HARTWIG KREMER**
A Geomorphological Framework for the Classification of Deltas and Estuaries	**COLIN D. WOODROFFE**
Mega-Estuarine Ecohealth and Challenge: High-Low Turbid Examples from the Yangtze and Nile	**ZHONGYUAN CHEN**
Dispersal and Accumulation of the Mekong River-Derived Sediment in the South China Sea	**PAUL LIU,** ZUO XUE , DAVE DEMASTER, LAP VAN NGUYEN AND THI KIM OANH TA
Influence of Delta Front on Tidal and Wave Actions along the Yellow River deltaic coast	**KATSUTO UEHARA**

2. BIOGEOCHEMISTRY AND NUTRIENT BUDGETING OF DELTAS

The Importance of Biology in Estuarine Fine Sediment Dynamics	**ERIC WOLANSKI**
Carbon Cycling in Mangrove Ecosystems	**KATHIRESAN, K**
Large Rivers- Can they be sink for CO_2?	**SUBRAMANIAN, V**
Mega Dam Initiative in the Tsangpo-Brahmaputra Basin: Modified Sediment Flux and Future Vulnerability of the GBM Delta	**CHANDAN MAHANTA** and RUNTI CHOUDHURY
LOICZ Nutrient Budgeting for Chilika Lake, Orissa	**RAY A K** AND RAMESH RAMACHANDRAN
Nutrient, REE and metal behavior in the Cauvery delta –estuarine complex in SE India	**AL. RAMANATHAN**, M. BALA KRISHNA PRASAD and RAJESH KUMAR RANJAN
Pathogenic indicators in coastal region of Tamil Nadu, India	**RATHINAM ARTHUR JAMES,** SIVANANDHAM VIGNESH, PERIYASAMY KUMARASAMY and ANNAMALAI RAJENDRAN
Organic Carbon Source and burial during the past one hundred Years in Pichavaram Mangroves, South India	**B SENTHILKUMAR,** R PURVAJA and R RAMESH

3. NUTRIENT BUDGETING FOR MUDDY COASTAL WATERS

Pichavaram	B. Senthilkumar, K.Kathiresan
Chilika	Ajaykumar Ray
Vembanad	A. Paneer Selvam
Sunderbans	Kakolee Banerjee
Bhitarkanika	AL.Ramanathan


Pichavaram


Chilika


Vembanad


Sundarbans


Bhitarkanika

Dr. Eric Wolanski during the session on Nutrient budgeting for muddy coastal waters

4. GLOBAL CLIMATE HAZARDS AND VULNERABILITY

Changing deltas and present crisis	**YOSHIKI SAITO**
Vulnerable deltas of South Asia	**RAMESH RAMACHANDRAN**
Luminescence Dating of Coastal Dunes at the Cauvery Delta Showing Rapid Environmental Changes	**BRIGITTE URBAN**, Alexander Kunz, Linto Alappat, Manfred Frechen, Ramachandran Ramesh and Seshachalam Srinivasalu
Clues for Tsunami Recurrence during the Past in the Cauvery Delta Region, India	**SESHACHALAM SRINIVASALU**, Natarajan Thangadurai, Balasubramanian Uma Maheswari, Paniadimai Judith D. Silva, Panchatcharam Saravanan and Ramasamy Ashokkumar
Inter-annual shoreline changes of Gahirmatha coast, Orissa	**MANI MURALI R**., Kesavadas, V. and Vethamony, P.
Climatic variability on Holocene deltaic core sediments of Muthupet Lagoon, SE-coast of India: Geochemical and paleoenvironmental implications	**M. JAYAPRAKASH, B**. Urban, P.M. Velmurugan, L. Giridharan and S. Srinivasalu
The cellular nature of littoral drift along the northeast Andhra Pradesh coast, India	**PRAVIN D. KUNTE**
Shoreline analysis in Gulf of Kutchch, Gujarat: A remote sensing approach	**NARAYANAN RM**, Tulasi Bai P.D, Rajkumar J, Sathish Kumar S, Pushpamalar P, Mary Divya Suganya G, Sathiyabama V.P, Elavarasu Veera, Narayan Kumar R, Rajaram P, Kalpana R, Kannadasan K, Periyakaruppan K, Kumaran E, Ramanathan G, Ponnurangam G.G, Vidhya P, Madhumitha R, Vetriselvan K, Pandiselvam P, Purvaja R and Ramesh R
Paleogeomorphic evolution of Mahanadi Delta –A cartographic appraisal using Geographic Information System	**R.NARAYANAKUMAR, RM.** Narayanan, A. Priya, S. Sathish Kumar V.P. Sathiyabama, P.Vidhya, R.Purvaja and R. Ramesh

5. HUMAN PERSPECTIVES

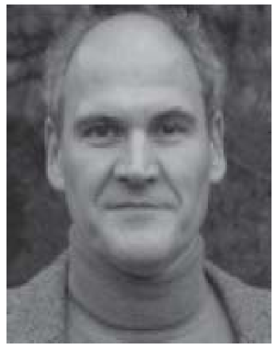
Vulnerability analysis of agrarian and fisheries sector in Cauvery delta	**AHANA LAKSHMI**, Annie George and Satish Babu
Participatory irrigation management in the tail-end region (TER) in the Cauvery delta	**ANNIE GEORGE**
Role of Mangroves in identifying the Vulnerable Hotspots of a Vulnerable Area: Measuring the Relative Vulnerability of Coastal Villages of Mahanadi Delta from Cyclone and Storm Surge Risk	**SAUDAMINI DAS**
Community Participation in the Management of Cyclone in the Delta region, Cuddalore District, Tamil Nadu	**SANDEEP SAXENA**
Need for Paradigm Shift: Disaster Management to Adaptation Strategy - A Study Based on Evidence from Indian Sundarban	**JOYASHREE ROY,** Chandan Roy and Anupa Ghosh
Groundwater Quality of Cauveri Deltaic Regions of Karaikal, Tamil Nadu	**L. ELANGO** and E. Vetrimurugan

6. POSTER PRESENTATIONS

GIS based Marine Pollution Studies In The Coast of Calicut, Kerala.	N.Hema, D.Madhumathi, R.Narayanakumar and R.Ramesh
Rapid Assessment of Water Quality and Faunal Diversity in the Harbour Area of Vishakhapatnam Port, South India	M.Murugesan, B.Senthilkumar, R Arivazhagan and R.Ramesh
GIS Based Marine Pollution Studies for the Coast of Mangalore, Karnataka	D.Madhumathi, N.Hema, Narayana Kumar and R.Ramesh

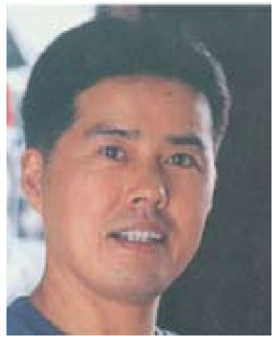
Participant interaction during the session on Nutrient Budgeting for Muddy Coastal Waters

PARTICIPANTS

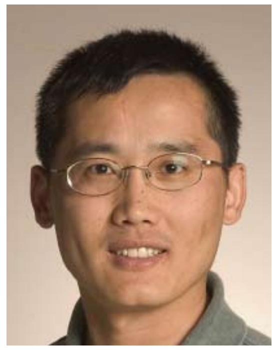


Hartwig Kremer
Chief Executive Officer, LOICZ
GKSS-Forschungszentrum Geesthacht
GmbH GKSS Research Centre GmbH
LOICZ IPO (International Project Office)
Max-Planck-Strasse 1
D-21502 Geesthacht, Germany

Colin D. Woodroffe
Professor
School of Earth & Environmental
Sciences (SEES)
University of Wollongong
Northfields Ave
NSW, 2522 Australia



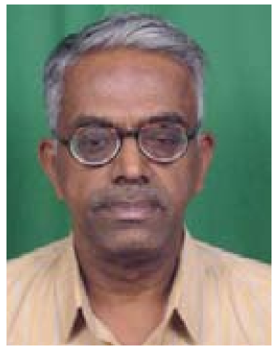
Zhongyuan Chen
Professor
Leader PI of APN Project
State Key Laboratory of Estuarine
and Coastal Research/Department of
Geography,
East China Normal University,
Shanghai, 200062, China P.R.



Paul Liu
Associate Professor
Department of Marine, Earth and
Atmospheric Sciences
Campus Box 8208
North Carolina State University
Raleigh, North Carolina 27695-8208

Katsuto Uehara
Research Institute for Applied
Mechanics
Kyushu University, 6-1 Kasuga Koen
Kasuga 816-8580
Japan

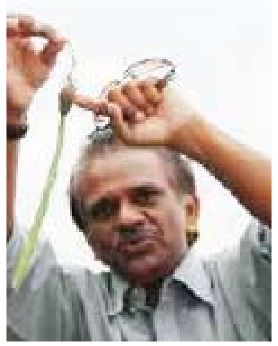
Ramesh Ramachandran
Director
Institute for Ocean Management
Anna University Chennai
Chennai 600025, India



Subramanian, V
Emeritus Professor
School of Environmental Sciences
Jawaharlal Nehru University
New Delhi- 110 067, India

Eric Wolanski
Professor
Australian Centre for Tropical
Freshwater Research
James Cook University
Townsville, Queensland, Australia

Purvaja Ramachandran
Scientist & Faculty
Institute for Ocean Management
Anna University Chennai
Chennai 600025, India



Kathiresan, K
Professor
CAS in Marine Biology
Annamalai University
Parangipettai 608 502
Tamil Nadu, India

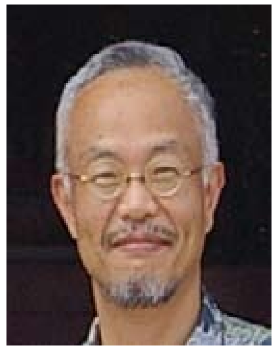
Ajay Ray
Research Associate
Institute for Ocean Management
Anna University Chennai
Chennai 600025, India

Ramanathan, AL
Professor
School of Environmental Sciences
Jawaharlal Nehru University
New Mehrauli Road
New Delhi 110067, India

Arthur James, R
Assistant Professor
Department of Marine Sciences
Bharathidasan University
Trichy 620024, Tamil Nadu, India

Senthil Kumar, B
Scientist
Institute for Ocean Management
Anna University Chennai
Chennai 600025, India

Pravin Kunte
Sr. Scientist
National Institute of Oceangraphy
Dona Paula
Goa 403 004, India



Yoshiki Saito
Geological Survey of Japan
Central 7, Higashi 1-1-1
Tsukuba 305-8567, Japan

Brigitte Urban
Professor&Speaker of the Research Group
Ecosystem Functioning and Global Change
Wilschenbrucher Weg 84a, W.422
and Herbert-Meyer-Straße 7, S.007
29556 Suderburg, Germany

Ahana Lakshmi
Visiting Faculty
Institute for Ocean Management
Anna University Chennai
Chennai 600025, India

Seshachalam Srinivasalu
Assistant Professor
Department of Geology
Anna University Chennai
Chennai 600025, India

Mani Murali,R
Scientist
National Institute of Oceangraphy
Dona Paula
Goa 403 004, India

Jayaprakash, M.
Lecturer
Department of Applied Geology
University of Madras
Chennai 600025, India

RM. Narayanan
Research Associate
Institute for Ocean Management
Anna University Chennai
Chennai 600025, India

R.Narayanakumar
Research Associate
Institute for Ocean Management
Anna University Chennai
Chennai 600025, India

Annie George
1 BEDROC, No.5 Mettu Bungalow
New Beach Road
Kadambadi,
Nagapattinam 611001, India

Saudamini Das
Institute of EconomicGrowth
University of Delhi
New Delhi 110067, India

Sandeep Saxena
Managing Director
Tamil Nadu Medical Services
Corporation Limited
Government of Tamil Nadu
Chennai 600008, India

Hema Achyuthan
Professor
Department of Geology
Anna University Chennai
Chennai 600025, India

Anupa Ghosh
The Bhawanipur Education Society College
5 L.L.R.Sarani
Kolkata 700021, India

Elango, L
Professor
Department of Geology
Anna University Chennai
Chennai 600025, India

Paneer Selvam, A
Senior Research Fellow
Institute for Ocean Management
Anna University Chennai
Chennai 600025, India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