An Assessment of Nutrient, Sediment and Carbon Fluxes to the Coastal Zone in South Asia and their Relationship to Human Activities

Final Report for APN Project
- Ref Nos: 2001-20 and 2002-05 -
(April 2001- February 2004)

submitted to APN

by

Sri Lanka National Committee of IGBP
Sri Lanka Association for the Advancement of Science
120/10 Vidya Mawatha, Colombo 00700, Sri Lanka

Participating Countries:

Australia, Bangladesh, India, Nepal, Pakistan, Sri Lanka and USA

31 March 2004

Final Report for APN Project

1. Project Title

An Assessment of Nutrient, Sediment and Carbon Fluxes to the Coastal Zone in South Asia and their Relationship to Human Activities (APN 2001-20/2002-05).

2. Abstract

Information on scientists and organizations working on coastal studies were gathered and a network of coastal scientists was established. Literature surveys were carried out on nutrient and sediment studies in inland waterways and coastal zones including estuaries, and the findings were tabulated. A website was maintained to provide information on the network and the progress achieved.

Gap-filling studies were undertaken, involving collection of primary data on nutrient and sediment concentrations at estuaries and up-streams as well as water flow rates at different intervals of time. The nutrient budgets were calculated using LOICZ methodologies for a number of sites in all four countries; Bangladesh, India, Pakistan and Sri Lanka. Studies were also made on the impacts of human intervention in the coastal zones. The findings of the work carried out under the project and by others were presented at a regional workshop held in December, 2002 in Sri Lanka.

Studies on nutrient fluxes made on new sites in 2003 as well as refining previous calculations for improving the nutrient budgets previously obtained, resulted in the reporting of seven nutrient budgets for South Asia. A set of regional models of sediment flux for rivers in South Asia was developed. Measurements of related parameters were made sharing the facilities provided under the project. A 3-dimensional model on lagoons and estuaries was used to study the behaviour of three lagoons in Sri Lanka. Areas for further studies were also identified.

3. Project Information

3.1 Principal Investigator

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3.2 Funding

3.2.1 Allocations by APN

Year 1 (April 2001 - February 2002) Project Ref: APN 2001-20	US$ 40,000
Year 2 (April 2002 - February 2003) Project Ref: APN 2002-05	US$ 63,000
Year 3 (April 2003 - February 2004) Project Ref: APN 2002-05	No cost ext.

3.2.2 Budget and Work Breakdown

Item	Amount US $	Amount US $
Year 1		
Data Collection	11,500	
Gap-Filling Studies	21,500	
Familiarisation Visits	2,000	
Networking	1,000	
Overheads	4,000	
Sub-Total		**40,000**
Year II/III		
Gap-Filling Studies (continuation)		
Synthesis of fluxes and Budget Modelling	12,000	
Capacity Building and Familiarisation Visits	12,000	
Regional Workshop	10,000	
Publications, Web Maintenance & Network	20,000	
Overheads	2,000	
Sub-Total	7,000	**63,000**
Total		**103,000**

3.2.3 Receipts

While the entire project was funded by APN, a portion of the APN funds was administered by the START International Secretariat. According to the policies of these agencies, only a part of the funds is remitted at the beginning while the balance is released after receipt of the final project reports. The amounts received with the dates of receipts are given below.

Project No.	Date	Remitter	Amount US $
2001-20	26 June 2001	APN	36,000
	15 May 2002	APN	4,000
2002-05	20 May 2002	APN	16,000
	02 Nov 2002	START	38,700
	17 May 2003	APN	4,000
	17 June 2003	START	2,000
Total			**100,700**
Balance Due		START	**2,300**

3.2.4 Other Contributions

Several sources made both monitory and in-kind contributions towards the project, as described below.

Institution	Support	Details
LOICZ, Netherlands	US $ 5,000 in cash	Expenses towards the Regional Workshop on Material Fluxes, December, 2002
LOICZ, Netherlands	In-kind	Meeting the expenses of Resource persons who attended the Regional Workshop, December, 2002
Centre for Water Research, University of Western Australia	In-kind	Provision of staff time, computer, software and other facilities for training of Dr. Wijeratne
Marine Science Research Centre, State University of New York, Stony Brook	In-kind	Hosting visit of Dr. Wikramanayake and Dr. Ratnasiri in June, 2002, and the participation of Dr Goodbread at the Regional Workshop
National Science Foundation, Sri Lanka	Co-funding US$ 3400	Funds to purchase spectrophotometer for the Open University for gap-filling studies
National Science Foundation, Sri Lanka	In-kind	Hosting of web-site from 2003 onwards
NARA, Sri Lanka	In-kind	Staff time, Use of equipment in field and laboratory for gap-filling studies
University of Moratuwa, Sri Lanka	In-kind	Staff time, Use of equipment in field and laboratory for gap-filling studies
Open University of Sri Lanka	In-kind	Staff time, Use of laboratory equipment for gap-filling studies
Eastern University of Sri Lanka	In-kind	Staff time, Use of laboratory equipment for gap-filling studies
Industrial Technology Institute, Sri Lanka	In-kind	Use of laboratory equipment and consumables for gap-filling studies
University of Sri Jaye'pura, Sri Lanka	In-kind	Staff time, Use of GIS facilities for gap-filling studies
Coastal Resources Mangmt. Project, SL	In-kind	Assistance with field data collection, permission to use hydrodynamic data
Institute of Marine Sciences, Bangladesh	In-kind	Staff time, Use of laboratory equipment for gap-filling studies
National Institute of Oceanogaphy, India	In-kind	Staff time, Use of laboratory equipment for gap-filling studies
Dept, of Hydrology and Meteorology, Nepal	In-kind	Staff time, Use of laboratory equipment for gap-filling studies
National Institute of O'graphy, Pakistan	In-kind	Staff time, Use of laboratory equipment for gap-filling studies

3.3. Participating Countries & Institutions

3.3.1 Countries

Bangladesh, India, Nepal, Pakistan and Sri Lanka (Active)
Australia and USA (Collaborating)

Though Nepal does not have a coastline, it was included in the project because the major rivers bringing sediments to the South Asia seas originate from the Himalayan mountains, and Nepal was carrying out a regional sediment monitoring programme.

3.3.2 Lead Scientists and Organizations

Country	Institution	Lead Scientist
Bangladesh	Institute of Marine Sciences University of Chittagong, Chittagong	Dr Nuruddin Mahmood nuruddin@abnetbd.com
India	National Institute of Oceanography Dona Paula, Goa	Dr S N de Sousa* sndsousa@csnio.ren.nic.in
Nepal	Hydrology and Meteorology Department Kathmandu	Dr K P Sharma keshav@dhm.gov.np
Pakistan	National Institute of Oceanography Karachi	Dr Shahid Amjad niopk@cubexs.net.pk
Sri Lanka	Open University of Sri Lanka Nugegoda	Dr Nalin Wikramanayaka tomwiks@yahoo.com

* Retired from service at NIO in February, 2004

4. Introduction

4.1 Background

In mid-nineties, the Sri Lanka National Committee of IGBP submitted a proposal to START seeking funds to hold a regional workshop on estuarine modelling, subsequent to a decision taken at a planning meeting of SASCOM held in Colombo. The proposal was accepted and a Regional Workshop on Estuarine Modelling and Coastal Zone Management was held for coastal scientists in April 1999 in Colombo, as a joint activity of START/LOICZ/IGBP.

The workshop identified the need to train coastal scientists in the region on biogeochemical budgeting and socio-economic modelling, for which funds were sought from APN. This resulted in holding the second Regional Training Workshop on

Biogeochemical Budgeting and Socio-Economic Modelling in September 2000 in Colombo, as a joint activity of APN/LOICZ/START. The workshop concluded that it was necessary to collect and synthesize existing information and undertake small-scale local studies to fill in critical gaps in knowledge before attempts were made to develop a regional model.

Subsequently, a proposal was submitted to APN seeking funding for a two-year project to study in detail the nutrient, sediment and carbon fluxes in South Asia. However, the APN decided to initially fund only a one-year programme, and at the end of the first year, the project was extended to another year. Since funds for the second year came late, the project was extended to a third year at no additional cost. This report gives the findings of this 3-year study from April 2001 to February 2004. The main activity carried out in the second year was the Regional Workshop on Assessment of Material Fluxes to the Coastal Zone in South Asia and their Impacts, held on 08-11 December, 2002 in Sri Lanka, as a joint activity of APN/LOICZ/SASCOM. The Proceedings of the workshop has been published separately.

4.2 Scientific Significance

The South Asian region accommodates a population of approximately 1.4 billion people, which is more than one fifth of the global population. The major rivers in the region are well known for their high sediment concentration during the months of summer monsoon. In particular, the rivers originating from the Himalayas are known as some of the highest sediment laden rivers of the world. These large rivers along with other medium and small rivers of the region transport a significant amount of sediment in addition to other riverine materials towards the ocean.

It is estimated that the region contributes almost 15% to 20% of the global sediment flux towards the oceans. The sediment received by the oceans at river mouths has created some of the largest deltas of the world such as the Ganga-Brahmaputra delta. An assessment of these fluxes, their impacts on socio-economic conditions and the linkages with policies is necessary for the understanding of global biogeochemical cycles and the impacts of global change in the coastal zones.

4.3 Objectives

The objectives of the initial one year project were limited to:

1. Establish a network of researchers and institutions engaged in research and policy analysis related to fluxes of material to the coastal zone.
2. Identify, assess and share existing studies (methodologies and results) related to material fluxes, their origins and impacts on the critical functions of coastal systems.
3. Identify critical gaps in information and knowledge of processes and undertake some regional studies to address these needs.

In the extended programme, the objectives were expanded to cover the following:

1. Extend gap-filling studies to cover the 1st half of the year, which is essential to construct a more complete year-round picture and collect data on human activities in coastal areas.

2. Synthesis of existing information on nutrient and sediment fluxes with a focus on the linkages to socio-economic conditions and policies and to build a regional model for South Asia.

3. Capacity building of participating scientists through study visits to collaborating institutions in Australia/USA and within the region.

4. Hold a Regional Workshop to review and analyse the findings of the studies, compare the results and present the biogeochemical budgets constructed for different sites.

5. Prepare a set of detailed recommendations for the policy makers and formulate proposals for further studies to be carried out under the Workshop agenda.

6. Publish the Proceedings of the Workshop in collaboration with LOICZ for distribution among coastal scientists.

This report covers the activities undertaken in all three years; 2001/2004. Activities reported for the two previous years are essentially those reported in the two previous progress reports. It has to be stressed here that work of this nature has to be carried out at least over a year without a break, enabling the seasonal variations to be established properly. However, the delay in the receipt of funds in 2002 resulted in the disruption in the collection of data in the summer and autumn months of 2002, and the time was spent on continuing the desk activites undertaken in 2001.

5. Desk Activities Conducted

5.1 Creation of a Network and a Website

Information on national organizations and scientists working on coastal problems in each participating country were first obtained and a database was established. A website giving the information in respect of each participating country's activities, details of the scientists involved in the project and reports of studies undertaken during year one was posted in the web. The URL was http://www.coastal-fluxes.slt.lk. However, with the termination of the project in February 2004, this site has now been discontinued and instead a new site has been hosted at http://www.nsf.ac.lk/slaas/cfweb/

In year two, a number of new scientists and institutions within the region other than those identified during the year one of the project, who were working on related fields were contacted as part of the continuation networking process. This was an outcome of the study visits carried out in February by the Sri Lankan Team Leader and the study reviews done for each country.

The first issue of the "South Asia Coastal Fluxes" newsletter, which described the objectives and overall activities of the project was printed and distributed. The PDF version of the newsletter has also been posted on the website for downloading.

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With a view to interact closely with participating scientists, the Team Leader from Sri Lanka visited NIO, Pakistan in September 2001. Due to various logistical reasons, the visits to NIO, Goa and Bangladesh had to be postponed and were carried out only in February 2002.

A list of scientists and other persons involved in research and monitoring of aquatic environment, with their field of specialization, as provided by the Country Team Leaders, was compiled for each country. The details are found in Appendix I.

5.1.1 **Bangladesh**:

The scientists who are mostly from the Institute of Marine Sciences of the University of Chittagong are included. In addition, several scientists working in various government institutions are also included. Their details are given in Appendix I under Bangladesh.

5.1.2 India:

The NIO, Goa established contacts with scientists in India involved in collection of data on environmental parameters in the coastal and estuarine waters, and other related activities, who could possibly contribute to the Project in the form of sharing the data available with them. Their contact details are given under Network Information found in Appendix I

With partial support from the Project, an International Workshop on 'Marine Pollution and Eco-toxicology' was organized by NIO, Goa, in Goa during February 25-26, 2004. It was felt that the topics to be discussed in the Workshop were relevant to the objectives of the Project, and that the proposed Workshop would give us an opportunity to establish a network of coastal scientists who are participating in the Workshop. The aim of the Workshop is to bring together the environmental scientists, ecotoxicologists, educationists, policymakers and students on a common platform to discuss and highlight recent advances in marine pollution and eco-toxicology and their relevance to developing countries. The contact details of these scientists are given in Appendix I.

5.1.3 Nepal:

A brainstorming workshop was organized in Kathmandu for national communication of the needs and issues related to sediment monitoring activities and researches in Nepal. The workshop report given in Appendix I, provides the list of participants who are not only the users of sediment information but also the key figures in Nepal involved and interested in sediment monitoring and research activities.

5.1.4 Pakistan:

The National Institute of Oceanography (NIO), Karachi organized several meetings between NIO scientists and scientists of various Universities and organizations of Pakistan involved in the studies/field similar to the objectives of this Project, and established a national network of Pakistani coastal scientists. Beside that NIO scientists also disseminated the results and findings of the project at various national, international, governmental and non-governmental forums. The Pakistani team also continued to collect and assess data from various researchers and organisations within the country. Their details are given in Appendix I.

During the field trip to different barrages and dams, the team members availed the opportunity to educate the people, from different walks of life, about the importance of delta and the consequences of drastic reduction in sediment and water budget of the Indus River down stream Kotri Barrage. Torrential rains and flood in the lower Indus Delta stimulated the interest to widen the sampling area not only to document nutrients but also to cover the socio economic aspect of the project.

5.1.5 Sri Lanka:

Unlike in the other four participating countries, where a single research institution was the project partner, the Sri Lanka team comprised scientists from several institutions, with the Sri Lanka Association for the Advancement of Science (SLAAS) serving as the lead institution. Therefore while the funds were disbursed by the Project Office at the SLAAS and coordinated by the Team Leader, Sri Lanka, the activities were actually carried out by a number of institutions.

A list of researchers and institutions involved in studies related to the sources, quantification and impacts of nutrient and sediment fluxes has been compiled. These details and some additional information are given in Appendix I to this report.

5.2 Literature Survey of Secondary Data

Each country team prepared the assessments of existing information on nutrient and sediment fluxes with an emphasis on the linkages to socio-economic impacts and policies, and to build a regional model for South Asia. The papers prepared based on these Country Syntheses were presented at the Regional Workshop held in December 2002 in Sri Lanka. It was identified that these syntheses should be a part of an on-going process, with new information added on as and when they become available. The updated versions will be posted on the website.

5.2.1 Bangladesh

In Bangladesh, many workers conducted investigations to record physical, chemical and biological parameters of rivers, estuaries, lagoons and neritic waters including nutrients and carbon flux in different parts of the world. Most of the information available indicated about water qualities other than micronutrients with few exceptions. However, the existing information has being aggregated here to serve as a ready reference and to find the direction towards the researchable areas in the Bangladesh context. The final report has been prepared with the compilation of data in their Country paper titled "A review of research works on the water quality of the lotic, estuarine and marine environment in Bangladesh." This printed document was presented and circulated among the participants in the Regional Workshop held in Sri Lanka in December, 2002. This is reproduced in the Workshop Proceedings published separately.

5.2.2 India

During the first year, secondary data on the following were collected and compiled.

- Data on water supply and waste water collection, treatment and disposal in Class I towns in India, each major river basins, non-basin coastal areas and non-basin non-coastal areas.

- Data on population (human and cattle), urban water supply, waste water, organic pollution load and discharge, rainfall, river flow, water abstraction, land use, fertilizer consumption, irrigation and pesticide consumption of Ganga River basin (Northwest coast of India)

- Collection of existing data on water quality, river discharge and chemical data including chloronity, dissolved oxygen, nitrate, nitrite, phosphate and silicate at following sites:

    - Mandovi Estuary, Goa, Central West coast of India
    - Zuari Estuary. Goa, Central West coast of India
    - Periyar Rover basin, Southwest coast of India
    - Muvattupuzha Estuary, Southwest coast of India

In the second year, following secondary data were collected and compiled.

- Available secondary data in respect of Tapi and Narmada Rivers (northwest India) on the following aspects: precipitation, temperature, salinity, suspended sediment load, nutrients, freshwater inflow, wastewater influx from agriculture, industries and other sources, and their respective pollutants load.

- Similarly, secondary data on sediment load and nutrients in respect of Narmada River, east coast of India

- Secondary data on pollutants load in Ganga River along the east coast of India.

These data were synthesized into one Country Report, which was presented at the 2002 Regional workshop. The report is published in the Workshop Proceedings.

5.2.3 Nepal

Data available in the literature have been compiled for several stations in South Asia. The basic approach in the study has been the application of statistical tools as the nature of sediment process and quality of data are inadequate for a conceptual or deterministic modelling. Statistical software has been used to analyse the data. The data are also being analysed by creating a temporal database wherever possible. The stations providing useful sediment information are geo-coded using Geographic Information System (GIS). ArkView software with the available extension of spatial analyst is used to further process the data with spatial dimensions. The sites for which the data were available are described in a report, which is given in Appendix II.

5.2.4 Pakistan

During the first quarter of this project, NIO Pakistan, gathered a number of relevant published reports and research papers. The data present in the archives of NIO has a large number of data and samples collected from Pakistan's 990 km long coastline. These samples and data had been collected during various national/international coastal and marine survey programmes. A list of papers and reports on the data availability and previous findings are given under Pakistan in Appendix II.

5.2.5 Sri Lanka

As part of the objectives of the project, a survey of literature was carried out in order to document the followings in Sri Lanka:

(1) Research work carried out on the dynamics of nutrients, sediment and carbon from their source of origin to the sink, and effects of these material fluxes to the resources in the coastal zone (estuarine and nearshore areas),

(2) Statistics such as coastal fisheries catch, agrochemical usage, etc., and

(3) Recommendations implemented by the state or other organisations to alleviate the impacts due to these material fluxes to the coastal zone.

The aim of this process is to assist any interested individual or organisation to identify literature regarding the above mentioned aspects and possible gaps and limitations in research and other activities that related to land-ocean interactions that have been carried out in Sri Lanka.

This synthesis mainly concentrates on discussing existing research information in various forms such as publications, departmental reports, technical papers, unpublished thesis, etc. A more comprehensive assessment of the collected literature has been carried out to extract data that were readily available for further analysis. Possible information sources and contact details of resource persons have been listed in the third section. Finally, overviews of other foreign-funded projects have been briefly discussed. The complete synthesis report will be posted in the Project website. The list of literature cited is given in Appendix II.

6. Gap-filling Studies

The availability of funds for the participating agencies to undertake several gap-filling studies was an important feature of the project. The small sum of money spent on this activity went a long way in collecting very important information on the estuaries having significance even at global scale.

The findings of various gap-filling studies were presented at the Regional Workshop held in December 2002 in Sri Lanka. The abstracts of papers presented at the Workshop are given in Appendix III and the full papers are found in the Proceedings of the Workshop published separately. The gap-filling activities undertaken in each country are given below.

6.1 Bangladesh

As gap filling studies, samples were collected to record water quality parameters including micronutrients (PO_4-P, NO_3 -N, NO_2 -N, NH_4-N and SiO_3-Si etc.) from the Meghna River-estuary and the Karnaphuli River-estuary. Due to lack of a research vessel of our own and the huge expenditure involved in cruises through the rivers, monthly collection of samples was impossible. Therefore, considering the three main seasons in the annual hydro-meteorological cycle of our country, three sampling rounds were chosen to cover an annual cycle (pre-monsoon, monsoon and post-monsoon).

6.1.1 Lower Meghna Estuary Nutrient Budget

A gap filling research work was undertaken to determine the nutrient flow status of the lower Meghna estuary, which is a combined flow of the Ganges and Brahmaputra, two of the major rivers in South Asia, and many other rivers. Three sampling rounds were chosen to cover an annual cycle; Pre-monsoon, monsoon and Post-monsoon. These samplings for all three periods were completed by the middle of January 2002. Water samples were drawn from surface waters and from a depth of 3 m for the determination of different physico-chemical parameters including nutrients from five selected stations of the lower Meghna river-estuary using a mechanised vessel. Some of the parameters were recorded in situ, and samples for determination of nutrients were frozen for analyses in the laboratory of the Institute of Marine Sciences on the following day.

The study of water, nutrient and salt transport through the lower Meghna estuary was continued in 2002. Although, vastness and complexity of the estuary made it almost impossible to sample each and every creek and channel, an attempt was made to fit a single layer simple box model to study the budget of these materials in the lower reaches of the river estuary. Although some of the past works aggregated in the above document say about micronutrients in the study area, but these were not useful for material flux study especially in the line with fitting the results to any flux or transport model. Therefore, gap-filling studies were undertaken to fill this gap. Results of this study based on field sampling and analyses, were described in a paper titled: “Water, salt and nutrient flux through the lower Meghna River-estuary, Bangladesh” presented at the 2002 Regional Workshop, and the paper is reproduced in Appendix IV.

Fig. 1. Study sites in Bangladesh

6.1.2 Karnaphuli Estuary Nutrient Budget

Another gap-filling study was carried out on Karnaphuli River, which originates in the Lusai hills of Assam, India and empties into the Bay of Bengal through the south-eastern part of Bangladesh. In the estuarine reaches it is receiving untreated municipal and industrial wastes from Chittagong City and other types of pollutants from harbour and other activities. The current research examined the state of the major Nitrogen and Phosphorus species of nutrients in the lower reaches of the river heavily stressed by human activities. LOICZ recommended methodology was adopted to budget these nutrients and other materials. The model revealed that the estuary is a hetero-trophic and denitrifying ecosystem. A paper titled “Material flux through the Karnafully River, Bangladesh” describing nutrient budgets in the study area was presented at the 2002 Regional Workshop. The paper is reproduced in Appendix IV also.

6.1.3 Other Gap-Filling Studies

Some extra research studies were carried out by six postgraduate research students of the Institute of Marine Sciences, University of Chittagong making use of, and sharing the field work facilities established for the present study. They drew samples of plankton, periphyton and benthos from the selected sites during the regular sampling cruises through the Karnaphuli river. It is an important river of Bangladesh, the city of Chittagong is located on its right bank which is greatly influenced by excessive human activity.

Abstracts of these dissertations are given in Appendix V under the heading: "Abstracts of by-product research works of Bangladesh Chapter, APN 2002-05".

6.2 India

6.2.1 Secondary Data Compilation

Data was collected on the pollution potential of different industries in coastal states of India. Details of different large and medium industries in the coastal states of India within 25 km inland form the shoreline were obtained, including industry-wise particulars like status of water abstraction/use, waste water and solid waste generation, effluent treatment and disposal system, etc. Data was collected on water supply and waste water collection, treatment and disposal in Class II towns in India for each major river basin, non-basin coastal areas, and non-basin non-coastal areas.

Data on nutrients and particulate matter collected from various estuaries in India; Narmada, Tapi, Mandovi, Zuari, Mahanadi and Ganga Basin in West Bengal, were compiled and analysed to evaluate the fluxes of these materials to the coastal zone. These were described in the Country Paper presented at the 2002 Regional Workshop, which is published in the Workshop Proceedings.

6.2.2 Budget Calculations

Under Gap-Filling Studies, two nutrient budgets were calculated, one for the Tapi Estuary, and the other for the Muvattupuzha Estuary. Data collected during an earlier study on nutrients, waste discharges, ground water and other related physical and environmental parameters from the Tapi Estuary Basin were analysed to prepare the Biogeochemical Budgets for the Tapi Estuary. Data collected at the Tapi Estuary were:

- Mouth of the estuary: average values (1984-1999) for water temperature, salinity, suspended solids, pH, dissolved oxygen, BOD, nitrate-N, nitrite-N, Ammonia-N, Phosphate-P.

- Data on water temperature, salinity, suspended solids, pH, dissolved oxygen, BOD, nitrate-N, nitrite-N, Ammonia-N and Phosphate-P at 5 stations in the estuary during Nov.'83; April-May'84; Jan.'85; Jan.'90; Feb.'92; April'95 and April'99

- Normal rainfall in Tapi river basin

- Peak flood river discharge during 1968-1983.

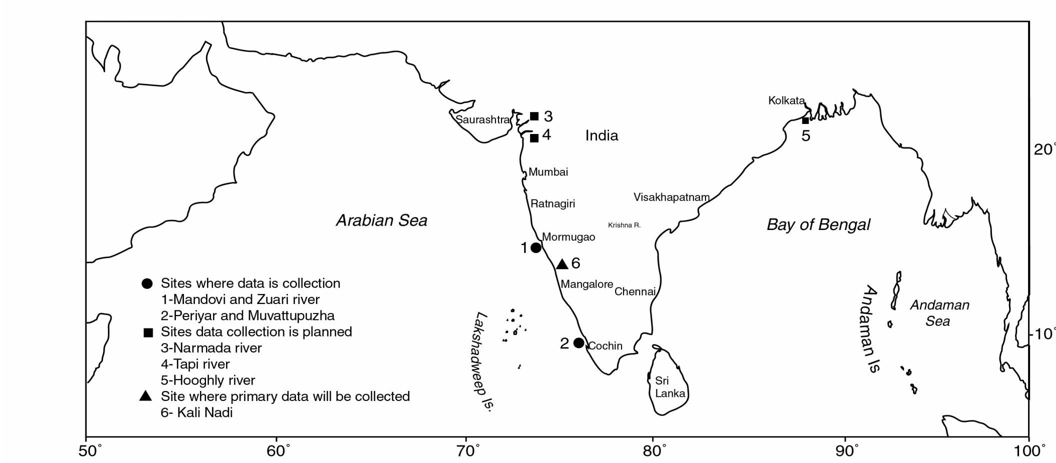

Fig. 2. Study sites in India

Taking into consideration the various comments and suggestions made by Dr. Laura David, on the paper 'Biogeochemical Budgets of Tapi" during its presentation at the 2002 Regional Workshop, the above budget calculations were revised by including the freshwater fluxes from other sources, like irrigation, industrial and domestic wastes and others, and their respective pollutants load. As per the suggestions, the estuary was split into two boxes based on salinity gradient. The revised version of "Biogeochemical Budgets of Tapi Estuary" is given in Appendix IV to this report.

Data on temperature, precipitation, catchment area, river flow, freshwater inputs and pollutants load of wastes from other sources, were collected at the Muvattupuzha River Estuary. Surface runoff into the Muvattupuzha Estuary during monsoon season was calculated utilizing the monthly average temperature and rainfall data in this area, using the method described in website:
http://data.ecology.su.se/MNODE/Methods/runoff.htm.

Utilizing the data collected, biogeochemical budgets for the Muvattupuzha Estuary were calculated for 3 seasons (pre-monsoon, monsoon and post-monsoon) – These budgets are given in Appendix IV to this report.

6.3 Nepal

6.3.1 Sediment Monitoring Programme

The first phase of the project introduced a simplified sediment sampling method at few hydrometric stations of the Department of Hydrology and Meteorology. The simplified method was used particularly to collect the monsoon season sediment flow with several samples as such data were very few for deriving results with a better confidence. The pilot experiment during the 2001 monsoon was carried out successfully. The field methods were re-evaluated with the standard methods at a hydrometric station on the

Narayani River at Narayanghat. Experiments were carried out to simplify the quantification of sediment discharge through simplified sampling and analysis procedure that need easily available and less expensive equipment and minimum level of training. The data obtained from the simplified procedure at two different sites (Narayanghat on the Narayani, and Betrawati on the Trishuli) in Nepal were compared with the standard methods. These were described in a poster presentation made at the Regional Workshop. The full paper on the monitoring programme is given in Appendix VI.

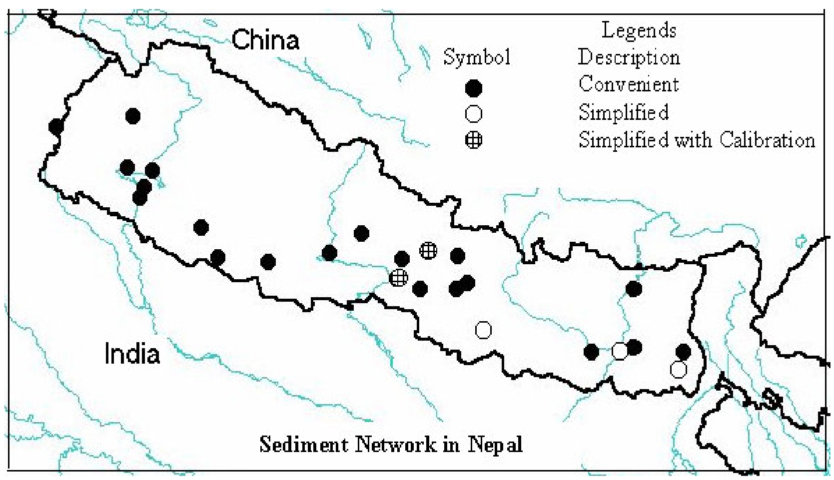

Fig. 3. Sediment Monitoring Network in Nepal

6.3.2 Regional Sediment Flux Study

Work was undertaken to study the sediment fluxes to coastal zone in South Asia for the areas lacking sediment transport information, using statistical modelling approach. Regression analyses were carried out with sediment yield as a dependent variable and basin area, precipitation, river discharge, river length, average elevation of the basin, elevation difference within the basin, and basin slope as a predictors. The analyses were carried out using linear model with linear and logarithmic scales. The study area is bounded by the Kirtar and Suleiman range in the west, the Hindu Kush, Karrakoram, and Nyenchentanglha mountain ranges in the north, mountains lying at the Thai-Myanmar border in the east and the Indian Ocean in the south. The study was further extended in the third year to assess the total nutrient load into the rivers flowing from the South Asian countries and discharging into the Arabian sea and the Bay of Bengal, based on available published literature and reports.

Regarding the human activities, several critical issues were realized that could influence the pattern of sediment flux. Several studies were found that could relate human activities to sediment movement at micro-catchments or at plot level. Attempts to quantify such impacts for large basins did not yield noticeable conclusion that could be stated with high degree of confidence; however, the impact of reservoir construction on sediment transport was distinctly clear. Such impacts were found highly significant on central and south Indian rivers. Excluding the Indus, the impacts of reservoir construction on ocean ward sediment flux was not found to be significant in the Himalayan region, as there were only few dams on the tributaries of the Ganga and Brahmaputra rivers. The preliminary findings of these studies were presented at the 2002 Regional Workshop, which was published in its Proceedings. The full paper describing this work is given in Appendix VI, along with its data base.

6.4 Pakistan

6.4.1 Collection of Primary Data

The NIO, Karachi has selected stations on the Khobar Creek, Gizri Creek (Left Bank Out Fall Drainage/Tidal Link Canal) and Kotri Barrage areas for collecting water, sediment samples and physical data as per the requirement of LOICZ model. Sampling was also carried out in the Karachi Harbour area It is envisaged that the data collected from these sites would help us in determining the sediment and biogeochemical budget of the Indus River and would also help in deriving a input-output model for the Khobar Creek.

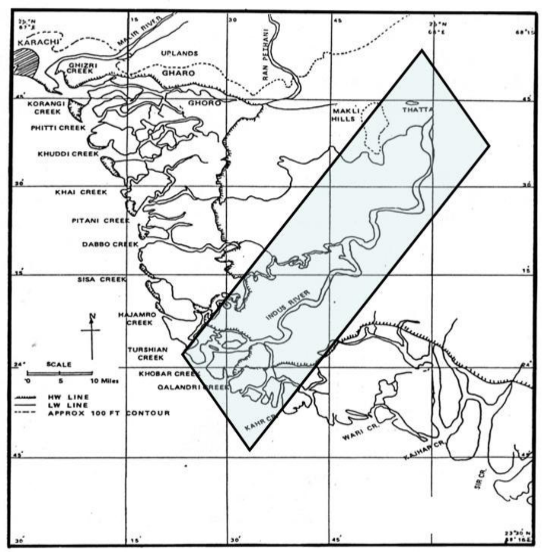

Fig. 4. Study Area in the Indus Estuary in Pakistan

The field trip to Khobar Creek was carried out in the first week of November 2001. A 40 km long stretch in the creek was surveyed and sampled. The boat could not go further upstream mainly due to shallow depths and fishing nets. Water and sediment samples were taken along the surveyed area. The samples were analysed for their chemical and sedimentalogical composition. Kotri Barrage, about 100 km upstream from the Khobar Creek was surveyed and sampled for comparison and nutrient fluxes.

6.4.2 Nutrient Budgets and Sediment Study

In the second year, the study was concentrated on the Khobar Creek, which is presently the only creek that carries the fresh water of Indus River into the Arabian Sea. An intensive study, comprising of current metering, echo-sounding, water and sediment sampling was undertaken down stream Kotri Barrage to Khobar Creek to quantify sediment and biogeochemical budgets. Sampling of water and sediment was also carried out from all the barrages and head works on the Indus River. The preliminary findings of these studies were presented at the 2002 Regional workshop and are published in its Proceedings.

On the basis of physical characteristics it can be classified as partially-mixed coastal plain estuary. Hydrograhical and hydrochemical characteristics of the river exhibit seasonal variability. Budgets for the estuary were calculated for two seasons: wet season (July - August) and dry season (November-December). For each season, budgets for water and salinity, nitrogen and phosphate were determined. Further sedimentation on the riverbed and current flows were also studied. These budgets are described in a paper appearing in Appendix IV to this report.

The southern and southwestern parts of Pakistan had been most affected by floods due to excessive monsoon rains during the last two weeks in July and the first week of August in 2003. The team in Pakistan gave special attention to this area to document the impact of these rains and floods on the sediment and nutrient fluxes as well as on socio-economy of the area. Sediment and water samples were collected from the most affected areas such as Badin and Thatta districts as a supplementary work to cover the objectives of the APN Project. The data collected are still being analysed and the results will be communicated through the web in due course.

Several papers were presented at international meetings based on work carried out under gap-filling studies. Abstracts of papers presented on these studies at the 32nd International Geological Congress held in Florence are given in Appendix VII.

6.5 Sri Lanka

Several gap-filling studies including nutrient budget calculations were undertaken during the project period of 2001 - 2004. First, the nutrient budget calculations are described and next the other gap-filling studies. It was possible to "piggy back" the studies and data collection required for LOICZ type budgeting on to existing studies by the provision of a relatively modest amount of supplementary funding. The study of the Negombo Lagoon was a good example – where the project only funded the water quality analysis. Most of the expenses related to transport and mobilization were avoided as the sample collection was conducted at the same time when field measurements aimed at collecting data for a hydrodynamic model for a component of the Coastal Resources Management Project was being carried out on a separate programme.

The result of the additional funding from the APN project was a set of water quality measurements *collected at the same time* as the hydrodynamic measurements. The existence of simultaneous complementary data increases the value of both the hydrodynamic and water quality data sets immensely.

6.5.1 An Assessment of Nutrient Budgets of Lunawa Lagoon, Sri Lanka

Under Gap-Filling Studies, the biogeochemical budget calculations on Lunawa Lagoon were carried out. Lunawa lagoon is a shallow coastal body of water located on the west coast of Sri Lanka, in a highly populated and industrialised area. It has a rather elongated shape, and the water surface area is approximately 20 ha and the perimeter is around 4.5 km.

The study at Lunawa lagoon describes the application of LOICZ budgetary model to predict the exchange of dissolved inorganic N (nitrate, nitrite and ammonium) and P (phosphate) between the lagoon and the adjacent ocean, carried out with the available data. It has been realized that some critical data is missing, especially in the case of Nutrients and other non-conservative components. However, as a first attempt, it has provided sufficient understanding of the system.

The results of the calculations were presented at the 2002 Regional Workshop and the complete paper is given in Appendix IV.

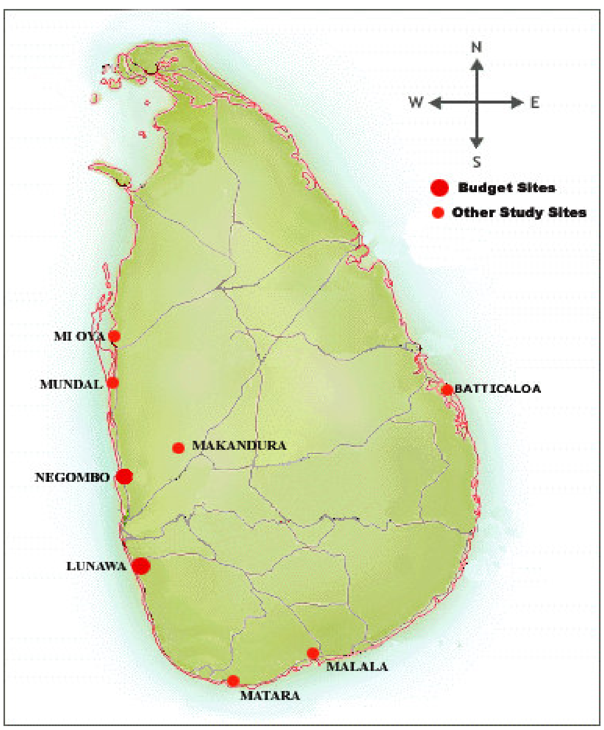

Fig. 5. Study Sites in Sri Lanka

6.5.2 Study of Nutrient and Carbon Budgets in Negombo Lagoon

The Negombo Lagoon ($7^0$4'-$7^0$12' N: $79^0$47'- $79^0$51' E) is situated in the west coast of Sri Lanka. The estuary receives water from Attanagalu Oya (Ja-Ela and Dandugam Oya) drainage basin and performs a dominant morphological feature of the watershed. The brackish water mass is 32.39 km^2 with an average depth of 1m and considered to be the estuarine part of the contiguous wetland system of the Muthurajawela Marsh Negombo Lagoon. The main fresh water source, Attanagalu Oya empties at Ja-Ela and Dandugam Oya at the southern tip of the estuary. In addition the Hamilton canal is the connecting watercourse of the Kelani estuary and the Negombo Lagoon running parallel to the west coast from the north to the south along the Muthurajawela Marsh.

The Department of Civil Engineering of the University of Moratuwa, who were carrying out another study to improve the water flow of the Negombo Lagoon, requested supplementary funds from the APN project to collect data on water quality during this field measurement program. Samples for water quality testing were collected from 10 locations from lagoon mouth, lagoon and the three main waterways feeding the lagoon. The water samples collected from the 10 locations for a dry and a wet period from 02 January 2003 to 10 February 2003 were tested for their following physical, microbiological, chemical, and biological parameters:

- pH, Temperature, Conductivity, and Salinity
- TDS, BOD5, and COD
- Total N, Total P, Nitrate, Phosphate, and Ammonia
- Coliforms, Zooplankton Concentrations, Chlorophyll and Algal Biomasses.

These data were used to generate budgets for the Negombo Estuary based on LOICZ one Box one Layer, two box one layer and three box one-layer models. The period starting from February to September (2002) is considered as the Dry season and the period from October to January (2002/2003) is considered as the Wet season. The budgets obtained are described in a paper titled "Negombo Estuarine System: Exploratory Steady-State CNP Fluxes", given in Appendix IV.

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6.5.3 Study of Nutrient Runoff from Rainfed and Irrigated Paddy Lands

High nutrient fluxes were observed in some of the rivers in Sri Lanka. A preliminary assessment showed that runoff from fertilizer was the only possible source of these nutrients. Therefore a study of the nutrient runoff from rain-fed paddy cultivation was commenced during 2001/2002 project year. Detailed measurements of the rainfall, runoff and nutrient concentrations were made in a small (approximately 200 ha with 70 ha of paddy) catchment. The study showed that the nutrient runoff, particularly nitrogen runoff, from rain-fed paddy could be extremely high if the pattern of rainfall was unfavourable. The study also showed that farmers were using Urea well in excess of the recommendations, possibly in response to a preferential fertilizer subsidy for Urea. The results of this study were presented at the Regional Workshop.

However, as most paddy cultivation in Sri Lanka is carried out under irrigated conditions, it was decided to repeat the study for irrigated paddy as well. The study was carried out with assistance from the Rice Research and Development Institute (RRDI) of the Department of Agriculture. The National Science Foundation provided funding of approximately US $ 3,400 for the purchase of a spectrophotometer for water quality analysis for the study. The Project provided funds for consumables, stipends of research and field assistants and transport.

The study area was a small catchment, about 100 ha in extent, with about 40 ha of paddy cultivation located close to RRDI at Bathalagoda. The runoff of fertilizer was quantified by detailed measurements of stream flow and water quality in the stream draining the Maha Oya catchment. The water quality parameters measured were NO_3^- N, NH_3-N and PO_4-P. Some measurements of Total-N and Total-P were also made. Detailed measurements of the rainfall and the variation in the levels of six wells in the catchment were made in order to understand the hydrology of the catchment. All details of the cultivation, including dates and quantities of fertilizer application, were obtained by a weekly questionnaire survey of the farmers.

Furthermore, detailed measurements of the quantity and nutrient content of the water supplied to and draining from this catchment were carried out over the cultivation season extending from April to August 2003. The fertilizer application to the fields was quantified by means of a weekly survey of the approximately 120 farmers engaged in cultivation.

Due to the severe drought that prevailed during the cultivation season, there was very little uncontrolled runoff from the fields. A preliminary analysis of the data shows that nutrient losses in the runoff were less than 10% of the amount applied as fertilizer. The quantity of fertilizer used and the timing of the application was more in conformity with the recommended guidelines than was the case for the rain-fed paddy cultivation.

Due to the below-average rainfall experienced during the study period it was decided to continue the study over the cultivation season extending from October 2003 to January 2004 within the same catchment. However, the rainfall experienced during this season was also significantly below average. While very low nutrient runoff was recorded, these results were not representative. The results of this phase of the study will be posted in the Webmail once the current analysis is completed.

6.5.4 Human Impact on Wetland Ecosystems: A Case Study at the Mundel Lake and Its Environs

A new gap-filing study was introduced in Sri Lanka to quantify the human activities in a selected coastal system in the environments of coastal lake and its surroundings. The site selected was Mundal lake in the North Western coast. Initial assessment of the area indicated that the quality of physical, social and economic environments of the lake and its surroundings have declined due to degradation of the lake and the other wetlands of its surroundings. In the absence of proper management and legal framework, this declining has aggravated further. With the objective to present a broad overview of the current human impacts in respect of the Mundal Lake and its surroundings, this study highlights the main impacts associated issues on physical, faunal and floral characteristics of the area. The final conclusions would also reflect the views and opinions of the residents on these impacts and issues. The findings of these studies were presented at the 2002 Regional Workshop and the paper was published in its Proceedings.

6.5.5 Study of Hydrodynamics and Water Quality of the Batticaloa Lagoon

The Batticaloa Lagoon, covering a total area of about 115 km^2, is the largest lagoon on the East coast of Sri Lanka and the third largest in the country. The environment of the lagoon has deteriorated significantly over the last two decades due to the impacts of pollution from sewage, solid waste, agricultural runoff and prawn farms.

While detailed studies of the lagoon environment have been severely restricted by the civil conflict in Sri Lanka, which continued for decades in the North and East up to recent times, some significant basic studies have been carried out by the Eastern University of Sri Lanka (EUSL) despite significant constraints in funding, equipment and expertise. The coast-to-coast distance from Colombo makes it difficult for other institutions to carry out detailed sampling etc. due to the high mobilization costs.

This study was therefore conceived as a combination of gap-filling studies and capacity building. The participating agencies were the Oceanography and Environmental Science Divisions of the National Aquatic Resources Research and Development Agency (NARA), the EUSL, the Open University of Sri Lanka (OUSL) and the Industrial Technology Institute (ITI). The project provided funds for consumables, travelling and subsistence. The study will be described here while the capacity building aspects will be described in the next section.

The study commenced in early October, 2003 at the end of the dry season and was limited to the northern portion of the lagoon and the main entrance channel – a total area of 55 km^2. The Physical Oceanography Division of NARA carried out the following tasks.

- i) A bathymetric survey of the area using an echo-sounder
- ii) Measurement of the horizontal variation of surface salinity and temperature using a towed instrument during the bathymetric survey
- iii) Measurement of the temperature and salinity at 10 minute intervals for three months at two locations – entrance channel and top end of the lagoon – using fixed instruments
- iv) Continuous measurement of the water level in the entrance channel
- v) Measurement of the surface and bottom salinity and temperature at 9 selected locations twice in two days

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Water quality samples were collected at the 9 locations mentioned above during the field measurement campaign. These were analysed by the Department of Chemistry of EUSL, with supervision and training provided by the Environmental Science Division

of NARA and supplementary analyses by the OU and ITI. Samples were taken from the same locations three more times over the next three months after the commencement of the rainy season. Details of the data collection and the results of a preliminary analysis of the hydrodynamic data are presented in a paper "Physical processes and water quality of Batticaloa Lagoon." appearing in Appendix VIII.

The results of this initial analysis have led NARA to initiate a long-term study of this portion of the lagoon throughout 2004. The scope of the study is to be broadened to include water quality parameters such as Dissolved Oxygen, Chlorophyll, Zooplankton etc. It is also planned to incorporate the measurements into a mathematical model of the lagoon. A scientist from NARA has already been trained in the mathematical modelling of lagoons at the University of Western Australia (see Section below). The results of the water quality analysis will be combined with the results of the hydrodynamic studies at the next stage, to develop nutrient budgets for this portion of the Batticaloa Lagoon.

6.5.7 Three-dimensional Hydrodynamic Modelling of Sri Lankan Estuaries and Lagoons using the Estuary Lake Computer Model (ELCOM)

Hydrodynamic numerical models are not only used to describe the present physical environment in coastal water bodies, but also to predict changes in hydrodynamics resulting from future changes in bathymetry, freshwater inputs and climate. The models are used as an aid in developing management strategies to increase water exchange by deepening of inlets or re-opening of sandbars. At best, models may also lead to an advance in the conceptual understanding of the various processes involved in the dynamics.

Under the Capacity Building component of the Project, a Physical Oceanographer from National Aquatic Resources Research and Development Agency (NARA) was sent for a training programme on three-dimensional hydrodynamic modelling of Estuaries at the Centre for Water Research (CWR), University of Western Australia, Perth, Australia from 10 November to 7 December 2003. Prof. Charith Pattiaratchi of CWR has provided this training using the Estuary Lake Computer Model (ELCOM) developed at the CWR. During training, ELCOM was applied in to several Sri Lanka Lagoons (Putalam, Negombo and Jaffna Lagoons). The report summarising the results of numerical modelling using ELCOM to above Sri Lanka Lagoons is found in Appendix VIII. A copy of the ELCOM software is available at NARA for use by other researchers.

7. Capacity Building Programmes

The participating institutions were requested to provide opportunities for capacity building utilizing the project funds in carrying out their proposed work plans. All the countries reported such activities. Inquiries were also made from these institutions for their need to train young coastal scientists at our project partner institution in Australia, but received only a negative response. The Capacity Building activities undertaken by individual countries are described below.

7.1 Bangladesh

Six postgraduate research students of the Institute of Marine Sciences, University of Chittagong were assisted by the Project to collect data from the estuaries during field trips arranged under the Project. They submitted their M.Sc. dissertations titled:

- An assessment of Material Budget along with some Physico-chemical parameters of the Lower Meghna River-estuary, Bangladesh.
- A comparative study on plankton and benthos of the Meghna River-estuary during monsoon and postmonsoon.
- Macrozoobenthos of the Meghna River-estuarine bed with special reference to polychaete faunal biodiversity.
- Composition, distribution and abundance of Periphyton from different habitats and locations of the Karnafully River-estuary.
- Study of Zooplankton of the Karnafully River-estuary from the biodiversity and environmental points of view.
- Seasonal distribution of Phytoplankton in the Meghna River-estuary of Bangladesh with notes on biodiversity.

One of these students is continuing work towards a PhD degree. The abstracts of these six studies are given in Appendix V.

The project also supported the participation of two of Bangladesh post-graduate students at the 2002 Regional Workshop, as a capacity building exercise.

7.2 Nepal

A simplified set of equipment and procedures were developed during this project to conduct sediment experiments in a few selected stream-gauging sites in Nepal. This method has already been adopted by (DHM) in its regular sediment sampling and analysis programs leading to the publications of data. DHM is also organizing a training program this year to disseminate the results and train technicians in the revised sediment sampling technique. The procedure and preliminary results of the experiment were also presented in a poster session at the 2002 Regional Workshop in Sri Lanka. The complete paper is given in the Appendix VI.

7.3 Pakistan

The following junior scientists were trained at the NIO, Karachi on both field work and data analysis related to the Project.

1. Mr. M. Danish, NIO Pakistan
2. Mr. M. Q. Memon, NIO Pakistan
3. Ms. S. Kehkashan, NIO Pakistan
4. Mr. M. Zafar, NIO, Pakistan

7.4 Sri Lanka

Project activities such as the gap-filling studies and the analysis of existing and new data to develop nutrient budgets etc. developed the capacity of all the participating institutions in aspects ranging from field data collection to water quality analysis to modelling. The activities carried out with support from the project have already been the basis of the three Masters' theses while more thesis work is planned. An opportunity was made available for one scientist to receive training overseas. These are described below.

7.4.1 Post-Graduate Studies.

The following studies formed theses for MSc degrees.

- Exploratory C, N and P Budgets for Negombo Lagoon - R N Mallawarachchi - M. Sc. in Environmental Engineering, University of Moratuwa – completed in 2003

- Runoff of Agro-chemicals from Rain-fed Paddy Cultivation – W. N. C. Priyadarshini - M.Sc. in Environmental Science, University of Colombo – to be submitted in April 2004

- Strategies for the improved management of the coastal zone of Sri Lanka - P. Dissanayake – M. Sc. in Environmental Management, University of Moratuwa - to be submitted in April 2004

It is expected that at least one more M.Sc. thesis will be submitted based on the measurements carried out in the Batticaloa Lagoon.

7.4.2 Training of Dr. E. M. S. Wijeratne in Three-dimensional Hydrodynamic Modelling

The Centre for Water Research (CWR) of the University of Western Australia is a collaborating institution for this project. Dr. Charitha Pattiaratchi of CWR offered to host and train a scientist in three-dimensional hydrodynamic modelling as part of this project. The lack of regional expertise in such modelling had been identified at the Training Workshop in Bio-geochemical Budgeting held in Colombo in September, 2000 with funding from APN and LOICZ.

While this opportunity was offered to scientists from all of the participating institutions, only the Sri Lankan group was able to allocate the funds necessary for travelling and subsistence and avail themselves of this offer. Dr. E. M. S. Wijeratne of the

Oceanography Division of NARA was selected for the training based on his past work on the two-dimensional modelling of estuarine hydrodynamics.

The training of Dr. Wijeratne in three-dimensional modelling fits in very well with the program of estuarine research that has been carried out by NARA over the past decade or so. The program originated with field studies of estuarine water exchange and circulation and the parallel development of models. These models increased in sophistication from simple box models through one- to two-dimensional models.

Dr. Wijeratne spent four weeks at CWR from November to December, 2003. The project provided funds for airfare, accommodation, meals and incidental expenses while CWR provided in-kind contributions of training, computer facilities, software, office space etc. Dr. Wijeratne was trained in the use of the model and then applied the model to several Sri Lankan estuaries using data that had been collected by NARA over the past several years.

The key outcomes of the training programmes were identified by Dr. Wijeratne as

i) Training on 3-D hydrodynamic modelling, particularly handling of Estuary Lake Computer Model (ELCOM)

ii) Provision ELCOM model to NARA under a license agreement

iii) Establishment of ELCOM in the Oceanography Division, which can be used by researchers who are working on estuaries and lagoons in Sri Lanka and the region

The results of the modelling of Sri Lankan estuaries carried out by Dr. Wijeratne are given in Appendix VIII.

It is noteworthy that the first Workshop in 1999 was held on the topic Estuarine Modelling and Coasatl Zone Management, and that it has been possible to achive its objectives during the current project.

7.4.3 Training of staff of the Eastern University in Water Quality Analysis

As described in a previous section, the Eastern University is the only research institution located on the East Coast and has therefore a major role to play in future research into and monitoring of the coastal environment in the East. However, the capacity to carry out such work is limited by the lack of trained personnel and laboratory consumables.

Therefore, development of the capacity of the Department of Chemistry of the Eastern University to carry out water quality analysis was included as one of the objectives of the study of the Batticaloa Lagoon. The staff members of the department were involved in the field measurements and trained to use a hand-held GPS to repeat water sample collection at the same location.

All the consumables required for the water quality analysis were purchased with funds from the Project. Staff of the Environmental Science Division of NARA visited Batticaloa during the field measurement campaign and supervised the water quality analysis. Subsequently, two Assistant Lecturers of the Department travelled to Colombo and spent two days at NARA undergoing further training in water quality analysis.

Since these training activities the researchers and laboratory staff of the department have repeated the water sample collection and analysis three times on their own, as described above.

8. Seminars and Workshops

Several national, regional and international meetings of coastal scientists were organized under Project activities, both for scoping and for the purpose of disseminating information. These are summarised below.

8.1 India

The Project provided partial funding to hold an **International Workshop on 'Marine Pollution and Eco-toxicology, organized by NIO, Goa, in February 2004.** It was felt that the topics to be discussed during the Workshop were relevant to the objectives of the Project, and that the proposed Workshop would give the participating coastal scientists an opportunity to establish a network among themselves.

The aim of the Workshop is to bring together the environmental scientists, ecotoxicologists, educationists, policymakers and students on a common platform to discuss and highlight recent advances in marine pollution and eco-toxicology and their relevance to developing countries. Among the topics discussed at the Workshop were:

- Marine pollution monitoring
- Modelling of estuarine and coastal pollution
- Coastal zone management
- Biogeochemical cycling

The titles of some of the relevant abstracts of papers presented at the Workshop are given below and their abstracts reproduced in Appendix IX.

- Integrated Coastal and Marine Area Management (ICMAM) Plan for Goa - An Overview by S.N. de Sousa

- Marine Water Quality Assessment For Mumbai West Coast by S.S.Dhage, A.A.Chandorkar, Rakesh Kumar, A. Srivastava, and I. Gupta

- Studies on the complexation of humic substances with metals and their effects on the bioavailability and toxicity of metals in the Mangrove environment of Sundarban, India. by T. K. Jana, H. Ghatak, S. K. Mukhopadhyay, H. Biswas, T. K. De and S. Sen.

- Methane dynamics in the Hooghly estuary, Northeast coast of the Bay of Bengal, India. by S. K. Mukhopadhyay and T. K. Jana

- The Integration of Tools and Data Bases for Oceanographic Applications in a GIS Environment by Suryanarayana and Amit V.S.

- Model for estimating Index of Environmental Degradation of Water Quality of Coastal Sea by Goutam Kumar Sen and Durba Chakraborty

- BOD-DO Modeling for water quality analysis around a waste-water outfall off Kochi, southwest coast of India by M. T. Babu, V. Kesava Das and P.Vethamony

- Application of Remote Sensing Technique for formulation of Integrated Coastal Zone Management (ICZM) Plan of West Bengal, India by S. Bhattacharyya*, Kakoli Sensarma and Rajib Das

8.3 Nepal

The Department of Hydrology and Meteorology (DHM), Kathmandu, the Department of Water Induced Disaster Prevention (DWIDP), Lalitpur and Hydro Lab Pvt. Ltd.(HL), Lalitpur jointly organized a **Technical Brainstorming Workshop on River Sedimentation - Needs and Issues, on 24-25 January 2003**, as a part of the Project activity. The workshop highlighted the need for regular monitoring of sediment flow, not only for coastal related studies but also for preventing sediment-related disasters within the country. The detailed report on the workshop is given in Appendix X.

8.4 Pakistan

NIO scientists disseminated the results and findings of the project at various national, governmental and non-governmental, fora. Some of the worth mentioning events were: 7th National Symposium on Analytical and Environmental Chemistry, Jamshoro 2003; and World Bank's Workshop on spatial Information Analysis for sustainable management of Indus Basin in Pakistan, Islamabad May 2003.

8.5 Sri Lanka

8.5.1 Seminar on "Material Fluxes to the Coastal Zone: Synthesis of Sri Lankan Studies and Plans for the Future", 13th September 2002, 8.30 am - 3.30 pm

A one-day National seminar/workshop on "Material Fluxes to the Coastal Zone: Synthesis of Sri Lankan Studies and Plans for the Future" was organized to complement the second year project activities in Sri Lanka. The objectives of the seminar were to bring together various stakeholders including researchers, managers, project administrators in studies of coastal fluxes and their impacts, to increase awareness among the participants of past, on-going and planned studies and projects, to improve coordination between these projects so that maximum benefits are achieved, to increase the awareness of relevant regional and global scientific programs, to identify priorities for research from both a local resource management and a global science perspective, and to discuss possible multi-disciplinary and regional projects for the future, with particular reference to the coastal areas of the north and east of Sri Lanka.

The seminar consisted of invited presentations by selected researchers, group discussions and panel discussions. Twenty seven stakeholders involved in research in the relevant fields, in environmental and resource management who will use the results of the research, and in administering projects and other sources of funding for such studies. This activity helped to identify various gaps in related subjects and issue that should be discussed during the Regional Workshop.

The detailed programme of the seminar and the list of participants are given in Appendix XI

8.5.2 Regional Workshop on "Assessment of Material Fluxes to Coastal Zone in South Asia and their Impacts", 08 -11 December 2002, Negombo, Sri Lanka

The Sri Lanka Association for the Advancement of Science (SLAAS) hosted the above 3-day Regional Workshop during 08 -11 December, 2002, in Negombo, Sri Lanka. This was the main activity of the Project in 2002. The objectives of this workshop were to:

(1) Review and analyze the findings of the studies,
(2) Compare results and present the biogeochemical budgets constructed for different sites, based on LOICZ methodologies and,
(3) Discuss issues related to - the origins of nutrient, sediment and carbon (referred to as materials); quantification of material fluxes to the coastal zone; and, environmental and socio-economic impacts, particularly their relationship to human dimension aspects.

A total of 48 persons which consisted of 6 overseas resource persons, 2 national resource persons, 17 overseas participants from the Region, 15 national participants and 8 observers and invited guest speakers. Twenty six (26) technical papers were presented on the first day of the workshop, which also included 4 poster presentations and a key-note address by Steven Goodbread of the Marine Sciences Research Centre, State University of New York, Stony Brook. The day-two was mainly focused on the integration of research and management in the region. The country leaders presented their country syntheses initially, which was followed by presentations and discussions on Sri Lankan coastal zone management programmes and on other regional programmes. The day ended with a presentation on LOICZ Synthesis and Future Plans given by Chris Crossland of LOICZ followed by a field visit to the nearby Negombo Lagoon.

The final day of the programme started with an address on the tidal exchanges of lagoons by Charith Pattiaratchi from the University of Western Australia. As part of an interactive session, Laura David made a brief introduction on flux calculations and budgets. The participants who already had sufficient amount of data for budgeting grouped together to calculate and improve their fluxes using LOICZ model, using the computer facilities and software made available at the venue, under the guidance of Laura David. The others grouped together to rank impacts and priority issues. Finally, the LOICZ representative proposed the possible method of collaboration with LOICZ to publish some selected papers presented during the workshop.

The abstracts of papers presented at the Workshop are given in Appendix III to this report. The full papers are published as Proceedings of the Workshop separately. The Programme, List of Participants and a Report of the workshop are given in Appendix XII to this report.

9. Participation at International Conferences and Scientific Meetings

Members of the study teams presented their project findings at several international meetings, and these are described below.

9.1 Pakistan

NIO scientists participated in 5th Asian Marine Geology Conference, Bangkok January 2004; First International meeting of IGCP 475 and APN Mega-Deltas Ayutthaya, Thailand January 2004 and the 32nd International Geological Congress Florence 2004, where the findings of the studies undertaken under the project were presented. The following papers were presented at the 32nd International Geological Congress Florence 2004, and their abstracts are given in Appendix VII.

- "Recent Changes in the Coastal Evolution of the Indus River Delta and Impacts from Human Activities" by Inam Asif, Amjad Shahid, Danish Mohammed, Tabrez Ali Rashid, and Tabrez Syed Mohsin

- "Distribution of Clay Minerals and Trace Elements in the Indus River System" by Tabrez Ali, Inam Asif, Danish Mohammed, Rehman Shafiq, Haq Rehan, and Siddique Azher

- "Natural and man made stresses on the stability of Indus Deltaic Eco Region" by Inam Asif, T. M. Ali Khan, S. Amjad, M. Danish, A. R. Tabrez

9.2 Sri Lanka

9.2.1 Network for Environmental Assessment and Remediation, July 2003, Geneva

The project provided supplementary funding to enable Dr. P. N. Wikramanayake, Team Leader, Sri Lanka, to attend the international conference organized by the Network for Environmental Assessment and Remediation (NEAR) entitled "The impact of global environmental problems on continental and coastal marine waters" held in Geneva, Switzerland, in July, 2003. Dr. Wikramanayake presented a paper entitled "Nutrient Runoff from Rain-fed Paddy Cultivation" which was based on gap-filling studies carried out in 2001/2002 with project funding.

Dr. Wikramanayake also presented this paper at the World Water and Environment Conference of the Environmental and Water Resources Institute of the American Society of Civil Engineers (ASCE) held in Philadelphia, U.S.A. in June, 2003.

9.2.2 LOICZ Synthesis and Futures Meeting: Coastal Change and the Anthropocene, Miami, USA, 29 May - 1 June 2002.

Dr. P. N. Wikramanayake, Country Team Leader in Sri Lanka attended the LOICZ Synthesis and Futures Meeting: Coastal Change and the Anthropocene, held in Miami, USA, 29 May- 1 June 2002, with funds provided by the Project. His interaction at the meeting resulted his being nominated for the Scientific Steering Committee of LOICZ for 2004-05.

Dr Janaka Ratnasiri, Principal Investigator, too attended the meeting sponsored by LOICZ. Initial discussions regarding establishment of a Regional Node of LOICZ in Sri Lanka were made informally at this meeting.

10. Outcomes and Products

The tangible outcomes and products generated by each participating country are described below.

10.1 Bangladesh

- Network of coastal scientists and organizations (see Appendix I)
- Report on Literature survey on coastal studies done previously (see Appendix II)
- Country status report entitled "A review of research works on the water quality of the lotic, estuarine and marine environment in Bangladesh" (see Regional Workshop Proceedings)
- Two biogeochemical budget papers entitled (see Appendix IV),
    - "Water, salt and nutrient flux through the lower Meghna River-estuary, Bangladesh" and
    - "Material flux through the Karnafully River, Bangladesh."
- Six postgraduate research students of the IMS, University of Chittagong who had submitted dissertations for their MSc degrees. (see Section 7.1 for titles).

10.2 India

- Network of coastal scientists and organizations (see Appendix I)
- Country Report describing the fluxes of Sediment, Carbon and Nutrients to the coastal zone in India flowing into the estuaries: Narmada, Tapi, Mandovi, Zuari, Muvattupuzha, Mahanadi and Ganga (see Regional Workshop Proceedings).
- Two biogeochemical budget papers on (see Appendix IV)
  - Biogeochemical Budgets for Tapi Estuary
  - Biogeochemical Budgets for Muvattupuzha Estuary, Kerala, India
  - Report on the International Workshop on Pollution and Eco-toxicology.

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10.3 Nepal

- Network of coastal scientists and organizations (see Appendix I)
- Report on Literature survey on coastal studies done previously (see Appendix II)
- A database of sediment flux in South Asian rivers. (see Appendix VI)
- A group of persons trained in sediment measurements using low-cost technology (see Section 7.2 and Appendix VI).
- A model describing the expected Sediment Flux in South Asian rivers. (see Appendix VI).

10.4 Pakistan

- Network of coastal scientists and organizations (see Appendix I)
- Report on Literature survey on coastal studies done previously (see Appendix II)
- A group of persons trained in water quality analysis (see Section 7.4)
- Biogeochemical budget for Indus Estuary (see Appendix IV)

10.5 Sri Lanka

- Network of coastal scientists and organizations (see Appendix I)
- A web-site describing the activities undertaken under the project and progress reports of the project <www.nsf.ac.lk/slaas/cfweb>.
- A newsletter giving information of the activities undertaken by the Project.
- Report on literature survey and country synthesis on coastal studies done previously (see Appendix II)
- Two biogeochemical budget papers on Negombo Lagoon and Lunawa Lagoon (see Appendix IV)
- Several papers on gap-filling studies on water quality, fertilizer run–off, nutrient fluxes to coasts, and human impact on a coastal lagoon (see Workshop Proceedings)
- Several papers on further gap-filling studies on flow of water in Negombo Lagoon, Physical Processes and water quality of Batticaloa Lagoon (see Appendix VIII).

- A three-dimensional Hydrodynamic Modelling of Sri Lankan Estuaries and Lagoons developed by a Scientist trained under the Project at the University of Western Australia in the application of the Estuary Lake Computer Model (ELCOM) (see Section 7.5 and Appendix VIII)
- A group of academic staff and technicians at the Eastern University trained in water quality analysis (see Section 7.5)
- Closer collaboration, through personal visits, with partner institutions; Institute of Marine Sciences Research, Bangladesh; NIO, Goa; NIO, Karachi, Marine Sciences Research Centre, Stony Brook, USA)
- Three post-graduate theses by students who had submitted work based on gap-filling research carried out under the Project (see Section 7.5)
- The Proceedings of the Regional Workshop on Assessment of Material Fluxes to the Coastal Zone of South Asia and Their Impacts, held in December 2002 at Negombo, Sri Lanka
- Final Report of the 3-year Project on An Assessment of Nutrient, Sediment and Carbon Fluxes to the Coastal Zone in South Asia and their Relationship to Human Activities (APN 2001-20/2002-05).

11. Conclusions

The current project along with the two previous projects funded by START and APN, stretched over a period of 5 years from 1999 to 2004, followed the sequence of scoping, training and gap-filling studies on coastal fluxes. They strengthened the capacity of coastal scientists in South Asia to undertake estuarine studies and develop biogeochemical models in accordance with internationally accepted methodologies. Several such budget sites were developed and it is hoped that these will be further refined with the collection of additional data in the future.

The Project met the following APN objectives for funding:

- synthesis and analysis of existing research and new research which addresses knowledge gaps in key areas, and
- capacity building and networking.

The provision of funding for gap-filling research studies as one of the project activities was an important feature in the Project. The justification for including budgetary provision for these studies was that the data needed to carry out LOICZ-type budgeting was not available or inadequate.

It was further submitted that the collection of such data was not included in any on-going monitoring programs in most of the areas considered. The review and synthesis of existing data and studies carried out under the project has shown that this presumption was in fact correct. All the biogeochemical budgets that have been developed as part of this project have utilized data from the gap-filling studies. Very few would have been possible using existing data.

However, the project activities taken as a whole have also shown that the gap-filling studies have served a much larger purpose than to generate data. The gap-filling studies were found to be the "engine" that drove all the other project activities – such as networking, building partnerships and capacity building. All the participating institutions suffered from a lack of funds to meet operational expenses such as consumables and transport even though equipment and trained manpower were often available.

It is noteworthy that funding from this Project enabled countries lie Bangladesh to undertake first water quality measurements in the plume of the Meghna River, which carries global-scale sediments to the sea. It is important that the IMS be supported to continue these studies, which is capable of carrying out these measurements at a fraction of the cost that would have been incurred by any other agency.

Another aspect of the work carried out in almost all the countries that need special mention is that every attempt was made to supplement and enhance existing programs and studies, while pursuing studies under the project. This coordination ensures that the project funds yielded the maximum benefit, without any wasteful duplication.

It also needs to be emphasised that countries spend vast sums of money obtained either on loan from international/regional funding agencies or as foreign aid, on development work associated with coasts, including rehabilitation of eroded beaches, arresting of salt water intrusion into urban water supply intakes and implemention of integrated coastal zone management projects. It is recommended that a small percentage of these loans or grants be set apart for gathering and analysis of basic data on nutrient and sediment fluxes, which will become useful in the management and implemention of various coastal projects that are being undertaken by the respective governments.

12. Future Directions

While the activities related to synthesis of existing data and gap-filling studies have immediate results in the form of data and publications, the benefits of networking and capacity building will only be fully realized in the future. Future activities were discussed at the Regional Workshop but a detailed proposal for follow-up studies has not been developed yet. However, it is hoped to continue at least the networking activities in some way until new projects are developed.

Considering the significant contribution made by South Asian rivers to the global sediment load, the importance of continuing studies with more regular and accurate data gathering needs no special emphasis. The countries in the region are at present engaged in determining the off-shore sediment thickness within their territories enabling them to lodge their claims for exclusive rights for economic benefits. This emphasises the need for further studies to quantify the sediments flowing into the oceans from our countries.

One significant outcome of the study was the realization of the lack of an adequate set of accurate and reliable data on nutrient and sediment flux flowing down the rivers in the South Asian countries. While India and Nepal have set up a large number of sediment monitoring stations, the same cannot be said about the other countries. In Sri Lanka, except for some occasional set of measurements initiated by individual researchers, there is no regular institutional programme to collect even the sediment data regularly.

There is also the need to strengthen the existing programmes to improve the accuracy and frequency of data. In view of the importance of these data both on a local and a global scale, it is hoped that policy makers give priority to these programmes by allocating adequate funding. The multi-lateral and bi-lateral funding agencies too should take note and provide adequate financial and technical assistance to set up networks of monitoring-stations, and for the training of staff.

There is an immediate need for developing national policy guidelines for the exploitation of coastal and off-shore resources, which would take into account the impacts of global phenomena such as sea-level rise due to enhanced global warming, global tourism, urbanization concentrating on coastal zones etc. Our countries are vulnerable to adverse impacts of the anticipated accelerated sea level rise. Hence, the quantification of both the physical and economic impacts and identification of adaptation strategies need to be addressed. It is essential to build capacity among local coastal scientists to undertake studies in these areas, possibly with funding from multi-lateral and bi-lateral agencies.

At the Regional Workshop held in December 2002 in Sri Lanka, it was decided that a proposal be prepared for submission to a funding agency seeking funds to strengthen the institutional and human resource capacity in the South Asian countries to undertake further studies on nutrient and sediment fluxes in South Asia, and to assess their impacts on socio-economic sectors as well as the impacts of human interventions on coastal fluxes, including land use changes and agricultural practices.

It may be noted that the 9th Conference of Parties to the UN Framework Convention on Climate Change held in December 2003, decided that a Special Climate Change Fund be established to support the implementation of adaptation activities in developing countries in sectors vulnerable to adverse impacts of climate change including coastal zones, and also to support technology transfer activities and capacity building including institutional capacity (Decision 5/CP9).

It would therefore be possible to submit a suitable regional proposal as decided at the Regional workshop to the implementing entity of the proposed special climate change fund seeking assistance for undertaking coastal studies by countries in South Asia. Thus the next step is to prepare a suitable proposal as a follow up to the activities undertaken under the current Project, linking it to coastal zone management activities required for identifying and implementing adaptation measures.

The best way to proceed in this direction is through a regional body such as the proposed Regional Node of LOICZ for the South Asian region. The regionalization of LOICZ activities through such nodes is a major goal of the second 10 years of the project. It has been proposed that the South Asian Node be established in Sri Lanka, hosted by a local institution. The node would extend the network and develop regional proposals on areas relevant to LOICZ for external funding. The successful co-ordination by Sri Lanka of studies carried out on coastal studies in South Asia during the past 5 years, more than justify the location of a LOICZ Node in Sri Lanka.

It is hoped that the activities undertaken by the Project could be continued and new activities undertaken with greater vigour under the proposed LOICZ Node with the active participation of all coastal scientists and organizations involved in coastal zone studies in South Asia.

PREFACE

The current project is the main activity of a five-year programme on coastal nutrient flux studies undertaken by the Sri Lanka National Committee of IGBP, commencing in 1998. The first activity was the Regional Workshop on Estuarine Modelling and Coastal Zone Management that was held in April 1999 in Colombo, in association with LOICZ and funded by START.

Consequent to a recommendation made by the workshop that coastal scientists in the region need training on biogeochemical budgeting and socio-economic modelling, the Regional Training Workshop on Biogeochemical Budgeting and Socio-Economic Modelling was held in September 2000 in Colombo, in association with LOICZ and funded by APN, START and LOICZ. The workshop concluded that it was necessary to collect and synthesize existing information and undertake small-scale local studies to fill in critical gaps in knowledge.

Subsequently, a proposal was submitted to APN, with Australia, Bangladesh, India, Nepal, Pakistan, Sri Lanka and USA as participating countries, seeking funds for a two-year project to study in detail the nutrient, sediment and carbon fluxes to the coastal zone in South Asia. Since funds for the second year came late, the project was extended to the third year at no additional cost. This report gives the findings of this 3-year study carried out from April 2001 to February 2004.

The main activity carried out in the second year was the Regional Workshop on Assessment of Material Fluxes to the Coastal Zone in South Asia and their Impacts, held as a joint APN/LOICZ/SASCOM activity during 08-11 December, 2002 in Negombo, Sri Lanka. The presentations made at this Workshop were largely based on studies carried out in 2001 and 2002, and the full papers have been published separately in the Proceedings of the Workshop.

The main body of this report summarises the various activities undertaken as indicated in the work plan of the Project, including Networking, Literature Survey, Gap-Filling Studies, Budget Synthesis, Capacity Building, Workshops organized and attended. The detailed reports submitted by the team members giving the actual data collected, the results of studies undertaken and the details of workshops held are presented in 12 Appendices as described in the Table of Contents.

Most of the work undertaken in 2001 on networking and literature survey is given in Appendices I and II, respectively. Where details of these studies were given in the respective Country Papers published in the Workshop Proceedings, they are not repeated in this report. Regarding the presentations made at the Regional Workshop held in 2002, only their abstracts are given in this report under Appendix III, since the full papers have been published separately in the Workshop Proceedings.

The estimation of biogeochemical budgets at several estuarine sites in Bangladesh, India, Pakistan and Sri Lanka using LOICZ methodologies was a key component of the study. A few were reported in the Workshop Proceedings. In view of the importance assigned to this component of the study, all the BGC budgets, including those reported in the Workshop Proceedings and those calculated during 2003, are given separately in this report under Appendix IV.

The details of gap-filling studies undertaken by each of the participating countries, other than those reported in the Workshop Proceedings, are given in Appendices V – VIII. The Appendices IX – XII describe the details of the various workshops organized by India, Nepal and Sri Lanka. Further details of these activities could be obtained from the respective Country Team Leaders.

The financial contributions made by APN and LOICZ, the technical assistance provided by LOICZ staff and its experts, the coordinating and organizational assistance provided by START and its South Asia Committee (SASCOM) are greatly appreciated. The valuable contributions made by the partner institutions; Institute of Marine Sciences, Chittagong, National Oceanographic Institute, Goa; Hydrology and Meteorology Department, Kathmandu; National Oceanographic Institute, Karachi; and the Sri Lanka Association for the Advancement of Science, Colombo, as well as the contributions from the partners in Australia and USA, are acknowledged with deep gratitude. Finally, my personal and sincere thanks go to the Country Team Leaders for their dedication, commitment and the untiring efforts, without which, the Project would not have been able to produce the amount of output described in the report.

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3. Nepal
4. Pakistan
5. Sri Lanka

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APPENDIX II

Literature Survey on
Coastal Nutrient Studies

1. Bangladesh Report
2. India Report
3. Nepal Report
4. Pakistan Report
5. Sri Lanka Report

NEPAL

Report on Literature Survey on Sedimentation in South Asia

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October 2001

Introduction

Soil loss and sediment transport from the Hindu-Kush-Himalayan range of mountains are often reported as environmental disasters and are often related to natural as well as human factors in the upstream mountainous areas of the basins. Similarly, significant loss of reservoir capacity in several reservoirs in south India exemplifies the sediment problem in South Asia. A brief account of the sediment delivery pattern and associated environmental factors has been presented by the author in the START/LOICZ/IGBP Workshop held in Colombo from 28 April to 1 May 1999. Significant portion of the transported sediment gets deposited in the immediate foothills, valleys and plains with some amount reaching up to the Bay of Bengal, Arabian Sea and Indian Ocean.

The large scale deposition of the sediment in the plains of the Ganga, Brhmaputra, and Indus besides other river plains of south India are major components of the regional sediment budget that influence the ocean-ward sediment flux in the region.

Following the Colombo workshop of 1998 and Colombo Training Program of 2000, the project on "A Study of Nutrient, Sediment and Carbon Flux to the Coastal Zone in South Asia, and their Relationship to Human Activities" has been implemented. Out of the fluxes of several biogeochemical processes, Nepal's role in this project is to study the sediment fluxes and its relationship with the human activities in South Asia.

The studies on sediment flux are aimed:

- To collect and assess details of existing studies and data on sediment fluxes and sediment yield.
- Synthesise existing information to quantify the sediment fluxes to the coastal zone
- Assess sediment yield and sediment fluxes in relation to changes caused by human activities.

1. Approach

Collection of data available in literature is the major approach in this study. In addition some supplementary data introducing a simplified method are being collected at few sites for attaining useful insight of the process. The four major stations (Narayani at Narayanghat, Bagmati at Pandheradobhan, Kosi at Chatara, and Kankai at Mainachuli) in Nepal where Measurements of sediment sampling were carried out during the 2001 monsoon with simplified techniques. The location of the stations is given in Appendix I.

The basic approach in the study will be the application of statistical tools as the nature of sediment process, and quality of data are inadequate for a conceptual or deterministic modeling. The data are being analysed by creating a temporal database wherever possible. The stations providing useful sediment information are geocoded using a geographic Information System (GIS). ArcView with the available extension of spatial analyst is used to further process the data.

2.

3. Database

The Digital Elevation Model (DEM) for the region is obtained from the United States Geological Survey's EROS data center, Sioux Fall, USA. The Asian HYDRO1k data set is made up of six raster data layers (DEM, derived flow directions, flow accumulations, slope, aspect, and a compound topographic (wetness) index) and two vector (streamlines and basins) layers. Land-use and other demographic data for the region are available in coarse resolution for the whole of South Asia. However, land-use data for Nepal is available at 30-arc sec resolution. These spatial data will be the backbone of the spatial analysis of sediment flux. The GIS information will be used to extract basin characteristics and human factors that are likely to influence the erosion and sediment processes in the basins.

Sediment data for different stations in the region are not available in a data book formats. The available data are scattered and intermittent. Literature and some internal reports are the basic source of information on sediment. Based on these sources, some of the available data have been collected and compiled. Data on average streamflow, average basin precipitation, river length, average basin slope, average basin elevation etc are compiled whenever such data were available. Information on the record length was also available in certain cases, which was useful to assess the reliability and quality of available information.

The list of stations for which information has been collected is given in **Annex I** of this report. More data are being collected for which several contacts are being established with resource persons of the region. Since relatively longer time series and relatively finer spatial data are available for Nepal, some studies on sediment are being made for Nepal for analysis of some specific cases. Attempts are also being made for similar studies for other parts of the region subject to the availability of suitable information.

4. Methodology

The following steps are being followed for the accomplishment of the task.

- Literature review
- Database development
- Interpretation and assessment of data
- Modeling for the analysis of human impact

The list of collected literature is included in Annex II of this report. More literature is being collected for which a few contacts are being established with resource persons of the region as well.

The preliminary assessment of the available data shows several discrepancies and data gaps. Several data on sediment do not provide information on basin characteristics and streamflow. There is also a lack of information in several cases about the information of existing reservoirs upstream of the sampling locations. These aspects are likely to be major stumbling blocks in this study.

Most of the countries of the region have also classified hydrological data for restricted use, which is causing some problems for proper modeling of the sediment transport processes at basin scale. Hence, statistical approaches are being explored for modeling to derive preliminary outcomes and conclusions. Further analysis with deterministic modeling will depend on the preliminary outcomes and availability of other essential data. A GIS system, however, has been established for obtaining basic catchment characteristics (excluding streamflow).

2. Annex I. List of Station with Sediment Information in South Asia

River	Location	Basin	Region	Lat DD	Long DD	Area km^2
Beas	Belelive	Indus	Himalaya	31.93	76.21	6009
Beas	Pong	Indus	Himalaya	31.57	75.50	12562
Chenab	Alexandria	Indus	Himalaya	32.43	74.17	32500
Chenab	Chiniot	Indus	Himalaya	31.67	73.00	67542
Ghambir	Danda Shah B.					518
Gilgit	Gilgit Town	Indus	Hindu-Kush	35.90	74.20	12100
Gilgit	Alam B.	Indus	Hindu-Kush	35.86	74.55	26148
Gomal	Gulkatch	Indus	Sulaiman	31.95	69.55	39886
Gorband	Karora	Indus				634
Haro	Khanpur	Indus	Siwalik	33.86	73.00	777
Haro	Sanjwal	Indus	Siwalik	33.71	72.51	1799
Haro	Gariala	Indus	Siwalik	33.71	72.43	3055
Harrow	Hassan Abdel	Indus	Siwalik	33.80	72.75	6216
Hunza	Dainyor B.	Indus	Himalaya	36.39	74.89	13152
Indus	Kachural	Indus	Himalaya	35.36	75.49	112700
Indus	Pratab B.	Indus	Himalaya	35.68	74.66	142700
Indus	Darband	Indus	Himalaya	36.02	71.50	164724
Indus	Tarbela	Indus	Himalaya	34.10	72.83	165000
Indus	Kalabagh (Jinnah B.)	Indus	Himalaya	32.95	71.63	268065
Indus	Kalabagh	Indus	Himalaya	33.00	71.58	305000
Indus	Mouth	Indus	Himalaya	24.00	67.53	912000
Indus	Kotri	Indus	Himalaya	24.00	67.53	958000
Indus	Mouth	Indus	Himalaya	24.00	67.53	970000
Jhelum	Domail	Indus	Himalaya	34.12	74.00	13675
Jhelum	Mangla	Indus	Himalaya	33.15	73.73	33300
Kabul	Munda	Indus	Hindu-Kush	30.55	71.23	12458
Kabul	Warsak dam	Indus	Hindu-Kush	34.20	71.33	67340
Kabul	Nowshera	Indus	Hindu-Kush	34.00	72.00	90300
Kahan	Rohtas	Indus	Siwalik	32.98	73.67	1217
Kanshi	GT Road	Indus	Siwalik	33.32	73.38	1803
Kishanganga	Muzaffargadh	Indus	???	30.07	71.25	6734
Kunhar	Ghari	Indus	Hindu-Kush	34.98	71.40	2797
Kurram	Kurram	Indus	Sulaiman	33.85	70.18	6819
Poonch	Kotli	Indus	Himalaya	33.22	73.85	3236
Poonch	Palic	Indus	Himalaya	33.32	73.77	3937

River	Location	Basin	Region	Lat DD	Long DD	Area km^2
Rabi	Shahdara	Indus	Himalaya	31.65	74.38	8089
Shyok	Yugo	Indus	Himalaya	35.19	76.15	33700
Siran	Thapla	Indus	Siwalik	34.29	72.71	2849
Soan	Chirah	Indus	Siwalik	33.64	73.36	326
Soan	Dhok Pathan	Indus	Siwalik	33.14	72.62	6472
Soan	Mukhad Rd.	Indus	Siwalik	33.07	72.00	12432
Sutlej	Bhakra	Indus	Himalaya	31.40	76.47	56876
Banas	Dantiwala	Banas	Aravalli	24.32	72.35	2862
Bhadar	Bhadar	Bhadar	Mandav	23.82	70.78	2435
Mahi	Mahi	Mahi	Aravalli	23.57	74.54	25330
Mahi	Kadana	Mahi	Aravalli	23.22	73.52	25501
Mahi	Mouth	Mahi	Aravalli	22.25	72.94	37600
Tawa	Tawa	Narmada	Vindhya /Satpura	22.18	77.90	5983
Narmada	Garudeshwar	Narmada	Vindhya /Satpura	21.98	73.49	87892
Narmada	Mouth	Narmada	Vindhya /Satpura	21.59	72.83	98800
Girna & Panzan	Girna	Tapti	Deccan	20.46	74.81	4729
Tapi	Savkheoa	Tapti	Satpura /Deccan	21.14	75.35	49136
Tapti	Ukai	Tapti	Satpura /Deccan	21.28	73.65	62224
Tapti	Mouth	Tapti	Satpura /Deccan	21.07	72.73	66900
Kuttiyadi	Peruvannamuzhi	Kuttiyadi	W. Ghat	11.38	75.43	109
Malampuzha	Malampuzha	Bharatha	W. Ghat	10.83	76.69	148
Manali	Peechi	Periyar	W.Ghat	10.52	76.40	107
Bharathpuzha	Mangalam	Bharatha	W. Ghat	10.51	76.54	49
Aliyar	Aliyar	Bharatha	W. Ghat	10.46	76.98	195
Kailmani-muthar	Manimutharu	Tambraparni	W. Ghat	8.64	76.67	162
Vaigai	Vaigai	Vaigai	Cardamom	10.05	77.56	2253
Kundah	Upper Bhawani	Cauvery	Deccan	11.22	76.52	34
Kundah	Kundah/TN	Cauvery	Deccan			114
Bhawani	Lower Bhavani	Cauvery	Deccan	11.83	77.00	4200
Cauvery	Mettur	Cauvery	Deccan	11.92	77.88	42200
Cauvery	Musiri	Cauvery	Deccan	10.97	78.43	66243
Cauvery	Mouth	Cauvery	Deccan	11.43	79.82	87900
Pannalarui	Krishnagiri	Ponnaiyar	Deccan	12.32	78.11	5430
Ponniar	Sathnur	Penniar	Deccan	12.18	78.83	10826

Gundukamma	Cumbum Tank	Gundalakamm	Deccan	17.75	79.19	993
Palar	Palar	Palar	Deccan	12.98	78.38	1687
Pennar	Somasila	Pennar	Deccan	14.50	79.40	48660
Emerald Avala	Emerald Avlan					163
Aliaru	Pocharam	Krishna	Deccan	18.11	78.19	673
Bhima	Ghod	Krishna	Deccan	18.65	74.46	3629
Bhima	Takali	Krishna	Deccan	16.05	76.84	33196
Bhima	Yedgir	Krishna	Deccan	16.73	77.11	69863
Bhima	Yedgir	Krishna	Deccan	16.73	77.11	69863
Dindi	Dindi	Krishna	Deccan	16.54	78.60	3920
Issa	Himayatsagar	Krishna	Deccan	17.25	78.57	1308
Koyna	Shivajisagar	Krishna	Deccan	17.42	73.77	892
Krishna	Karad	Krishna	Deccan	17.32	74.25	5462
Krishna	Bagalkot	Krishna	Deccan	16.46	75.74	8610
Krishna	Huvanpur	Krishna	Deccan	16.39	76.64	11400
Krishna	Bawapuram	Krishna	Deccan	16.18	77.92	67180
Krishna	Srisailam	Krishna	Deccan	16.03	78.26	206041
Krishna	Morvakonda	Krishna	Deccan	16.04	78.35	210500
Krishna	Mouth	Krishna	Deccan	15.75	80.84	250000
Muneru	Pakhal L.	Krishna	Deccan	17.59	80.02	267
Muneru	Shanigram L	Krishna	Deccan	17.68	80.00	321
Wyra-Pangidi	Wyra	Krishna	Deccan	17.18	80.26	710
Nira	Sarati	Krishna	Deccan	18.00	74.80	7200
Nira	Sarati	Krishna	Deccan	18.00	74.80	7200
Sina	Wadakbal	Krishna	Deccan	17.46	75.26	12092
Tunga	Shimoga	Krishna	Deccan	13.93	75.52	2831
Tungbhadra	Tungbhadra	Krishna	Deccan	15.00	75.83	28180
Varada	Morol	Krishna	Deccan	14.82	75.37	4901
Krishna	Vijaywada	Krishna	Deccan	16.50	80.65	251360
Godavari	Dhlle	Godavari	Deccan	19.21	76.38	31000
Godavari	Gagra	Godavari	Deccan	19.07	76.65	34000
Godavari	Nanded	Godavari	Deccan	19.18	77.35	54000
Godavari	Basar	Godavari	Deccan	18.86	77.92	87000
Godavari	Sriramsagar	Godavari	Deccan	19.07	78.88	91751
Godavari	Mancherial	Godavari	Deccan	18.79	79.58	103000
Godavari	Perur	Godavari	Deccan	18.50	80.46	260000
Godavari	Rajhamundry	Godavari	Deccan	17.02	81.87	310000
Godavari	Mouth	Godavari	Deccan	16.61	82.34	312800
Indravati	Nowrangpur	Godavari	Deccan	19.21	82.62	5000
Indravati	Jagdalpur	Godavari	Deccan	19.07	82.08	7000
Indravati	P. Gudem	Godavari	Deccan	19.00	80.34	42000
Kaddam	Kaddam	Godavari	Deccan	19.12	78.41	2656
Lakhamvaram	Lakhamvaram L	Godavari	Deccan	18.15	80.08	268
Manair	Ramappa L.	Godavari	Deccan	18.25	78.53	184

Manjeera	Saigaon	Godavari	Deccan	17.86	77.02	10000
Manjeera	Raipalli	Godavari	Deccan	17.80	78.08	16000
Manjira	Manjira	Godavari	Deccan	18.07	78.00	16770

River	**Location**	**Basin**	**Region**	**Lat DD**	**Long DD**	**Area km^2**
Manjira	Nizamsagar	Godavari	Deccan	18.05	78.00	21694
Penganga	P. G. Bridge	Godavari	Deccan	19.82	78.64	19000
Pranahita	Tekra	Godavari	Deccan	19.75	79.98	100000
Purna	Purna	Godavari	Deccan	19.04	77.04	15000
Sabari	Konta	Godavari	Deccan	17.71	81.44	20000
Sidhapana	Magleaon	Godavari	Deccan	19.18	76.23	4000
Sileru	Machkud	Godavari	Deccan	18.14	82.12	1956
Wainganga	Pauni	Godavari	Deccan	20.75	79.70	36000
Wardha	Bamini	Godavari	Deccan	19.79	79.54	46000
Wainganga	Asthi	Godavari	Deccan	19.71	79.85	51000
Hamp	A'Kore	Mahanadi	Deccan	21.82	81.73	2210
Hasdeo	Bamnidih	Mahanadi	Deccan	21.89	82.75	9730
Ib	Sundargarh	Mahanadi	Deccan	22.07	84.13	5870
Jonk	Rampur	Mahanadi	Deccan	21.57	82.65	2920
Mahanadi	Rajim	Mahanadi	Deccan	20.95	81.64	8760
Mahanadi	Tikarapara	Mahanadi	Deccan	20.53	84.93	41000
Mahanadi	Basantpur	Mahanadi	Deccan	21.71	83.15	57780
Mahanadi	Hirakud	Mahanadi	Deccan	21.53	83.92	83395
Mahanadi	Tikarapara	Mahanadi	Deccan	20.53	84.93	88320
Mahanadi	Mouth	Mahanadi	Deccan	20.25	86.77	130000
Mahanadi	Naraj	Mahanadi	Deccan	21.75	82.48	132034
Mahanadi	Mouth	Mahanadi	Deccan	20.25	86.77	141600
Mand	Kurubhata	Mahanadi	Deccan	22.04	83.15	4625
Ong	Salebhata	Mahanadi	Deccan	20.96	83.65	4650
Pairi	Baronda	Mahanadi	Deccan	20.73	82.00	3225
Seonath	Simga	Mahanadi	Deccan	21.71	81.75	16010
Seonath	Jondhra	Mahanadi	Deccan	21.79	82.27	29645
Tel	Kantamal	Mahanadi	Deccan	20.61	83.77	19600
Brahmani	Samal	Brahmani	Deccan	20.75	86.70	28200
Mayurakshi	Mayurakshi	Hugli	Maikal	24.11	87.30	1860
Damodar	Panchet Hill	Hugli	Maikal	23.68	86.75	10966
Damodar	Rhondie	Hugli	Maikal	23.54	87.20	20000
Damodar	Mouth	Hugli	Maikal	22.28	88.04	20000
Barakae	Maithon	Hugli	Maikal	23.80	86.78	6294
Arun	Tribeni	Ganga	Himalayas /Tibet	26.93	87.15	29532
Bagmati	Chovar	Ganga	Middle Mts	27.67	85.30	585

Betwa	Matatila	Ganga	Himalaya	25.08	78.33	20750
Betwa	Dhukwan	Ganga	Vindhya	25.36	79.24	21340
Betwa	Sahijna	Ganga	Vindhya	25.89	80.00	49940
Betwa	Gandhisagar	Ganga	Vindhya	24.65	75.68	21875
Chambal	Gandhisagar	Ganga	Vindhya	24.65	75.68	22533

River	Location	Basin	Region	Lat DD	Long DD	Area km^2
Chambal	Udi	Ganga	Vindhya	26.72	78.93	139785
Gandak	Conflunce	Ganga	Himalayas	25.78	85.17	64300
Ghagra	Conflunce	Ganga	Himalayas	25.82	84.58	127000
Gomti	Conflunce	Ganga	Ganga P.	25.56	83.00	30400
Kaligandaki	Setibeni	Ganga	Himalayas	28.00	83.60	6630
Kankai	Mainachuli	Ganga	Middle Mts.	26.68	87.88	1148
Kansal/Sukhetri		Ganga	Siwalik			44
Karnali	Asaraghat	Ganga	Himalayas	28.95	81.43	19260
Karnali	Chisapani	Ganga	Himalayas	28.65	81.30	42890
Ken	Chilla	Ganga	Vindhya	25.78	80.44	288224
Kosi	Chatara	Ganga	Himalayas /Tibet	26.87	87.17	54000
Kosi	Baltara	Ganga	Himalayas /Tibet			
Kulekhani	Kulekhani	Ganga	Middle Mts	27.58	85.17	126
Lotharkhola	Lothar	Ganga	Middle Mts	27.60	85.72	169
Narayani	Narayanghat	Ganga	Himalayas	27.70	84.43	31100
Gandak		Ganga	Himalayas			45312
Ramganga	Ramganga	Ganga	Himalayas	30.13	79.01	3134
Ramganga	Conflunce	Ganga	Himalayas	27.84	79.49	32400
Rapti	Bagasoti	Ganga	Himalayas	27.90	82.85	3380
Seti	Phoolbari	Ganga	Himalayas	28.23	71.83	582
Seti	Banga	Ganga	Himalayas	28.98	81.15	7460
Son	Conflunce	Ganga	Maikal	25.52	84.76	71200
Sunkosi	Kampughat	Ganga	Himalayas	26.87	86.82	17600
Tamor	Mulghat	Ganga	Himalayas	26.93	87.33	5640
Tons	Ichari	Ganga	Middle Mts.	30.54	77.81	4913
Trishuli	Betrawati	Ganga	Himalayas	27.97	85.18	4110
Yamuna	Tajewala	Ganga	Himalayas	30.29	77.43	9572
Yamuna	Delhi	Ganga	Himalayas	28.67	77.23	28988
Yamuna	Okhla	Ganga	Himalayas	28.47	77.40	30013
Yamuna	Etawah	Ganga	Himalayas	26.77	79.02	81997
Yamuna	Pratappur (Allahbad)	Ganga	Himalayas	25.45	81.83	345848
Yamuna	Confluence	Ganga	Himalayas	25.45	81.83	366000
Phewa	Phewa Lake WS	Ganga	Himalayas	28.28	83.97	
Ganga	Hardwar	Ganga	Himalayas	29.97	78.15	95500
Ganga	Kannauj	Ganga	Himalayas	27.03	80.00	240000
Ganga	Allahabad	Ganga	Himalayas	25.50	81.72	358000

Ganga	Ghazipur	Ganga	Himalayas	25.57	85.58	
Ganga	Farakka	Ganga	Himalayas	27.83	87.91	648000

River	**Location**	**Basin**	**Region**	**Lat DD**	**Long DD**	**Area km^2**
Ganga	Calcutta	Ganga	Himalayas	23.79	98.45	750000
Ganga	Delta, BD	Ganga	Himalayas	23.79	98.45	1060000
Ganga	Brahmaputra Conflence	Ganga	Himalayas	23.75	89.69	990000
Burhi Dihing		Brahmaputra	Naga Hills	27.25	94.92	5180
Lhasa He		Brahmaputra	Tibetan Plateau	29.40	90.55	6225
Nyang He		Brahmaputra	Tibetan Plateau	29.27	88.21	6215
Brahmaputra	Delta, BD	Brahmaputra	Tibetan Plateau			559000
Brahmaputra	Ganga Confl.	Brahmaputra	Tibetan Plateau	23.85	89.75	666000
Ganga /Brahmaputra		GB	Himalayas	23.13	90.54	1648000
Irrawadi	Prome, Burma	Irrawadi	Hengduan /Arrakan			367000
Irrawadi	Delta	Irrawadi	Hengduan /Arrakan	15.85	85.06	430000

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SRI LANKA

Literature Survey of Coastal Nutrient Studies

Introduction

As part of the objectives of the project entitled "A study of nutrient, sediment and carbon fluxes to the coastal zone in South Asia and their relationship to human activities", a survey of literature was carried out in order to document the followings in Sri Lanka:

- Research work carried out on the dynamics of nutrients, sediment and carbon from their source of origin to the sink, and effects of these material fluxes to the resources in the coastal zone (estuarine and nearshore areas),
- Statistics such as coastal fisheries catch, agrochemical usage, etc., and
- Recommendations implemented by the state or other organisations to alleviate the impacts due to these material fluxes to the coastal zone.

The aim of this process is to assist any interested individual or organisation to identify literature regarding the above mentioned aspects and possible gaps and limitations in research and other activities that are related to land-ocean interactions that have been carried out in Sri Lanka.

Documentation of this appraisal has been carried out as follows:

This review mainly concentrates on discussing existing research information in various forms such as publications, departmental reports, technical papers, unpublished thesis, etc. A more comprehensive assessment of the collected literature has been carried out to extract data that were readily available for further analysis. Possible information sources and contact details of resource persons have been listed in the third section. Finally, overviews of other foreign-funded projects have been briefly discussed.

Existing research information

This section contemplates on demonstrating the overall contents of the literature particularly related to the current topic on discussion.

The preliminary assessment of the collected information and publications that were not readily available, nevertheless those that have been cited elsewhere and would be relevant to this study have been incorporated in this review. The published literature cited also includes work only in abstract form, which has been presented at various communications. It should be noted that the full reports of some studies have not been available either because, a full report has never been written, or when a full report has known to be written it could not be found within the institution or in libraries, or the author could not be contacted, or the author was not willing to release the paper or the applicable data.

The following synthesis has been discussed under four main topics which include,

- Status of coastal areas in Sri Lanka
- Origins of materials
- Quantification of fluxes, and
- Impact of fluxes and pollution control methods.

Each of these main sections has been divided into subcategories (listed in table form) for the ease of emphasising research work on specific issues. Significant information pertaining to this study has been highlighted under the column named as "Contents/Comments".

The current appraisal has made an attempt to identify important issues and studies performed by researchers attached to various institutions in Sri Lanka. Nevertheless, Dassanayake (1992) recognized some of the important institutions engaged in marine environmental research and laboratory facilities available for environmental studies. Also, the final parts of his report includes information on activities that could cause damage to the marine and coastal environment, environmental legislations, locations and extent of marine habitats in Sri Lanka and contribution from NGOs and general public for the protection of marine habitats.

Status Reports of coastal areas in Sri Lanka

A number of status reports and environmental profiles have been compiled covering most of the economically important coastal sites around Sri Lanka. These reports included the following areas

Batticaloa
Bellanwila-Attidiya Marsh
Bentota Estuary
Chilaw Estuary
Dutch Bay
Galle
Kalametiya
Kalutara
Koggala Lagoon
Lunama Kalapuwa
Malala Lagoon
Matara
Negombo Lagoon
Muthurajawela Marsh
Portugal Bay
Puttalam/Mundel Estuarine system

Out of the above sites, Negombo lagoon and Puttalam estuary have been well documented and updated more regularly comparative to the other areas. This is an outcome of their high socio-economic usage as well as their rapid environmental degradation.

Majority of these reports mainly consisted of the status of various characteristics of the area at the time of monitoring. These reports included basic information on the physico-chemical characteristics (e.g. physical features, geology, geomorphology, soils, climate, hydrology and water quality), biological characteristics (i.e. flora and fauna), ecological relationships within the area, human interaction with the surrounding environment (e.g. history of the area, human population, socio-economics and land use), resources including values of the area and status of various activities along the coast such as fishery, aquaculture, etc. Some of these studies have also identified the conservation measures taken, various research activities and site-specific development plans. Most of this information has been used as a basis to prepare management plans and to institute possible recommendations to avoid adverse environmental impacts in the future.

The present report gives the literature referred to in the preparation of the analysis referred to above, categorised according to the institution where the documents were available. The report of the analysis itself is not published here due to its length (over 70 pages). However, it will be posted on the project website.

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APPENDIX III

APN/START/LOICZ Regional Workshop on Assessment of Material Fluxes to the Coastal Zone in South Asia and their Impacts

08 – 11 December 2002, Negombo, Sri Lanka

Abstracts of Papers presented

TECHNICAL PRESENTATIONS-KEYNOTE ADDRESS

Consideration of Future Changes in River Sediment Flux for Coastal Planning (Abstract only)
Steven L.Goodbred, Jr., USA

DELIVERIES ZONE TO THE COASTAL

Fertilizer Runoff from Rain-fed Paddy Cultivation (Abstract only)
Nalin Wikramanayake, B.C.Liyange, W.N.C.Priyadarshini and L.K.Ratnayake, SRI LANKA

Estimation of Nitrogen and Phosporus Fluxes to Embilikala and Matala Lagoons in Southern Sri Lanka
S.C.Piyankarage, A.P.Mallawatantri, Y.Matsuno and K.A.S.Patiratne, SRI LANKA

Water, Nutrient and Sediment Flux Study through the Lower Meghna River Estuary (Hatiya Channel)
Nuruddin Mahmood[1], Sayedur Rahman Chowdhury, Sharif, Mohammad Muslem Uddin, Abu Syeed Muhammad Sharif, and Mohammad Saeed Ullah, BANGALADESH

Material Flux through the Karnaphuli River
Sayedur Rahman Chowdhury[1], Nuruddin Mahmood, Mohammad Muslem Uddin, Abu Syeed Muhammad Sharif and Mohammad Saeed Ullah, BANGALADESH

Study of Nutrient, Sediment and Carbon Fluxes into the Indus Delta System
S.H.Khan, A.Inam, M.Danish, M.Saleem, S.M.Tabrez, S.M.Ali, D.A.Razzaq, S.Amjad and S.Kidwai, PAKISTAN

A Study of Sediment Fluxes to Coastal Zone in South Asia and their Relationship to Human Activities
K.P.Sharma, NEPAL

Silica Fluxes in Three River Systems in Sri Lanka

BIOGEOCHEMISTRY

MATERIAL CONSENTRATIONS TO COASRAL WATERS

COASTAL IMPACTS

A.S.L.E.Corea and J.M.P.K.Jayasinghe, SRI LANKA

Impacts of the Reclamation of Acid Sulphate Soil Sediments on Coastal Environment
J.M.P.K.Jayasinghe and A.S.L.E.Corea, SRI LANKA

Human Impact on Wetland Ecosystems - A Case Study – The Mundel Lake and its Environs- Sri Lanka
K.N.J.katupotha, SRI LANKA

Human Activity Management in Coastal Zone of Sri Lanka
*L.W.Seneviratne, S*RI LANKA

POSTER PRESENTATIONS

A Simplified Procedure for Sediment Monitoring – Reducing Gaps in Sediment Information
K.P.Sharma and R.G.Kharbuja, NEPAL

A Study on the Impact of Sedimentation and Organic Matter in the Sediments on two reef sites in the Southern Coastal Belt of Sri Lanka
A.G.Bandaranayake, P.R.T.Cumaranatunga and M.F.M.Fairoz, SRI LANKA

Biochemical Studies in the AchanKovil River basin, Kerala
A.L.Ramanathan, INDIA

Impact of Shrimp Culture on the Mi-Oya Estuary
A.S.L.E.Corea and J.M.P.K.Jayasinghe , SRI LANKA

Impact from Anthropogenic Process that Affect two near Shore Coral Reefs Located in Matara and Weligama Southern in Sri Lanka
M.F.M.Fairoz, P.R.T.Cumaranatunga and P.B.Amarasinghe, SRI LANKA

Consideration of Future Changes in River Sediment Flux for Coastal Planning

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Abstract

One of the major issues facing South Asia's growing populations is water supply. As water needs grow and engineering structures like dams and barrages are emplaced, patterns of river runoff and associated sediment supply will change dramatically. Damming impacts on the Indus River and delta system are the most striking in the region, but many other rivers will invariably be altered in coming decades. Water usage and damming serve to greatly decrease the amount of sediment reaching the shoreline, often by an order of magnitude or more. This material that is being lost normally contributes to coastal stability in the face of rising sea level, and in many areas it is sufficient to drive actual progradation of the shoreline. Beyond obvious engineering changes to South Asia's river systems, the region is also likely to experience shifting rainfall patterns under anticipated changes in global climate. Response of the South Asian monsoon system to global warming is not certain, but it may result in a prolonged and more intense southwest monsoon and increased runoff and floodplain incision. This would have the effect of increasing discharge to coast in a natural system. In conjunction with shifting land use practices, this natural variability may introduce important changes in sediment fluxes and coastal evolution. As developing nations design their strategies for sustainable development in the coastal zone, it will be important to consider likely natural and anthropogenic influences on sediment delivery to the shore. For example, use of barrages or offtakes instead of dams would have the effect of supplying water during the dry season but also allow the major wet-season sediment pulse to reach the coast.

Keywords: erosion, land reclamation, dams, climate change, land use

Fertilizer Runoff from Rain-fed Paddy Cultivation

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Abstract

Frequent algal blooms in the coastal lagoons of Sri Lanka are associated with rainfall events. Computed nutrient fluxes in rivers can only be explained by very high loss of fertilizers from the cultivation in the catchment areas. A detailed study of a small catchment was undertaken to quantify the runoff of fertilizer and understand the mechanisms involved. The principal results of the study are presented here.

The catchment was approximately 100 ha in extent with 30 ha of paddy and 40 ha of coconut and other crops. However, over 90% of the total fertilizer used was applied to the paddy cultivation. The study was undertaken during the main cultivation season of 2001/2002. 77 farmers cultivated about 26 ha of rain-fed paddy during this season.

The runoff of fertilizer was quantified by detailed measurements of stream flow and water quality in the stream draining the selected catchment. The water quality parameters measured were NO3-N, NH3-N and PO4-P. Some measurements of Total-N and Total-P were also made. Detailed measurements of the rainfall and the variation in the levels of six wells in the catchment were made in order to understand the hydrology of the catchment. All details of the cultivation, including dates and quantities of fertilizer application, were obtained by a weekly questionnaire survey of the farmers.

The results showed that the overall application of nitrogen fertilizer was about 1660 kg of nitrogen while the total loss in runoff (as dissolved inorganic N) was about 1000 kg. The corresponding figures for phosphorous were about 450 kg applied and about 50 kg of PO4-:P in the runoff. However, the runoff was very variable and strongly related to the rainfall with about 90% of applied N being lost during two weeks of heavy rain. The reason for the high losses was that the fields were flooded to overflowing by the heavy rains.

The results of the questionnaire survey showed that the fertilizer application was very haphazard, with application rates usually exceeding recommendations. This was particularly true in the case of Urea, the sole source of nitrogen, with average application rates of more than 2 ½ times the recommended quantity. The disproportionate application of Urea is due to the skewed fertilizer subsidy structure, with the subsidy for Urea being more than that for other fertilizers.

Keywords: catchment, fertilizer, cultivation, runoff

Estimation of Nitrogen and Phosporus Fluxes to Embilikala and Malala Lagoons in Southern Sri Lanka

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Abstract

Bundala National Park wetlands of Sri Lanka are one of the most important wintering areas for migratory shore birds in south Asia. Embilikala and Malala lagoons of the wetland system are impacted by agricultural return flows from the Lunugamwehera Right Bank and Badagiriya irrigation schemes. The drainage canals of tract 5 (1017 ha) and tracts 6 and 7 (670 ha) discharge into the Embilikala lagoon. Agricultural return flows of the Badagiriya area (850 ha) discharge into the Malala lagoon through Malala Oya. This study intended to estimate nitrogen and phosphorus loads entering Embilikala and Malala lagoons and to examine the seasonal variations of nutrient loads to better understand the factors affecting them.

Water samples were analyzed for Nitrate-nitrogen, ammonia-N, total-N, total reactive phosphorus and total phosphorus using spectrophotometric methods. The US Army Corps of Engineers FLUX software was used to compute nutrient loads using daily flow and periodic concentration data.

The estimated average monthly flow and nutrient loading to the Embilikala-Malala lagoon system were 3.89 MCM of drainage water, 6493 kg of TN and 620 kg of TP. The canals of tract 5, tracts 6 and 7 and Malala Oya contributed about 41 %, 35 % and 24 % to the total volume of drainage and nutrient loads discharged to the lagoon system, respectively.
In the canal of tract 5, reactive phosphorus content was 78% of its total phosphorus load and in the canal of tracts 6 and 7 and Malala Oya, they were 34% and 55%, respectively. The highest nitrate-N contribution (66%) to the total-N load was observed in the canal of tracts 6 and 7; during the 1999-2000 *Maha* season it was 72%.

On average, the nutrient delivery from both tracts 5, 6 and 7 of Lunugamwehera Right bank and Badagiriya agricultural systems were about 2.50 kg ha^{-1} of nitrogen and 0.24 kg ha^{-1} of phosphorus monthly.The nutrient loads and the drainage volume of the canal of tracts 6 and 7 were influenced by rainfall events while those of tract 5 canal were influenced by the irrigation input to its command area.

The monthly volume of drainage to the Embilikala-Malala lagoon system was about 25% of its total capacity. Although the change in nutrient concentrations in the Embilikala and Malala lagoons could be marginal at times due to high dilution, accumulation of nutrients

within the system could increase the nutrient concentrations and create a long term ecological problem in the two lagoons since it is a closed system.

Key words: nitrogen, phosphorus, lagoons, irrigation, drainage

Water, Nutrient and Sediment Flux Study through the Lower Meghna River Estuary (Hatiya Channel)

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Abstract

Water, Nutrient and Salt transport through the lower Meghna estuary, a combined flow of the Ganges and Brahmaputra and many other rivers, was studied. Despite a very complex network of rivers and channels, a simple approach of measuring these parameters for an annual cycle during premonsoon, monsoon and postmonsoon seasons covering an area of about 532 km^2 results in knowledge in this previously untouched arena of material flux. Although, vastness and complexity of the estuary made it almost impossible to sample each and every creek and channel, an attempt was made to fit a single layer simple box model to study the budget of these materials in the lower reaches of the river estuary.

Keywords: nutrient flux, Meghna-estuary, Bangladesh

Material Flux through the Karnaphuli River

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Abstract

Karnaphuli river originates in the Lusai hills of Assam, India and empties into the Bay of Bengal through the north-eastern part of Bangladesh. During its course through Bangladesh it is dammed for hydroelectric power generation forming an artificial hill-bound lake. At the downstream reaches, it receives water from two major perennial tributaries and numerous other streams. Watershed is characterized by mainly derelict or cultivated hills and foothills, and human settlement areas with agricultural fields. In the estuarine reaches it is receiving untreated municipal and industrial wastes from Chittagong City and other types of pollutants from harbor and other activities. The current research examines the state of the major Nitrogen and Phosphorus species of nutrients in the lower reaches of the river heavily stressed by human activities. LOICZ recommended modelling approach is adopted to budget these nutrients and other materials. The model reveals that the estuary is a heterotrophic and denitrifying ecosystem.

Keywords: Material flux, Karnaphuli estuary, Bangladesh

Study of Nutrient, Sediment and Carbon Fluxes into the Indus Delta System

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Abstract

Continued change in river course, as a result of human intervention by constructing dams on the river and diverting the river water for irrigation purpose. This has resulted in the drastic reduction of sediment and water discharge of River Indus into the Arabian Sea and the delta has become increasingly saline over the last few decades. NIO has conducted this study of the lower part of Indus River system has been studied to evaluate the biogeochemical budget and understand the current nutrient, sediment and carbon flux in the Indus River Delta which harbours seventh largest mangrove forest and contributes significantly towards tangible and intangible oceanic resources of Pakistan.

The bottom configuration of the Khobar Creek is relatively smooth with average depth of 6m. However, at places river bed is much deeper (>14m) and rugged. The current velocity in the Khobar creek ranges between 14.0 and 89.0 cm/sec. The sediment samples collected from the area are, in general, fine grained and normally range between fine sand and clay size fraction. The suspended sediment levels in the section downstream from Kotri Barrage to Khobar Creek fluctuate with the amount of water released into the system from the dams and barrages upstream as the level varied from 12 ppm to 6440 ppm for the surface waters (0 – 0.25m). The organic carbon and calcium carbonate content in the sediment samples obtained from the area averages <1% and <10% respectively. The light penetration was up to a depth of < 1.0m.

Major nutrients (nitrite, ammonia, phosphate and silicate) were measured in Indus River water at several locations over a distance of about 200km from Kotri Barrage (lower part of Indus River) to Khobar Creek. Substantial variability in the concentration was observed in all the four major nutrients in fresh water along the river course downstream Kotri Barrage to the saline water in Khobar and adjoining creeks. The average concentration range of nutrients observed from Kotri Barrage to Khobar Creek was NO_2 (0.024-1.32 µM); NH_3 (1.73-3.2µM); PO_4 (0.36-0.92µM); SiO_3 (41.5-52.1µM).

The salinity values in Khobar Creek during July-August (SW Monsoon) period were observed between 0 and 14‰ whereas during February (NE Monsoon), when there is no water discharge from Indus River, the salinity was around 35‰.

Keyword: sediment discharge, nutrients, current velocity, sediment, Carbon flux

Sediment Fluxes to Coastal Zone in South Asia and their Relationship to Human Activities

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Abstract

Statistical modeling approach was adopted to study the sediment fluxes to coastal zone in South Asia for the areas lacking sediment transport information. Regression analyses were carried out with sediment yield as a dependent variable and basin area, precipitation, river discharge, river length, average elevation of the basin, elevation difference within the basin, and basin slope as a predictors. The analyses were carried out using linear model with linear and logarithmic scales. The analysis showed that the sediment yield of a basin is significantly related to the basin area, river discharge and river length. Since river length is significantly related to basin area and since the data for discharge is not complete in the database, we considered basin area as the best independent variable to predict sediment yield. Although the relation between basin area and sediment yield was better with the introduction of elevation difference in the watershed, such addition of a variable was not considered at this stage as the improvement was marginal (improvement of R^2 from 76% to 80%) and that the available DEM was not adequate for elevation data for several basins. The equations, thus obtained for the estimation of sediment yield, can be summarized as:

2. For the whole of South Asian Region
   $S_y = 1260(A)^{0.93}$, (1)
3. For the Hindu Kush-Himalayan Region
   $S_y = 6310(A)^{0.83}$, (2)
4. For the south and central region of the Indian subcontinent
   $S_y = 930(A)^{0.95}$, (3)

where Sy is the annual sediment yield (t) and A is the basin area (km^2). Based on these computations, the total oceanward sediment flux from South Asia was estimated at 3.2 $*10^9$ t per year.

Regarding the human activities, several critical issues were realized that could influence the pattern of sediment flux. Several studies were found that could relate human activities to sediment movement at micro-catchment or at plot level. Attempts to quantify such impacts for large basins did not yield noticeable conclusion that could be stated with high degree of confidence; however, the impact of reservoir construction on sediment transport was distinctly clear. Such impacts were found highly significant on central and south Indian rivers. Excluding the Indus, the impacts of reservoir construction on oceanward sediment flux was not found to be significant in the Himalayan region, as there were only few dams on the tributaries of the Ganga and Brahmaputra rivers.

Key words: Sediment flux; sediment yield; human activities; modeling; South Asia.

Silica Fluxes in Three River Systems in Sri Lanka

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Abstract

Sri Lanka is an island nation in the Indian sub-continent, which has no natural lakes but 103 perennial and seasonal rivers drain the entire land mass in a radial pattern discharging 39 % of the surface precipitation into the Ocean. At present 6,873 MCM of river water has been tapped in low land irrigation tanks and cascading highland hydropower reservoirs which have inundated about 1000 km^2 of the island surface area (65,525 km^2). A majority of these reservoirs are rich in filamentous diatom, *Aulocosiera granulate* and the bio-assimilation of silica results in a significant loss of dissolved silica within the reservoir system. The gradients of dissolved silica from headwaters to downstream were measured four times in three river systems namely Maha Oya, Deduru Oya and Mi Oya located ad jointly to determine whether the fluxes have been affected by the constriction of reservoirs across the rivers.

Irrespective of the size of the watersheds and their geographical locations, the Maha Oya, which has not been regulated by constructing dams and has the 39 % of discharge of the total precipitation volume carries the highest amount of dissolved silica (8374 t yr^{-1}) into the Indian Ocean. The Deduru Oya, which has the 1.73 times of the Maha Oya watershed (1510 km^2) and the 34 % of discharge of the total precipitation volume empties 4564 t yr^{-1} of dissolved silica while the Mi Oya which has the similar watershed area of the Maha Oya but the least percentage discharge of the total precipitation volume (16 %) discharges about 2018 t yr^{-1}. The silica leaching in the Maha Oya watershed was 5.549 t km^{-2} yr^{-1} while it was 2.800 t km^{-2} $yr^{-1}$and 5.798 t km^{-2} yr^{-1} in the Deduru Oya and Mi Oya respectively. These preliminary results indicate that the silica leaching is primarily determined by the annual precipitation volume, its parentage discharge and catchment geochemistry but the retention is favoured by the presence of manmade reservoirs.

Keywords: dissolved silica, reservoirs, river basins, diatom, Sri Lanka

Biogeochemical Budgets for Tapi Estuary

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Abstract

The Tapi Estuary (21°10'N, 72°40'E) is a tidal estuary originating in the Multai Ghats in the Betour district of Madhya Pradesh (India) at an elevation of 752 m. The 720 km long river, after passing through the 3 Indian states of Madhya Pradesh, Maharashtra and Gujarat, discharges into the Gulf of Kambhat (Cambay), NW-coast of India, near Hazira. Numerous tributaries feed the river in its upper reaches, while in the plains it branches off into a few distributaries, and in the lower reaches it takes a meandering course. During the SW monsoon (June to September) the river is also fed by the runoff from its catchment area of 65,145 km^2. The river discharge to the sea is controlled by the Ukai and Kakrapar dams constructed on the river at 115 and 141 km, respectively, from the mouth upstream. The average runoff of the river is around $7,686 \times 10^6$ $m^3.yr^{-1}$ with a peak discharge (av. 8,000 $m^3.s^{-1}$) occurring during the SW monsoon. The average rainfall in the catchment area is 984 $mm.yr^{-1}$, 85% of it occurring during the SW monsoon. The average salinity at the mouth is 32.52 psu and decreases rapidly in the upstream direction, a decrease by 10 psu occurring within 10 km from the mouth while a further 10 psu decrease occurs in the next 6-8 km. This steep salinity gradient results in the salinity falling to below 0.1psu within a distance of 30-32 km from the mouth.

The present study is based on the data on salinity, phosphate, nitrate, nitrite and ammonia collected by the Regional Centre of NIO, Mumbai (Bombay) at 9 stations covering a length of about 60 km of the lower estuary from the mouth towards upstream and the adjoining coastal sea, during three occasions between October 1983 and May 1984, covering the entire dry season. LOICZ Biogeochemical Guidelines were followed to calculate the biogeochemical budgets for water, salt and nutrients (DIN & DIP) for this estuary utilizing the above data. The study indicates that the estuary loses water at the rate of about 81.4×10^6 m^3 day^{-1} in the form of residual flux (V_R) at the estuary-sea interface. This results in export of salt to the tune of $1,667 \times 10^6$ psu m^3. d^{-1}. Exchange between the estuarine water and the adjoining seawater replaces this salt loss. The estuary also shows a net export of both DIP and DIN ($\Delta DIP = 61.7 \times 10^3$ $mol.d^{-1}$; $\Delta DIN = 1,610 \times 10^3$ $mol.day^{-1}$. The source of this is not understood. Probably, it reflects the inputs coming from the agricultural, domestic and industrial wastes.

Biogeochemistry of the Cauvery Estuary and Pichavaram Mangroves – SE Coast of India

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Abstract

The Study area is a very sensitive marine ecosystem with high productivity and therefore has both biogeochemical and socio-economical significance. The study area undergoes changes by removal and addition of organic and inorganic materials brought by the rivers. Spatial and temporal variation in the nutrients in the water, suspended and surfacial sediments has been observed. The water is alkaline in nature. TDS and EC increase in summer. Excess nitrate and phosphate is contributed by agricultural sources. Dissolved silica released in excess due to the biological activity and mangrove deforestation. Bicarbonate and sulphate show a minor variation with little fluctuation. It was found that there are multiple sources controlling the water chemistry. POC and PON show a decreasing trend towards the sea. Dissolved silica and phosphorous shows more erratic variation in the estuary compared to mangroves. The delta C thirteen (O13C) shows a marginal conservative behavior in the estuary. Enhanced levels in particulate accompany reduction in the dissolved Si and P concentration in estuary. P in sediment occurred in all size fractions and possibly as ferric and/ or Calcium Phosphorous. Organic Carbon is higher in the mangrove sediment in comparison to estuary. Similarly the heavy metals are enriched in the mangrove sediments indicating their unique chemical behavior and the existence of trapping mechanisms.

Keywords: biogeochemistry, nutrients, physiochemical processes, dilution effects, mixing effects

An Assessment of Nutrient Budgets of Lunawa Lagoon, Sri Lanka

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Abstract

Lunawa Lagoon is a shallow coastal body of water located on the west coast of Sri Lanka. It has a rather elongated shape, and the water surface area is about 20 ha and the perimeter is about 4.5 km. Lagoon is surrounded by highly populated area and some heavily polluting industries. Untreated effluents have been discharged from industrial sites into the small tributaries that feed into Lunawa lagoon. In addition, domestic wash water generated by residents in the area is discharged into open ditches draining into the Lagoon. The problems are amplified by the presence of a sand bar, which blocks the connection of the lagoon to the sea, restricting water flow and exchange. This hasresulted in decrease in salinity and an increase in accumulated nutrients and pollutants in the lagoon.

The paper describes the application of LOICZ budgetary model to predict the exchange of dissolved inorganic N (nitrate, nitrite and ammonium) and P (phosphate) between the Lunawa Lagoon and the adjacent ocean. This budgetary model is defined as a mass balance calculation of specific variables for a defined geographic area and time period. The model should include all major sources and sinks and usually requires a substantial amount of quantitative data for the area.

Present study was carried out with the available data for the Lunawa lagoon. It has been realized that some critical data is missing, especially in the case of Nutrients and other non-conservative components. However, as a first attempt it provides sufficient understanding of the system.

Keywords: nutrient budgets, effluents, Lunawa Lagoon

Nutrient Characteristics in the Coastal and Coral Reef Environment of the Gulf of Mannar Biosphere Reserve, India

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Abstract

The present study was carried out for a period of two years from July 1995 to June 1997 at Manoli island (Station 1), Hare island (Station 2) and Mandapam coast (Station 3) in the Gulf of Mannar Biosphere Reserve. At these stations, monthly variations in the concentrations of nutrients viz. particulate organic carbon (0.48- 4.32 mg C l^{-1}), nitrate (1.65 – 12.48 µM), nitrite (0.02 – 3.76 µM), inorganic phosphate (0.02 –1.23 µM) and reactive silicate (0. 42 - 14.25 µM)) were recorded, which showed characteristic behaviour and spatio-temporal differences.

The reef environment (stations 1 and 2) recorded higher POC than that of the coastal waters (station 3). It could be mainly due to the production of coral mucus and contribution from the macrophytic vegetation of the coral reef areas. The primary peak of POC observed during the premonsoon season could be due to reef associated seaweeds whose biomass was maximum during that season. At station 3, as there were no suitable substrata for seaweed growth, only phytoplankton might have contributed to POC production in addition to land run off during the monsoon season.

The monsoonal maximum of nitrate and nitrite concentrations recorded in the reef areas could be attributed to the biological activity, in addition to terrestrial inputs . In the coral reef environment, population density of ammonifiers, nitrate reducers and nitrogen fixers was high in both water and sediments during the monsoon season, suggesting the possible role of these microbes in releasing the nutrients into the water column. Total mean concentration of nitrite (1.18 µM) and nitrate (8.15 µM) was higher at station 3 than at stations 1 and 2, as station 3 has terrestrial source of input during monsoonal season.

At the reef stations 1 and 2, slightly higher values of phosphate have been recorded than at coastal station 3. Lower values of PO_4 recorded during the postmonsoon and summer seasons could be due to its utilization by phytoplankton which occurred in higher densities in the reef areas during these seasons and also by zoozanthalle. Levels of phosphate recorded from the Gulf of Mannar are optimal (0.02 to 1.23 µM), for the growth of corals. Reactive silicate is not an essential element for the corals but required for the reef associated organisms. During the study period, monsoon season recorded maximum silicate concentration at all the three stations whereas the postmonsoon and summer seasons recorded the minimum values. The latter could be attributed to the

utilization of this nutrient by the flourishing growth of phytoplankton especially diatoms during these seasons and lack of fresh water input into the reef areas.

Keywords: Coral reef, nutrients, phytoplankton, seaweeds

Heavy Metals Uptake by Marine Biota in Pondicherry Coastal Zone, Bay of Bengal - India

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Abstract

The physical and chemical environments of the open oceans have not been affected by events over the past 300 years, principally because of their large diluting capacity. In contrast to the open oceans, regional seas close to the large population centres show clear evidence of increasing concentrations of several substances over the past 100 years or so years. Such increases are more apparent in coastal areas, which are closer to sources and have less dilution capacity. Coastal studies have been undertaken to determine the concentration of heavy metals in marine environment and to further assess accumulation of the toxic elements in the organisms. An increase in concentration of Cd, Cu, Pb, and, Zn with decrease in salinity was observed at all the stations exhibiting a significant negative correlation between salinity and heavy metals. The sediment metal concentration (Zn, Cu, Pb and Cd) showed higher values during low salinity period (monsoon). When compared to other stations, the sediment metal concentration was higher at Station IV. It is mainly due to the entry of metal rich domestic municipal and agricultural waste from the adjacent area .The concentration of metals in Prawn (*Pinaeous monodon*) showed negative correlation with salinity . The higher concentration in organism during low salinity monsoon period is again mainly due to fresh water inflow to the coastal zones. The biological effect of such increase in concentration is often a process of biomagnification. An example of biomagnification can be quoted from this study on Zinc; a heavy metal, which has a concentration of 22.41 μg per litre in coastal waters gets enhanced to 67.25 μg per litre in shell fish, *Pinaeous monodon*. This means that Zinc in marine environment has cycling through the food chains such as plankton to shrimp and gets magnified to man .So controlling these heavy metals concentration is very important from the stand point of ecosystem stability.

Keywords: heavy metals, biomagnification

An Environmental Assessment of Metal Accumulation in the Karnafully Estuary, Bangladesh

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Abstract

Seasonal variations of trace metal concentrations in water and sediment samples of the Karnafully estuary were analyzed by atomic absorption spectrophotometer from January to December 1996. Subsurface water and surficial sediment samples were collected from 5 stations of the lower estuary. In water, metal concentrations ($\mu g.ml^{-1}$) were found to range from 0.125 to 0.482 for Cu, 0.033 to 0.540 for Pb, 0.206 to 0.985 for Zn, 0.101 to 0.572 for Ni, 0.008 to 0.168 for Cd, 0.282 to 0.931 for Mn, 4.20 to 22.23 for Fe and 0.132 to 0.513 for Cr. In sediment, metal concentrations ($\mu g.g^{-1}$) were found to range from 10.118 to 36.254 for Cu, 11.000 to 36.211 for Pb, 0.155 to 7.466 for Zn, 16.985 to 35.112 for Ni, 0.135 to 1.077 for Cd, 11.955 to 29.554 for Mn, 559.66 to 1117.78 for Fe and 18.154 to 44.057 for Cr. Distribution of trace metals in sediments were not related to the corresponding distribution in water; although the concentrations of trace metals in water were low, the corresponding contents in sediments were high. Water and sediment from the study area focused generalized pollutant influence, which might be due to the combination of large population, high industrialization, shipping activities, discharge of untreated domestic and industrial wastes and city run-off.

Keywords: metals, water, sediments, estuary, pollution.

The Complex Estuarine Formation of Six Rivers (Cochin Backwater System on West Coast of India) – Sources and Distribution of Trace Metals and Nutrients

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Abstract

The largest backwater system on the western coast of India is the Cochin Backwaters (256 km^2) to which 16 major industries discharge nearly 0.104M m^3 d^{-1} of wastes containing organic wastes at 260 t d^{-1}. The backwater receives freshwater from 6 rivers - 5 in south, one in the north and 33% of river discharge is from Periyar. The river discharges of 19,000 M m^3 y^{-1} also carries a substantial portion of the fertilizer load (20000 t y^{-1}). Trace metals in estuarine sediment had shown a post - monsoon enrichment of Zn, Pb, Cu and in the northern and southern limbs of the estuary. The dissolved iron had an opposite trend to that of it in the sediments. The strong influence of fresh water modifies the sediment to leach out chromium as inferred from low values (<30ug/g) at the bar mouth. The entire region is enriched with manganese (141- 337 ug/g) with the lowest values around the bar mouth. High values of Zinc (>1000 ug/g) were noted in the east channel and low levels (~90 ug/g) at the bar mouth. The dissolved zinc had enrichment in the backwater with 116 ug/l in the year 1986 and with 879 ug/l in 1991. Nearly 80 tons of Zinc seems to have accumulated in the water body. The copper content in sediment ranged between 5 - 53 ug/g with high values in the northern limb and the dissolved copper had a range of 1 -3 ug/l. The distribution of Nickel and cobalt were similar and a concentration of Ni (0.60 ug/g) indicates the absence of pollution. Significant correlation of iron with other metals (except Mn) indicates that elemental accumulation in sediments may be controlled by precipitation of iron on to organic matrix. The significant correlation between metals (except Mn) shows a common source of metals. Natural processes control the distribution of most metals, while Zn is influenced more by anthrpopogenic input. Cochin bar mouth and harbor region was not enriched in metals to greater levels. The northern part, an enrichment of metals, especially Zn is evident. Absence of build up in harbor and bar mouth may be due to periodic dredging and removal of recent sediment deposit. Strong negative correlation between salinity and nutrients within the estuary indicate that nutrient levels are controlled by upstream discharge. The estuary acts as sink for silicate during neap tide. The nutrients NO_3 and PO4 were present at very low levels up to mid 1960s and the levels had increased during 80's. The levels for nitrate and phosphate were 0.75 uM, 2.0 uM during 1965 and were 3.9 uM, 6.0uM during the year 2000. A build up of N & P after 1975 was observed in the backwater and from 1980 onwards, the concentration remained high. It is estimated that the backwater is receiving 42.4 10^3 mol d^{-1} inorganic PO_4 and 37.6 * 10^3 mol d^{-1} of organic nitrogen through Periyar. The export to coastal waters is only 28.2 * 10^3 mol d^{-1} inorganic PO_4 and 24* 10^3 mol d^{-1} of inorganic NO_3. Thus estuary seems to act as a sink for nutrients. Associated with the diminishing of flushing rate, a nutrient build up is taking place for the backwater system.

Keywords: trace metals, nutrient sources

Nutrient level of coastal waters in and around Mumbai (Bombay)

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Abstract

The coastal belt of India is about 7500 km including the Bay of Bengal on the east coast and Arabian Sea on the west. Whereas, 720 km coast stretch touches Maharashtra including five districts namely Thane, Mumbai, Raigad, Ratnagiri and Sindudurg. Mumbai (Bombay) is an island situated on the west coast of Indian peninsula on the Arabian sea and encircled with the shore line of about 167 km, is one of the major sinks on the western peninsula of Indian subcontinent. Coastal area in and around Mumbai receives anthropogenic input including heavy metals, pesticides and hydrocarbons in addition to sewage. The city coastline is highly indented with creeks, estuaries and bays. Moreover, the coastline has undergone extensive changes due to reclamation that have interfered with natural erosion processes and causes intense erosion as witnessed in some parts of Mumbai. Mahim, Malad creeks in the city and Vasai, Manori, and Thane creeks around Mumbai receive around 2161mld of domestic waste, and a BOD load of 425 tones/day. Along with this 243mld of industrial waste with a BOD load of 24.3 tones/day is also discharged into these creeks. Although sewage treatment plants are located at some of the areas of Mumbai, substantial quantity of untreated domestic waste is released into nearby creeks, bays and directly into the coast. Therefore, more than 300 tones of suspended solids, 40 tones of nitrogen and 7 tones of phosphorus enter everyday into marine ecosystem around Mumbai. During present investigation nutrient like phosphate and nitrate along with other physicochemical characteristics were monitored in some of the coastal spots in and around Mumbai. The results of present investigation reveal a high level of phosphate and nitrate in coastal waters of some of the sites of Mumbai in comparison with earlier studies.

Keywords: India, Maharashtra Mumabi, phosphate, nitrate

Impact of Reduced River Discharge on the Mangrove Ecosystem and Socio-economy of Indus Delta

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Abstract

The coastal zone of Indus Delta has come under the environmental stress from progressively reduced inputs of nutrients, sediments and freshwater as a result ofreduced Indus Discharge. This situation has resulted in increased water salinity and influx of seawater intrusion into the coastal land and also affects ground water resources. Consequently, the Indus estuary areas in most part of Indus Delta have shrunk and its estuarine fauna and flora have come under stress. The nutrient supply from silt has reduced considerably thereby reducing overall productivity of the area. Major impacts have been caused in the coastal zone of Indus Delta by progressive reduction of freshwater supply to the coastal zone, reduced cover of mangrove forests, over-exploitation of fisheries resources and migration of population from affected areas.

Keywords: coastal zone, mangroves, river discharge

The Anthropogenic Affects and Natural Hazards on the Stability of the Indus Delta and Creek System

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Abstract

The Indus Delta consists of more than seventeen major and minor creeks and extensive mudflats that are under stress due to lack of a coordinated management plan and consequently harsh natural environment. Extensive use of fresh water for irrigation in recent years has caused a decline in the Indus River discharge. Construction of barrages, dams, and link canals has reduced the freshwater flow downstream from 180 billion m^3/year to less than 43 billion m^3/year (IUCN, 1991). Current development programmes would further reduce the outflow into the sea by 12 billion m^3/year (Meynell and Qureshi, 1993). The reduced sediment and water discharge from the Indus River is causing stunt growth of mangroves and also affecting the long-term sustainability of the delta and adjoining area.

A cyclonic event in 1999 had a negative impact on the Left Bank Out fall Drainage (LBOD), a man made drainage system on the left bank of Indus River. Breaches have occurred in the tidal link, resulting in major geomorphic and ecological changes due to sea water intrusion. Ground investigation and the interpretation of satellite imageries indicate momentous erosion of coastal islands in the vicinity of Indus Delta. Assessment of past and present findings indicates an alarming increase in the erosion rate of both Bundal and Buddo Islands since the 1980's. The accelerated hydrodynamic changes have occurred probably due to deepening and widening of the approach channels of Port Bin Qasim resulting in destabilisation of sediments in older Indus Delta.

The recorded sea level rise at Karachi and adjoining Indus Deltaic area, based on the data for the past 100 years, is 1.1 mm/year and it is expected to be more than double during the next 50 to 100 years, resulting in 20-50 cm rise in sea level (UNESCAP, 1996). There are no direct measurements available on subsidence rates in the Indus Delta, however, experience in other deltas indicate that subsidence rates at the delta must have increased due to lack of sediment flux. Indus Delta could experience a relative sea level rise of up to 8 to 10mm/yr as per the projected rate of global component of sea-level rise of up to 6mm/yr in the next century. If the present trends continue the Indus Delta will ultimately establish a transgressive beach dominated by aeolian dunes, due to lack of sediment inputs and high energy waves (Haq, 1999).

In conducive man made changes coupled with natural physical forcing in the Indus delta and adjoining area will conspicuously change the geomorphic and hydrodynamic setting of the delta, that may result in the associated changes in the prevailing physical processes, which in turn will have a negative influence on coastal resources, infrastructures, industries, ecosystems and socio-economy of the area.

Keywords: Indus Delta, sediment flux, ,anthropogenic affects

Recent trends in environmental degradation in the coastal areas developed for shrimp culture

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Abstract

Shrimp industry in Sri Lanka developed rapidly during the last decade resulting in rapid degradation of the coastal environment in the North Western province. The land allocation for shrimp culture was less than 500ha in 1985 and increased to over 4000ha by 2000.

Reduction of environmentally sensitive areas has caused a reduction in Biodiversity. The mangrove cover has reduced by 41% due to shrimp culture activities. Migratory bird populations visiting the Mundel area have reduced by 48%. The species diversity in the lagoon fishery has reduced from 19 species in 1991 with catches dominated by Nematolosa nasus to 14 species in 2000 with catches dominated by Arius species. The only shrimp species caught in the Mundel lagoon is Peneaus monodon in small numbers while there was a good fishery for Peneaus indicus and Peneaus semisulcatus in the past.

The Mundel lagoon area has been reduced by 9%. Construction of dykes obstructing natural water drainage has increased the incidence of floods in the area. The water quality deterioration caused by direct discharge of effluents to the surrounding water bodies, has resulted in elevation of BOD levels, Nitrite, Ammonia and sulphide levels as well as the water pH and Suspended solid concentrations.

Populations of several pathogenic viral and bacterial species in the coastal area have increased even threatening the wild crustaceans in the natural environment. Use of probiotics to treat water as well as use of chlorine and lime without any technical guidance has resulted in further aggravating the problems.

Importance of introducing a monitoring system and educating farmers and their technical consultants could help in enhancing production with lesser impacts on the environment.

Keywords: coastal environment, shrimp, aquaculture, water quality

Impacts of the Reclamation of Acid Sulphate Soil Sediments on Coastal Environment

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Abstract

Acid sulphate soils dominate the coastal areas of monsoonal humid tropics where the tidal areas are covered with dense mangrove forests. One third of the world's acid sulphate soil sediments are distributed in South East Asia and south Asia. In Sri Lanka acid sulphate sediments are widely distributed in the coastal areas of South Western province.

Five different potential aid sulphate soil classes and six different acid sulphate soil classes have been identified from North Western, Western and South Western coastal areas. Some of these soil classes will have minimal adverse impacts while some have serious environmental repercussions upon reclamation. Conversion of these areas for aquaculture, agriculture and other development activities have resulted in several environmental, ecological and sociological consequences in coastal waters of Sri Lanka.

Acidifications of coastal waters, influx of iron, manganese and aluminum are some of the serious environmental consequences identified as a result of reclamation of pyretic sediments for aquaculture. Sudden fish kills, low natural production with frequent disease outbreaks are some short-term effects of the reclamation of acidic sediments. Long-term effects on coastal waters include reduction in biodiversity, reduction of fishery resources, increase availability of toxic elements and reduced availability of nutrients.

Detailed soil surveys to identify less harmful soil classes for reclamation is recommended to minimize the above impacts on the coastal environment.

Keywords: sulphate, reclamation, coastal areas

Human Impact on Wetland Ecosystems:
A Case Study – The Mundel Lake and Its Environs – Sri Lanka

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Abstract

The Mundal Lake and its environs can be considered as a disturbed wetland system due to excessive utilization of the resources beyond the sustainable limit. The area is located between Puttalam Lagoon (on the north) and the lower basin of the Deduru Oya (river) (on the south). The flat continental shelf on the western margin of the Lake consists of a straight coastline with wide beaches, berms and sand dunes. The old raised dune ridges bound the eastern margin.

The Mundal Lake and its surroundings are consisted of different types of landforms, and formation and evolution of these features have a close relationship with local climatic conditions, such as temperature, rainfall pattern, evapotraspiration, wind circulation and salinity levels. All these factors have contributed to the rich biodiversity in and around the lake.

Fishermen and farmers are hereditary people in the area. About twenty-thirty years ago, fertile patches of coconut lands were located along the sand barrier and old dune ridges, while mangrove associates and salt marshes associations covered the edges of lagoon and the creeks. But introduction new development activities such as aquaculture farms in recent years have disturbed the physical environment in and around the Mundal Lake. Use of tidal and mud flats and destruction of mangrove patches and salt marshes in large scale to construct prawn ponds are the main human impacts in the area. Damming and destruction of natural cannel network to intake water to ponds as well as to discharge of effluents from the prawn ponds, construction of dykes, canals, pipe lines and electric wire networks are the other destructive activities. Converting ridge and runnels and reclamation of mud flats to cultivate of coconut and other crops, and extraction of ground water thorough deep well to reduce the high salinity of the ponds are also have responsible for raise a number of issues of the area.

Keywords: wetlands, human impacts, pollution

Human activity management in coastal zone of Sri Lanka

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Abstract

Sri Lanka is an island with a long coastal belt. The wet zone has 2600 mm annual rainfall and it extends from Chillaw to Matara. Coconut cultivation is predominant in highlands. Salinity is the natural problem in the coastal zone. Drinking water is tapped from the drainage sources. In February and August months salinity enters the water supply inlets due to its low water levels. Also salinity enters paddy fields destroying the cultivation.

Human activity is now imposing a high threat in controlling salinity. Sand mining in rivers is the major reason for coastal zone structural damage. Increasing level of building construction and hence making bricks out of sand has caused heavy extraction of sand from all available locations. The natural phenomenon of making and maintaining sandy beaches has now disturbed. Sufficient sand is not reaching the river sea confluence to maintain sandy beaches. Erosion in beaches has caused extensive damage to the railway line and houses. The beauty of the beach is lost when revetments are formed to protect the eroded coastal line. Mining limestone in the SW zone has again caused the loss of coral reef and death of valuable and beautiful variety of corals.

Village level teaching programs for the protection of environment is planned. But the human activity is increasing with tourist industry in this area. Chemicals also had caused death of corals. Effluent released from hotels, dwellers and factories have caused chemical damage and eutrofication in lagoons.

Coastal zone management is assigned to Coast Conservation Department. The traditional irrigation and drainage of water is assigned to Irrigation Department. There is a necessity to control bank erosion of rivers. People do not seriously feel the gravity of coastal zone management. Investors think about the profit only and not on the long-term effects of the construction work. Mangrove trees are now reduced. This amounts to rise in sea level in coastal zone. Prawn farmers converted lagoons into busy areas but the addition of biomass has affected bio diversity. In Northern and Eastern coastal areas erosion is low but many locations are affected by erosion of lime. A national program combining all investors are necessary to develop a strategy to preserve sandy beaches and water quality in line with economic development   Fisheries, tourism, industries, agriculture, ports development and water quality have combined effect on management.

Key words: business activities, traditions, tourism, management

Poster Presentations

A Simplified Procedure for Sediment Monitoring – Reducing Gaps in Sediment Information

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Abstract

The work presented here is to simplify the quantification of sediment discharge through simplified sampling and analysis procedure that need easily available and less expensive equipment and minimum level of training. The data obtained from the simplified procedure at three different sites (Narayanghat on the Narayani, Betrawati on the Trishuli, and Karmaiya on the Bagmati) in Nepal were compared with the standard methods. In the simplified procedure, sediment was sampled by immersing a sampling bottle on the surface of the river at a convenient location, usually close to a bank. The sampled sediment was filtered using a Buchner Funnel and dried using a locally fabricated solar dryer at the sites. Sediment concentration obtained in this fashion was then used to obtain daily average sediment concentration by using a correlation relationship between the bank sample and the river average sediment concentration for a given stage. This procedure, however, required at least a one-time calibration of the gauging site with intensive sediment measurements at different water levels with standard method for obtaining a relationship between the bank sediment and the cross-sectional average sediment. The average sediment in this experiment was obtained by sampling the sediment at seven equally spaced verticals by depth integration method using US D-49 sediment sampler. The evaporation method, recommended by the United States Geological Survey, was used for laboratory analysis for the station calibration period. The study also included the comparison of filtration method and evaporation method as the filtration method was more feasible at field stations. The comparisons did not show significant difference. The studies carried out indicated that there are distinct advantages in replacing the existing depth integrated-single section sediment monitoring system with a simplified system such as the system proposed here, which can be easily applied at the site or field station. This system is likely to improve the condition of missing or less representative data found in developing countries primarily because of complex sediment sampling procedure, sophisticated equipment, and unavailability of skilled human resources. The results suggest that while developing sediment-sampling system, it is also advisable to pay more attention to representativeness of samples.

Key words: sediment, calibration, sampling, sampler, Nepal

A study on the impact of sedimentation and organic matter in the sediments on two reef sites in the southern coastal belt of Sri Lanka.

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Abstract

This study was carried out from March 2000 to April 2002 at shallow fringing reef site at Polhena (Matara) and patchy granite reef site in Tangalle. Above reefs have been subjected to severe anthropogenic activities in the past and at present they are mainly affected by freshwater discharges and coastal constructions. Main impact to Polhena Reef is caused by freshwater discharges from Nilwala River and Tangalle reef is currently affected by the discharges from Kirindi Oya, boat discharges from Tangalle fishery harbour and by the construction of groins at the harbour. Present study investigates the impacts of sedimentation due to above anthropogenic activities, on the distribution of benthic biodiversity on the above reefs.

Sediments accumulated during each month in traps fixed in different locations were collected, and the rate of sedimentation (g $m^{-2}day^{-1}$) was calculated. Percentages of organic matter content were also measured. On every sampling occasion, percentage cover of live benthic organisms (coral and macro algae) and other non-living material (mainly sand) within the sites were determined using the Line Transect Technique. Physicochemical parameters (water depth, Temperature, Turbidity Salinity, pH, Dissolved Oxygen concentration and Biochemical Oxygen Demand) of water in the sampling sites were also determined.

Highest and the mean sedimentation rates observed in Polhena and Tangalle were 3808 $gm^{-2}day^{-1}$ in July 2001 and 1845±833.4$gm^{-2}day^{-1}$ and 2026$gm^{-2}day^{-1}$ in September 2000 and 818.5±498.4 $gm^{-2}day^{-1}$ respectively. Highest and the mean percentage of organic content in Polhena and Tangalle reefs were 16.7% in April 2000 and 12.1±2% and 34.4% in October 2000 and 23±7.1% respectively. Polhena had a higher number of coral species (05) and a larger area was covered by live corals (18.35%) when compared with Tangalle(8.99 %). In Tangalle there were three species of corals and *Montepora sp* was the dominant species and *Pocillopora sp* and *Acropora sp* showed a lower distribution (less than 1%). In Polhena, *Podobacia sp* was the dominant species(27.21%) followed by *Pocilliopora sp*(18.38%) *Acropora sp*(5.33%) *Montepora sp*(3.62%) and *Galaxea sp*(.59%). A larger area of Tangalle reef site was covered by macro algae and sand (15.41% & 33.95%) when compared to Polhena (10.69%& 22.68%).

Above study although does not indicate the effects of sedimentation on the distribution of corals in the two reef sites studied herein, high macro-algal cover and low distribution of coral species at Tangalle reef could be related to the high organic matter content in the

sediments collected on the reef. Larger percentage cover of *Montepora sp.* at Tangalle also may have some relationship to the organic matter content of sediments collected on the Tangalle Reef and it needs further investigations.

Biogeochemical studies in the AchanKovil River basin, Kerala

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Abstract

The Achankovil river basin is a small river basin with uniform lithology and almost uniform meteorological conditions without much human impact to the river system. Hence an attempt has been made to understand their biogeochemical processes and their nutrient input to adjacent Lakes and coastal environments. Three seasonal sampling of water, suspended and surfacial sediments were collected. They are analysed for various major and minor dissolved ions and nutrients in waters. Suspended and sufacial sediments were analysed for nutrients and micronutrients. It is observed that the nutrients are enriched more in the monsoon period in comparison to pre and post monsoon periods. The Dissolved ions show seasonal and temporal variations. The lithology plays a major role in controlling the water chemistry. The river system is Nitrogen limited rather P during most of the time. The river system is enriched with DO through out the year. The sediments show higher concentration of C in comparison to P and S. The anthropgenic impact to the river is found to be very limited. Then based on our data and collected secondary data on climate, discharge, rainfall etc. A multibox linear model has been developed following the LOCIZ model. It is found that from the NIP and DIP budget, they are only received by the river system and not consumed by it and it is not releasing back to other system except to the coastal zone. The discharge of nutrients from the system seems to be high due to the supply from small tributaries Pamba and Manimala Rivers. The study reveals the control of lithology and climate control the nutrient chemistry of teh river system. We also estimate the nutrient budget of this river system.Core and surafacial samples were also studied for their mineralogy, texture and chemistry.The C, N and S weer studied in the sediments. The C/N ratio varies from 1.04 to 6.02 . The Kjeldhal nitrogen ranges from 0.3% to 0.5%.The S valuse are very low and ranges from 0.01 to 0.5%. The weathering index studies points out that the rate of weathering increases from upstream to downstream.The Nutrient content of core sediments shows a decereasing trend towards the surface.

Keywords: nutrient budget, weathering process, solute transport, river discharge

Impact of Shrimp Culture on the Mi-Oya Estuary

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Abstract

Rapid expansion of the shrimp culture industry has resulted in many environmental changes in the North western province of Sri Lanka. The Mi-oya estuary which was sparsely populated contained different habitats including mangroves, salt marshes and wooded areas consisting of a rich Biodiversity. The development of this area for shrimp culture altered the environment completely creating adverse impacts not only on Biodiversity, but on water quality degradation, and socio-economic structure of its inhabitants.

The total number of farms in this area exceeds 100 and the land utilized was over 800ha in 1998.. The mangrove coverage has been reduced by 68% while salt marshes and wooded areas have been reduced by 90% and 62% respectively. Siltation caused during farm construction and operation has caused depletion of the sea grass layer. Mi oya tributaries in the estuary area has been altered by construction of dykes and diverting water for shrimp culture purposes.

The water quality changes in the estuary from 1992 to 1998 indicates elevated salinity (21 ±2.3 to 29.7±4.76), pH (6.3± 0.86 to 7.9±0.43), nitrates (0.003±0.001 to 0.01±0.006), nitrite (0.004±0.001 to 0.02±0.005), ammonia (0.004±0.0003 to 0.008±0.005), sulphide (0.053±0.006 to 0.24±0.008 and total suspended solids 9 126.9±35.5 to 341.7±57.4).

The alterations to socio-economic structure include problems in water quality degradation, human health problems, reduction in fish catches, obstruction to traditional fishery and unequal rights for resource use.

The above conditions could be mitigated by giving due consideration to environment and socio-economic structure of the area prior to further developments and by adapting environment friendly culture practices that would reduce the pressure on the estuarine environment.

Sida - SAREC project no. SAREC / CE 19 is acknowledged for financial support.

Keywords: shrimp culture environment, aquaculture, environment impact

Impact from Anthropogenic processes that affect two near shore coral reefs located in Matara and Weligama Southern Sri Lanka

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Abstract

Coral reefs are biodiversity rich ecosystems, which have become a valuable resource to many coastal and urban communities of Sri Lanka. Their degradation have been resulted faster than the ability to recover naturally, due to certain anthropogenic activities performed intentionally or otherwise. Two near shore fringing reef lagoons located at Polhena (Matara) and Weligama of Southern Sri Lanka were subjected to underwater and socioeconomic surveys from August 1999 to December 2001, to assess the possible impacts due to anthropogenic activities. Objective of this study is to provide information on the impacts from anthropogenic processes, which are prerequisites for identification of management strategies to be implemented for coral reef conservation.

Most commonly observed anthropogenic activities at Polhena reef lagoon (PRL) are recreational activities by tourists and ornamental fish collection using harmful techniques and at Weligama Reef Lagoon (WRL) are anchorage of fishing boats and ornamental fish collection. Total live coral cover percentage at WRL (31.04±13.7) is significantly higher than at PRL (18.39±10.69). Dominant live coral species recorded at WRL is *Acropora formosa* (25.3 %) and at PRL was *Podabacia crustacea,* an opportunistic coral growing on dead *Acropora* (4.25 %). Tourists (mainly local) who come to PRL for swimming and bathing cause a major impact to coral recovery by harming the corals that newly generate and also those which regenerate. According to the observations made during the present study, an average of 577 visitors day^{-1} are engaged in different activities harmful to the young corals. Among such activities walking on the reef, trampling live corals, resting on the reef and collecting souvenirs, especially during low tide is dominant. Ornamental fish capture using destructive techniques and gears is presently under operation at PRL and WRL. Average number of persons engaged in it were 2 day^{-1} at PRL and 5 day^{-1} at WRL. Within the WRL fishing boats are anchored, using it as a natural harbor causing severe damage to the reef. This also causes an impact on the vegetative propagation of broken fragments of *Acropora formosa*. According to "Census of Marine Fisheries in Sri Lanka" Western, Southern and Eastern Provinces (1998), 56 fishing boats are operating from Weligama and according to our observations 38 boats day^{-1} are frequently anchored in an area of 0.036 Km^2 on the WRL.

Recovering percentage of the *Acropora formosa* branches and fragments were determined at the boat anchoring site and at other sites, which are not used for anchorage and it shows that boat anchorage is having a direct impact on the recovery of *Acropora formosa* (11.2 ± 2.4 and 35.8 ± 8.4 respectively). A proper management plan and enforcement of law is essential to rescue this fragile ecosystem from the anthropogenic activities.

APPENDIX IV

Biogeochemical Budgets for Estuaries in South Asia

Bangladesh

Water, Nutrient and Sediment Flux Study through the Lower Meghna River Estuary (Hatiya Channel)
Nuruddin Mahmood[1], Sayedur Rahman Chowdhury, Sharif, Mohammad Muslem Uddin, Abu Syeed Muhammad Sharif, and Mohammad Saeed Ullah

Material Flux through the Karnaphuli River
Sayedur Rahman Chowdhury[1], Nuruddin Mahmood, Mohammad Muslem Uddin, Abu Syeed Muhammad Sharif and Mohammad Saeed Ullah

India

Biogeochemical Budgets for Tapi Estuary
Meghana V. Bapardekar, S.N. de Sousa , M. D. Zingde

Biogeochemical Budgets for Muvattupuzha Estuary, Kerala, India
Betty D. Cherukara, S.N. de Sousa and M.D. George

Pakistan

Nutrient Budget calculated for the Indus River and Delta System
Asif Inam, M. Danish, A. R. Tabrez, Azhar Siddiqui, Shafiqur Rehman , and Rehan-ul-Haq

Sri Lanka

An Assessment of Nutrient Budgets of Lunawa Lagoon, Sri Lanka
S.P.Samarawickrama and S.S.L. Hettiarachchi

Negombo Estuarine System: Exploratory Steady-State CNP Flux Budget
Samarawickrema S.P and U.A.P.K Dissanayake

APPENDIX IV-A

BANGLADESH

Water, Nutrient and Sediment Flux Study through the Lower Meghna River Estuary (Hatiya Channel)
Nuruddin Mahmood[1], Sayedur Rahman Chowdhury, Sharif, Mohammad Muslem Uddin, Abu Syeed Muhammad Sharif, and Mohammad Saeed Ullah

Material Flux through the Karnaphuli River
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Water, Nutrient and Sediment Flux Study through the Lower Meghna River Estuary (Hatiya Channel)

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Abstract

Water, Nutrient and Salt transport through the lower Meghna estuary, a combined flow of the Ganges and Brahmaputra and many other rivers, was studied. Despite a very complex network of rivers and channels, a simple approach of measuring these parameters for an annual cycle during premonsoon, monsoon and postmonsoon seasons covering an area of about 532 km^2 results in knowledge in this previously untouched arena of material flux. Although, vastness and complexity of the estuary made it almost impossible to sample each and every creek and channel, an attempt was made to fit a single layer simple box model to study the budget of these materials in the lower reaches of the river estuary.

Keywords: nutrient flux, Meghna-estuary, Bangladesh

Study area description

The Meghna River is the main outlet of the Ganges-Brahmaputra river system collecting water from a vast catchment area of India, Bangladesh and Nepal. At the lower reaches of the river system the Meghna River is connected to numerous smaller rivers, channels and creeks before emptying into the Bay of Bengal to the southern middle part of Bangladesh. At the lower reaches, the river forms a huge estuary during the premonsoon

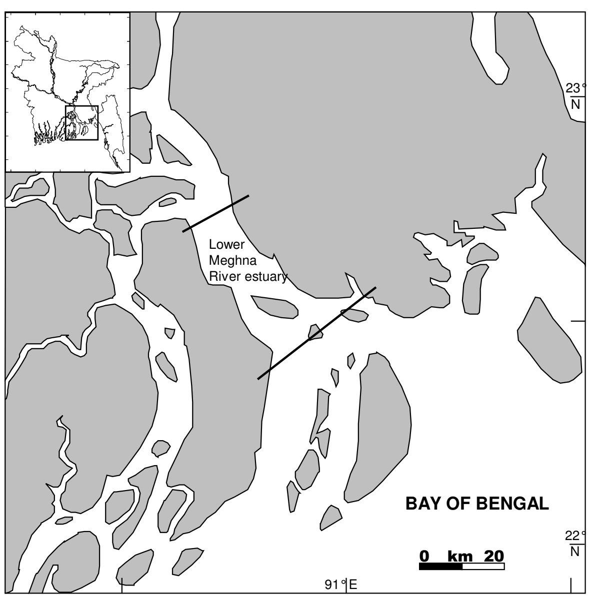


Fig. 1. Study area in the Lower Meghna Estusry

season and turns almost fresh during the monsoon and early postmonsoon. This paper presents the budgets of water, salt and nutrients for the Lower Meghna River estuary using the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al*, 1996).

For the water, salt and nutrient budgeting an area of approximately 532 km^2 between about 22°25'N, 90°40'E and 22°40'N, 91°05'E has been selected in the lower Meghna River (Figure 1). Average depth of the estuary is 5-6 m. Water level rises by about 1 m during the Monsoon from that of the premonsoon (Chowdhury, 1993).

Sampling and analysis

The lower Meghna River estuary and the mouth of the Meghna River were sampled during premonsoon, monsoon and postmonsoon seasons for a year between 2001 and 2002 for nutrients (NO_3^-, NO_2^-, NH_4^+, PO_4^- and SiO_2^-) as well as other water quality parameters. Water samples were collected, preserved, transported and analyzed following standard procedure (Barnes, 1959; Strickland and Parsons, 1965; Parsons and Stickland, 1968; APHA, 1975; Suess, 1982; Jin-Eong *et al,* 1985). Rainfall data and discharge data were collected from Bangladesh Meteorological Department and the Institute of Water Modelling (former Surface Water Modelling Center) respectively. Evaporation was calculated from other atmospheric data. Groundwater exchange and outfall were assumed to be negligible. Data used in this budgeting exercise is shown in Table 1 and Table 2.

Table 1: Chemical composition of water samples from Lower Meghna river estuary (System) and the mouth of the river (Bayside)

Site	Season	Salinity ppt	DIP $mmol/m^3$	NO_3^- $mmol/m^3$	NO_2^- $mmol/m^3$	NH_4^+ $mmol/m^3$	DIN $mmol/m^3$
Lower Meghna Estuary	Pre-monsoon	9.94	86.16	15.86	0.20	1.44	17.50
	Monsoon	0	23.73	15.76	0.12	0.10	15.98
	Post-monsoon	0	14.66	2.52	0.10	1.12	3.74
Mouth of Meghna river	Pre-monsoon	11.74	66.36	7.16	0.24	6.65	14.05
	Monsoon	0.1	23.73	4.33	0.24	0.22	4.79
	Post-monsoon	0.1	16.18	19.15	0.52	1.59	21.26

Table 2: Model input parameters and assumptions

Parameter	Pre-monsoon 10^6 m^3/day	Monsoon 10^6 m^3/day	Post-monsoon 10^6 m^3/day
Precipitation	83.524	230.755	16.736
Evaporation	34.261	44.688	52.774
Discharge	6.472	4399.357	1556.367
Groundwater	0 (assumed)		
Outfall	0 (assumed)		

Water and salt budget

Salinity data in the lower Meghna River estuary and the mouth of the river shows that the whole regime turns almost fresh during the monsoon and postmonsoon seasons. Presence of small amount of salt at the mouth in these seasons detected by means of electrical conductivity makes it possible to budget the system. No significant vertical stratification was observed. Results of the water and salt budgeting are shown in Figure 2a through 2c.

Figure 2a: Water and salt budget for the lower Meghna River estuary in the Premonsoon season

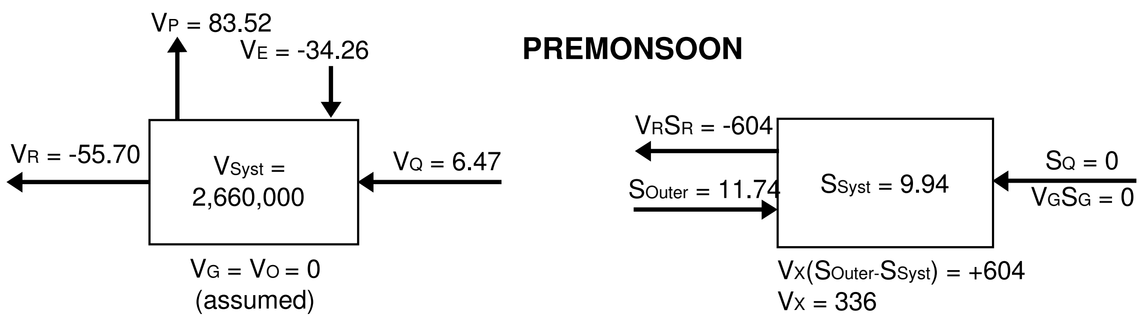


Figure 2b: Water and salt budget for the lower Meghna River estuary in the Monsoon season

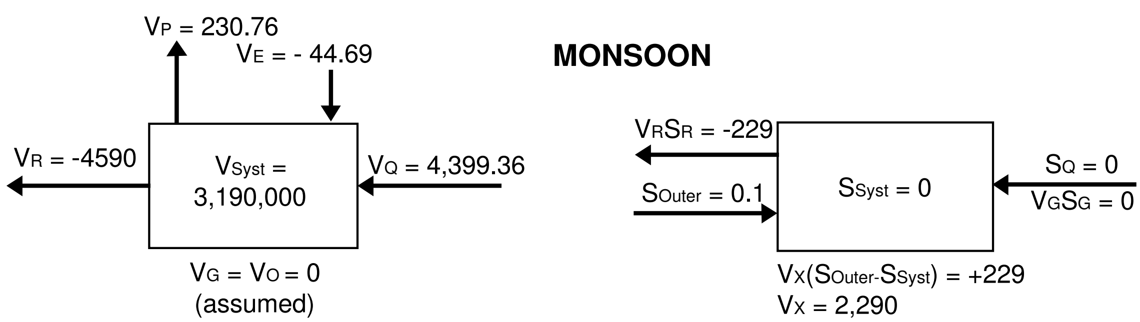
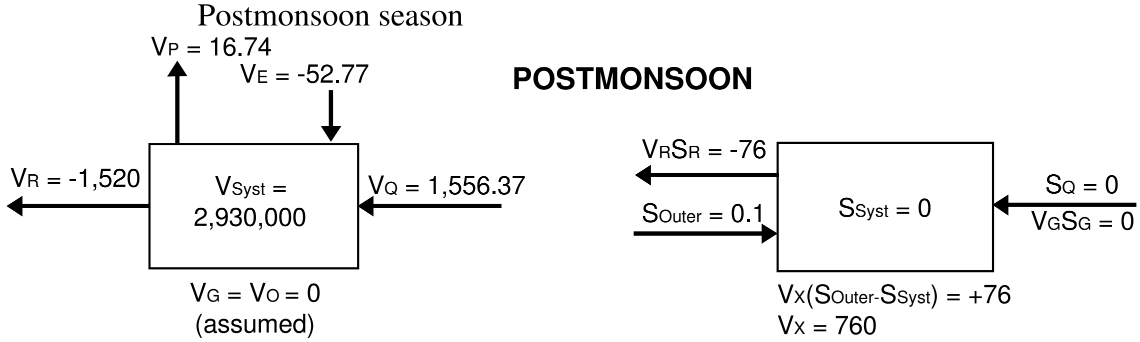


Figure 2c: Water and salt budget for the lower Meghna River estuary in the Postmonsoon season



NP budget

The one layer single box DIP and DIN budgets for the lower Meghna River estuary system are shown in Figure 3a through 3c. An increase in fluxes is noticeable during the monsoon season followed in time and magnitude by the postmonsoon season.

Figure 3a: DIP and DIN budget for the lower Meghna River estuary in the Premonsoon season (fluxes in 10^6 mmol/day)

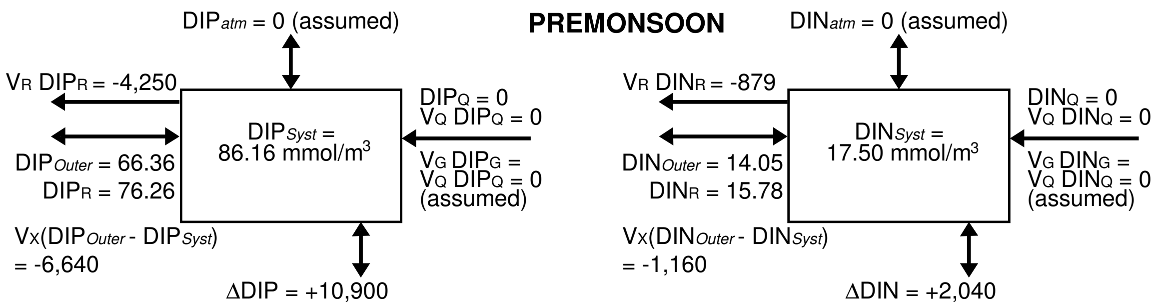


Figure 3b: DIP and DIN budget for the lower Meghna River estuary in the Monsoon season (fluxes in 10^6 mmol/day)

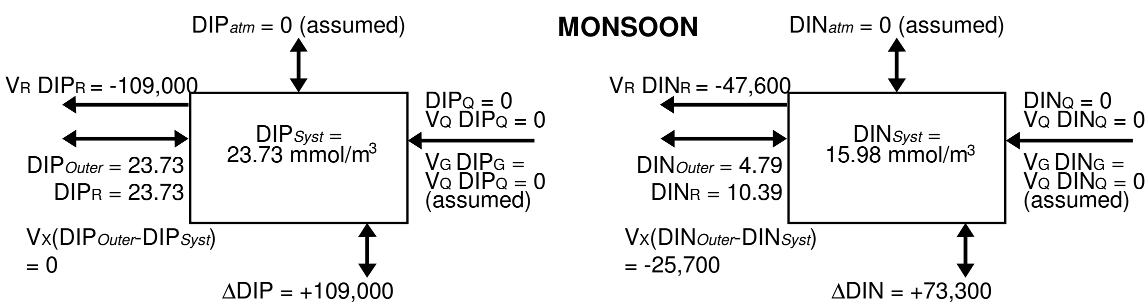
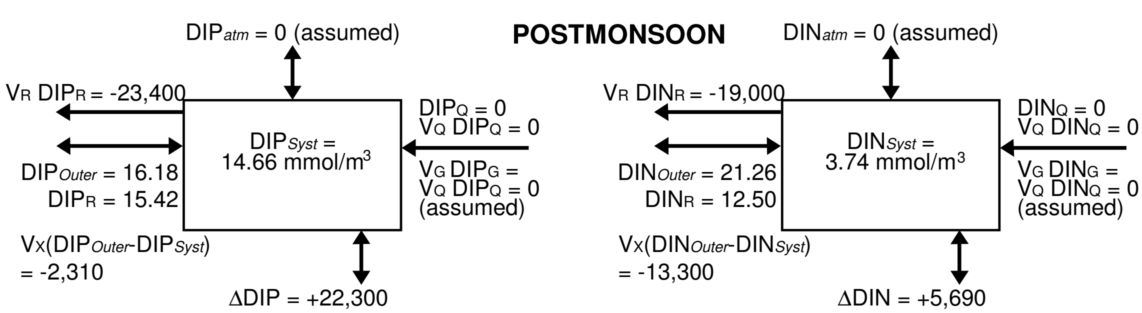


Figure 3c: DIP and DIN budget for the lower Meghna River estuary in the Postmonsoon season (fluxes in 10^6 mmol/day)



Stoichiometric calculations of aspects of Net System Metabolism

ΔP values in the lower Meghna River estuary are positive in all three seasons. This could be attributed to a net production of DIP within the system and suggests that the estuary is mainly heterotrophic. Based on Redfield N:P ratio of 16:1, ΔDIN_{exp} and (*nfix-denit*) were calculated for three seasons. Table 3 summarizes the ecosystem metabolism. High negative values of (*nfix-denit*) suggests an actively denitrifying system in the lower Meghna River-estuary.

Table 3: Estimated rates of nonconservative DIN fluxes and (nfix-denit)

Season	ΔDIP mmol/m^2/day	ΔDIN_{obs} mmol/m^2/day	ΔDIN_{exp} mmol/m^2/day	(nfix-denit) mmol/m^2/day
Premonsoon	20.48	3.83	327.65	-323.83
Monsoon	204.57	137.77	3273.12	-3135.35
Postmonsoon	41.89	10.69	670.27	-659.58

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Material Flux through the Karnaphuli River

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Abstract

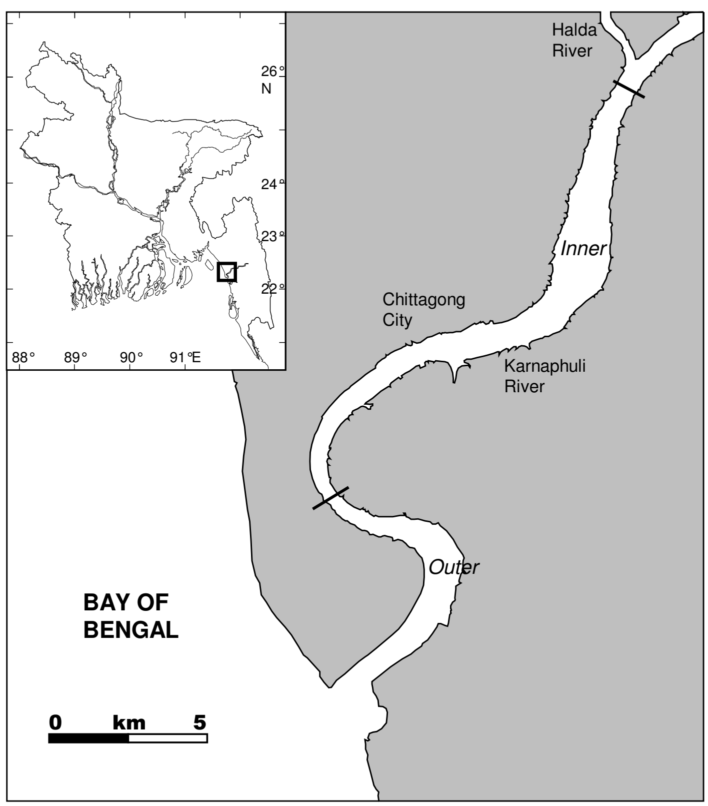
Karnaphuli river originates in the Lusai hills of Assam, India and empties into the Bay of Bengal through the north-eastern part of Bangladesh. During its course through Bangladesh it is dammed for hydroelectric power generation forming an artificial hill-bound lake. At the downstream reaches, it receives water from two major perennial tributaries and numerous other streams. Watershed is characterized by mainly derelict or cultivated hills and foothills, and human settlement areas with agricultural fields. In the estuarine reaches it is receiving untreated municipal and industrial wastes from Chittagong City and other types of pollutants from harbor and other activities. The current research examines the state of the major Nitrogen and Phosphorus species of nutrients in the lower reaches of the river heavily stressed by human activities. LOICZ recommended modelling approach is adopted to budget these nutrients and other materials. The model reveals that the estuary is a heterotrophic and denitrifying ecosystem.

Keywords: Material flux, Karnaphuli estuary, Bangladesh

The study area

Karnaphuli is one of the most important rivers of the eastern part of Bangladesh. It originates in the Lusai hills of Assam, India and enters into Bangladesh through its eastern boundary. In the hilly upstream reaches it has been dammed for generating hydroelectric power giving rise to an artificial lake. The controlled flow in the downstream receives freshwater flows from two major perennial rivers, i.e., the Halda and Ichhamati. Watersheds of these rivers comprise mainly of croplands and human settlement. Further downstream, it forms the estuary before emptying into the Bay of Bengal through the

Figure 1: Map showing the budget site - Karnaphuli River estuary



Chittagong coast. The city of Chittagong lies on the right bank of this river. Lower part of Karnaphuli river receives huge municipal and industrial wastes into the system. A material flux study in the Karnaphuli River estuary has been started and expected to be carried out for at least two consecutive seasonal cycles covering premonsoon, monsoon and postmonsoon seasons. This paper presents interim budgets of water, salt and nutrients for this estuary for the late monsoon season using the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al*, 1996) based on preliminary field work and analyses accomplished so far. A 17.5 km^2 segment of the estuary with an average depth of about 10m is selected for the present study (Figure 1).

Sampling and Analysis

Inner and outer segments of the Karnaphuli River estuary were sampled during the late monsoon of 2002 for nutrients (NO_3^-, NO_2^-, NH_4^+, PO_4^- and SiO_2^-) and other water quality parameters as a part of an ongoing material flux study. Water samples were collected, preserved, transported and analyzed following standard procedure (Barnes, 1959; Strickland and Parsons, 1965; Parsons and Stickland, 1968; APHA, 1975; Jin-Eong *et al,* 1985). Average from several samples for each parameter was used in this budgeting exercise. Rainfall data were collected from Bangladesh Meteorological Department and discharge values were interpolated from a previous work in the same estuary (Monwar, 2001). Evaporation was calculated from other atmospheric data. Rainfall, estimated evaporation and interpolated discharge were 83.52, 34.26 and 6.47 million m^3/day respectively. Groundwater exchange and outfall were assumed to be negligible. Salinity and nutrient data used in this budgeting exercise are shown in Table 1.

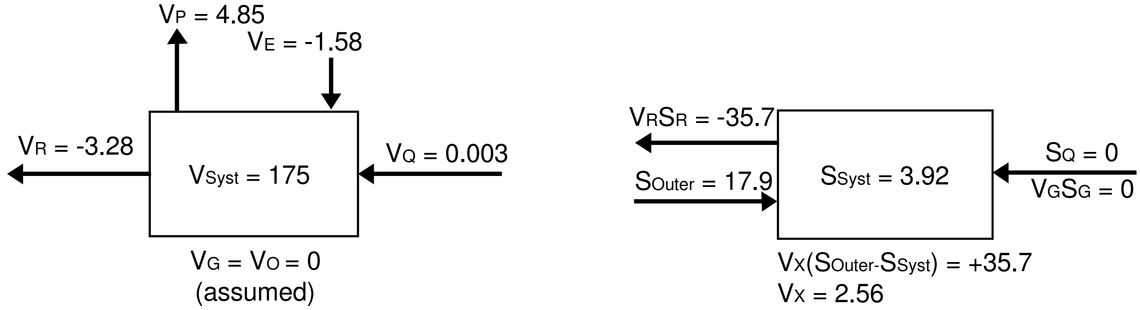
Table 1: Chemical composition of water samples from Karnaphuli river estuary

Site	Salinity ppt	DIP mmol/m^3	NO_3^- mmol/m^3	NO_2^- mmol/m^3	NH_4^+ mmol/m^3	DIN mmol/m^3
Inner segment	3.92	293.92	4.93	0.73	1.71	7.37
Outer segment	17.9	179.44	6.16	0.44	1.04	7.64

Water and salt budget

No significant vertical stratification in salinity was observed and a single layer system is conceived. Results of the water and salt budgeting are shown in Figure 2.

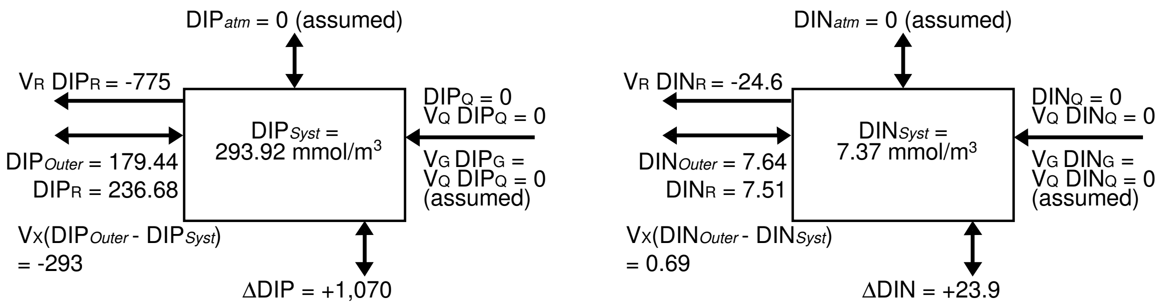
Figure 2: Water and salt budget for the Karnaphuli River estuary



NP budget

The one layer single box DIP and DIN budgets for the Karnaphuli River estuary system are shown in Figure 3.

Figure 3: DIP (left) and DIN (right) budget for the Karnaphuli River estuary (fluxes in 10^6 mmol/day)



Stoichiometric calculations of aspects of Net System Metabolism

Positive ΔP values could be attributed to a net production of DIP within the system and suggests that the estuary is mainly heterotrophic. Based on Redfield N:P ratio of 16:1, ΔDIN_{exp} and (*nfix-denit*) was calculated. Table 3 summarizes the ecosystem metabolism. High negative values of (*nfix-denit*) suggests an actively denitrifying system in the Karnaphuli River estuary.

Table 3: Estimated rates of nonconservative DIN fluxes and (nfix-denit)

Flux	ΔDIP	ΔDIN_{obs}	ΔDIN_{exp}	(nfix-denit)
$mmol/m^2/day$	61.03	1.37	976.48	-975.11
10^6 mol/day	1.07	0.0239	17.12	-17.06

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APPENDIX IV-B

INDIA

Biogeochemical Budgets for Tapi Estuary
Meghana V. Bapardekar, S.N. de Sousa , M. D. Zingde

Biogeochemical Budgets for Muvattupuzha Estuary, Kerala, India
Betty D. Cherukara, S.N. de Sousa and M.D. George

Biogeochemical Budgets for Tapi Estuary

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Introduction:

Tapi river is a major west flowing perennial river opening to the Arabian Sea in the Gulf of Khambhat (Cambay) near Hazira-Umbhrat. Alongwith the Mindhola River it is an important source of freshwater to the region (Figure 1). The 720 km long river originates near Multai in the Betoul District of Madhya Pradesh and commands a catchment area of 6.5 x 10^4 km^2. During its course the river passes through three states; Maharashtra, Madhya Pradesh and Gujarat. The river in its upper reaches receives discharge from 14 main tributaries, 4 on the right bank and 10 on the left bank of which the Purna and Girna are the most important accounting for 45 % of the total catchment area, while it branches into a few distributaries in the plains. During its seaward course the river meanders through the hilly terrain of Western Ghats before entering the coastal alluvial plains of Gujarat to meet the Arabian Sea. The shallow and wide lower segment of the river exhibits the characteristics of a typical estuary, Tapi estuary ($21^0$10' N, $72^0$40' E), with strong currents associated with significantly high tidal influence upto 25 km upstream and with salinity decreasing progressively in the upstream direction from average 32.53 psu at the mouth to 0.1 psu within a distance of 35 to 40 km. Table 1 gives the physical dimensions of the estuary.

The mean spring and neap tidal ranges are of 5.7 and 4.3 m respectively at Hazira. The tidal influence however decreases with distance with spring and neap tidal ranges of 2.3 and 0.4 m respectively at Surat. The maximum flood and ebb speeds often exceed 1 m/s with the tidal excursion of 7-20 km within the estuary and 11-13 km along the open coast.

About 71.5 % of the total population of 14,599,032 (1991 census) of the Tapi basin, is rural with no sewage facilities. The urban population is spread over 37 cities (7 class I cities with population >100,000; 7 class II cities with population between 50,000 and 100,000; and 23 class III cities with population ranging between 20,000 and 50,000). The overall population density is 208 km^{-2}. A major part (62%) of Tapi basin is predominantly agricultural while 26.6% of the area is under forest cover. The rest of the land (non-arable) is utilized for industrial activities and human settlements. There are 93 large and medium scale industrial units in the basin, plus innumerable small-scale units. Types of industries include fertilizers, engineering, thermal power, food and beverages including distilleries, textiles, chemical and metallurgical.

All these industries release their effluents in the adjacent estuary. A considerable amount of sewage generated in and around the Surat city is released to the inner segment of the estuary. The average annual ground water flow into the estuary is estimated at around 18,000 x 10^6 m^3y^{-1} while another 4,026 x 10^6 m^3y^{-1} comes from wastes (domestic, industrial, agricultural and others). Table 2 gives the water fluxes to the estuary during the dry season. Chemical fertilizers are used in the basin at the rate of 113 $kg.ha^{-1}$ which is higher than the rate in the Krishna and Ganga basins. The wastewater generation and pollutant load is summarised in Tables 3 to 5. Seaward segment of the estuary is well flushed with flushing time of 3-7 tidal cycles during dry season. The inner estuarine segment however is flushed at a much slower rate with a flushing time of 16-194 tidal cycles.

The average rainfall varies from 100 cm per year in the coastal plains to 150 cm per year in the ghat sections. About 85% of the precipitation occurs during the southwest monsoon period (June-September). The highest precipitation is usually received in the month of July, which amounts to 30% of the average annual rainfall. Evaporation over the area is about 6 mmd^{-1} (CPCB, 1993-94). The riverine discharge to the sea is controlled by the Ukai and Kakrapar Dams constructed on the river at 141 and 115 km upstream respectively. The annual river runoff measured at a gauging station at Ghala, a little upstream of station 9 is of 7,686 x 10^6 m^3 (CPCB, 1993-94). The river discharge is 8000 m^3/s or 691.2 x 10^6 m^3d^{-1} during wet season (SW monsoon i.e. June-September) which decreases to 10-45 m^3/s (Avg. 30 m^3/s = 2.6 x 10^6 m^3d^{-1}) during dry season (October-May) leading to stagnation in the riverine segment 25 km upstream, during the dry season. The peak discharge during floods exceeded 44000 m^3/s in 1968.

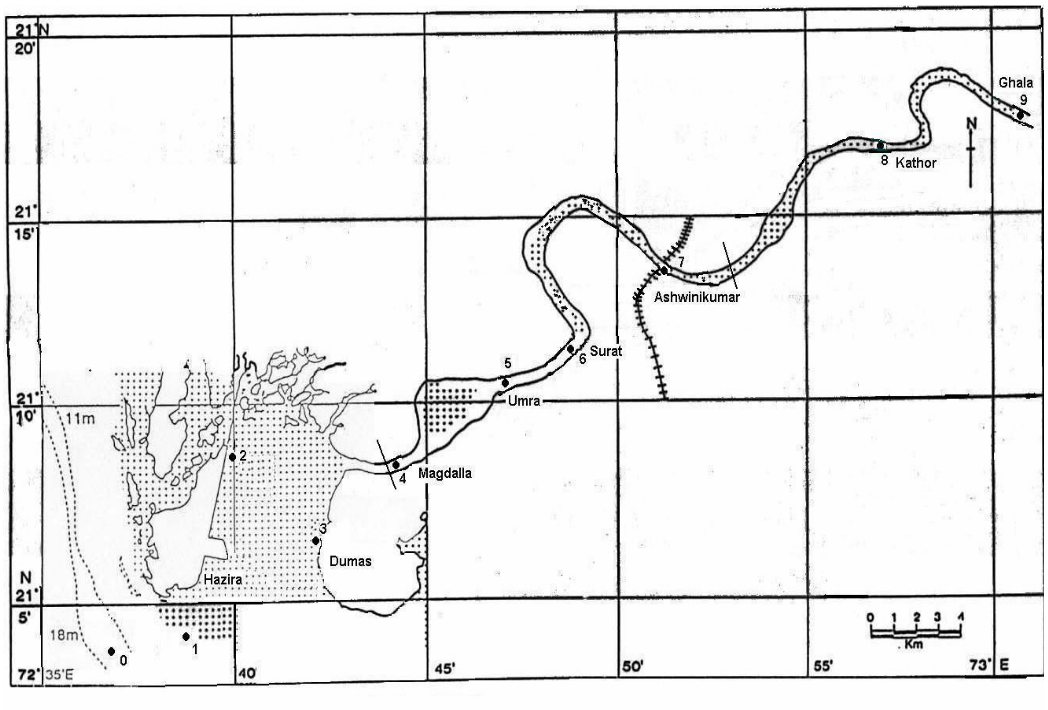

Figure 1: Tapi Estuary

The present study is based on the data on pH, temperature, dissolved oxygen, salinity, inorganic phosphate, nitrate, nitrite and ammonia collected by the Regional Centre of NIO, Mumbai (Bombay) at nine stations (stations 1-9) covering a length of about 60 km of the lower estuary from the mouth towards upstream and the adjoining coastal sea, during postmonsoon (November and December, 1983) and premonsoon (May, 1984) covering the entire dry season. We have no data on the above parameters for the monsoon season. However, due to the heavy river runoff (average 8000 m^3/s) during this season the rate of water exchange is expected to be very rapid which renders the computation of non-conservative fluxes unreliable. Consequently, the present work is restricted to the dry season only.

For the purpose of calculating the biogeochemical budgets, the estuary is split into 2 boxes based on salinity gradient; (i) The Outer Box (Box-2) with an average salinity of 16.75 psu is covered by stations 1-3, (ii) The Inner Box (Box-1) with an average salinity of 2.37 psu is covered by stations 4-7. Stations 8 and 9 which fall in the riverine (freshwater) section, defines the properties of freshwater (river flow) while station 0 defines the properties of the coastal ocean water.

Water samples from surface and bottom from all the stations were analysed for salinity, DIP and DIN (nitrate, nitrite and ammonia) during all three observations. The respective data on salinity, DIN and DIP were pooled together separately for Box-1, Box-2, river flow and ocean water and averaged to give seasonal averages for Box-1, Box-2, river flow and ocean water respectively. Table 1 summarises the size of the 2 boxes used for budgeting purpose; boundaries based on salinity gradients are shown in Figure 1. Table 6 gives the summary of measured variables (averages) for salinity, DIN and DIP in riverine, estuarine and coastal waters during the dry season.

Table 1: Physical dimensions of Tapi estuary.

System	**Area (10^6 m^2)**	**Average Depth (m)**	**Volume (10^6 m^3)**
Inner (Box 1)	19.4	2	38.8
Outer (Box 2)	22.4	6	134.4
Whole system	41.8	4	167.2

Table 2: Water fluxes for the Tapi river estuary during dry season.

Parameter	**Calculation**	**Flux (10^6 $m^3.d^{-1}$)**
Precipitation	7.92×10^{-4} $m.d^{-1}$ $\times$ 41.8×10^6 m^2	0.03
Evaporation	0.006 $m.d^{-1}$ x 41.8 x 10^6 m^2	0.25
Runoff (surface)	-	0 (assumed)
River runoff	30 $m^3.s^{-1}$ x 60 x 60 x24	2.6
Groundwater flow	18,000 x 10^6 m^3 / 365 days	49.3
Wastewater flow	4,026 x 10^6 m^3 / 365 days	11.0

Table 3: Wastewater generation in Tapi basin.

Details	**Annual wastewater discharge (10^6 $m^3.y^{-1}$)**
1. Agricultural waste	
Irrigation	2,938.0
2. Other waste	
Urban domestic waste	278.6
Industrial waste	761.9
Others	47.6
Total	**4,026.1**

Table 4: Pollutant load in agricultural wastewater.

Type	**Annual load ($MT.y^{-1}$)**	**Daily load (10^3 $mol.d^{-1}$)**
N	24,826	4860.0
P	6,478	572.6
K	6,848	481.0

Table 5: Pollutant load (BOD) through domestic and industrial waste.

Type	Source	BOD load (kg.d^{-1})
Rural	Domestic	156,689
	Cattle	91,767
Urban	Domestic	189,353
	Cattle	51,069
Total		**488,878**

Table 6: Summary of measured variables (averages) for dry season during 1983-1984.

Source	Salinity (psu)	DIN (µM)	DIP (µM)
River water	0.06	14.14	0.21
Groundwater	0 (assumed)	0 (assumed)	0 (assumed)
Other sources	0 (assumed)	0 (assumed)	0 (assumed)
Inner segment (Box 1)	2.37	18.20	0.81
Outer segment (Box 2)	16.75	21.65	1.10
Ocean water	32.53	17.85	1.23

Results:

Water and Salt budgets:

In a system at steady state, the volume of water entering the system must be equal to that flowing out of the system. Inflow includes runoff (V_Q), direct precipitation (V_P), surface runoff (V_S), groundwater flux (V_G), others like industrial, domestic wastes (V_O) and agricultural wastes (V_A), etc. As the contribution due to irrigation i.e. from the agricultural waste (V_A) and the other sources (V_O) is not known for the individual box, the whole influx is shown entering the Box 1, which in turn is going to Box 2 and then to the open ocean (Figure 1). In this particular system, most of the groundwater is expected to enter the system, through the various tributaries, upstream of the water gauging station, Ghala, and hence is accounted for in the river runoff (V_Q). The surface runoff during the dry season is nil. Removal includes evaporation (V_E) and residual flux to the sea (V_R)

Following the LOICZ biogeochemical guidelines (Gordon et al., 1996), water and salt budgets for dry season were calculated (Figures 2 and 3). Precipitation and evaporation were insignificant as compared to high river flow. Salt must be conserved in the system, hence salt flux out of the system carried by residual flow (V_R) must be balanced via mixing (V_X). The water exchange time (τ) for box 1 was 1.72 days while for box 2 it was

3.92 days and for the system as a whole was 4.87 days (Figure 2) during the dry season in 1984.

Budget of non-conservative material:

Table 7: Non-conservative nutrients and stoichiometrically derived net apparent biogeochemical processes.

1. Estuarine segment	□***DIP*** **(mmol.m^{-2} d^{-1})**	□***DIN*** **(mmol.m^{-2} d^{-1})**	***(p-r)*** **(mmol C.m^{-2}d^{-1})**	**(*nfix-denit*) (mmol N.m^{-2}d^{-1})**
Inner	–29.01	-240	+3075	+224
Outer	+0.12	+4.73	–12.40	+2.86
Whole system	**–13.4**	**-108.9**	**+1420**	**+ 105.5**

DIP and DIN Budgets:

The non-conservative fluxes of dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN) in Tapi estuary for dry season in its different estuarine segments are calculated using the data given in Table 6, and the results are illustrated in Figures (4 and 5) and table 7. The pollutant load from the agricultural wastewater, contributing to the N and P input is not known for the individual box and hence shown entering the Box 1, which successively flows to Box 2 and then to the open sea (Figures 3 and 4). During the present study, the system showed the removal of DIP at the rate of 29mmol m^{-2} d^{-1} (inner segment) serving as a sink, release at the rate of 0.12 mmol m^{-2} d^{-1} (outer segment) serving as a source and net removal at the rate of 13.40 mmol m^{-2} d^{-1} (whole system) serving as a sink for DIP. It also showed the removal of DIN at the rate of 240 mmol m^{-2} d^{-1} (inner segment) serving as a sink, production at the rate of 4.73 mmol m^{-2} d^{-1} (outer segment) serving as source and net removal at the rate of 108.9 mmol m^{-2} d^{-1} (whole system) serving as a sink for DIN.

***Stoichiometric relationships*:**

Primary production in this system is assumed to be dominated by plankton, with a C:N:P ratio $(C:N:P)_{part}$ of about 106:16:1. This ratio is used to calculate net system metabolism (*p-r*) from □*DIP* according to the relationship from Gordon et al. (1996):

(*p-r*) = -□*DIP* x $(C:P)_{part}$

The rate of nitrogen fixation minus denitrification (*nfix-denit*) can also be calculated from □*DIP*, □*DIN*, and the N:P ratio of particulate material in the system (Gordon *et al.* 1996).

(*nfix-denit*) = □*DIN* - □*DIP* x $(N:P)_{part}$

The *(p-r)* is calculated to be +3075 mmol C.m^{-2} d^{-1} (inner segment), -12.4 mmol C.m^{-2} d^{-1} (outer segment) and +1420 mmol C.m^{-2} d^{-1} (whole system), indicating the outer segment to be heterotrophic while the inner segment and the system as a whole to be autotrophic.

The balance between N-fixation and denitrification *(nfix - denit)* comes to +224 mmol $N.m^{-2} d^{-1}$ (inner segment), +2.86 mmol $N.m^{-2} d^{-1}$ (outer segment) and +105.5 mmol $N.m^{-2} d^{-1}$ (whole system), indicating that the entire system acts as N-fixing.

Tapi estuary – Water, Salt and Nutrient Budgets

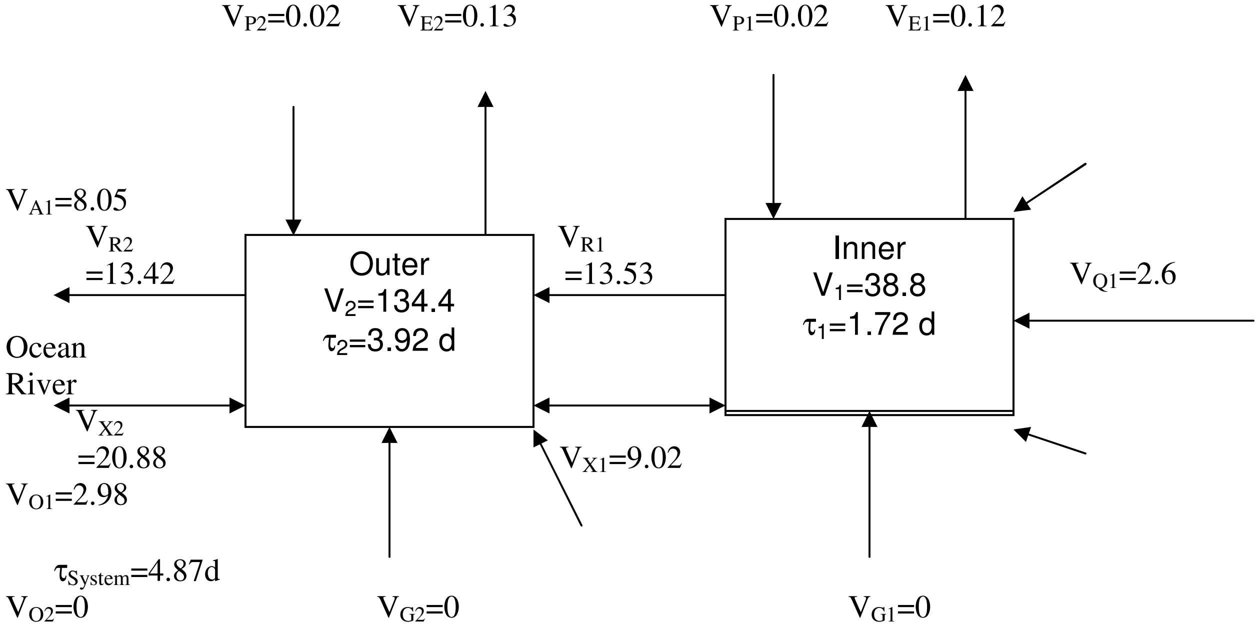

Figure 2: Water budget for Tapi Estuary during dry season in 1984.

(System volume is in 10^6 m^3 and water flux in 10^6 m^3d^{-1}).

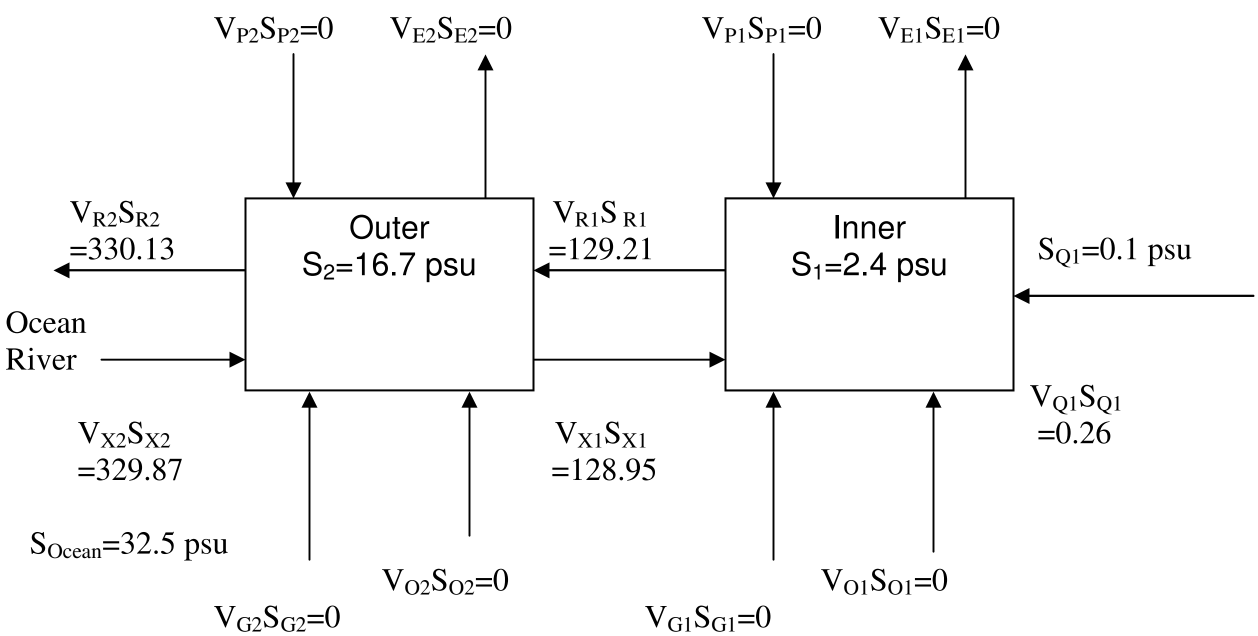

Figure 3: Salt budget for Tapi Estuary during dry season in 1984.

(Salt flux is in 10^6 $psu.m^3d^{-1}$).

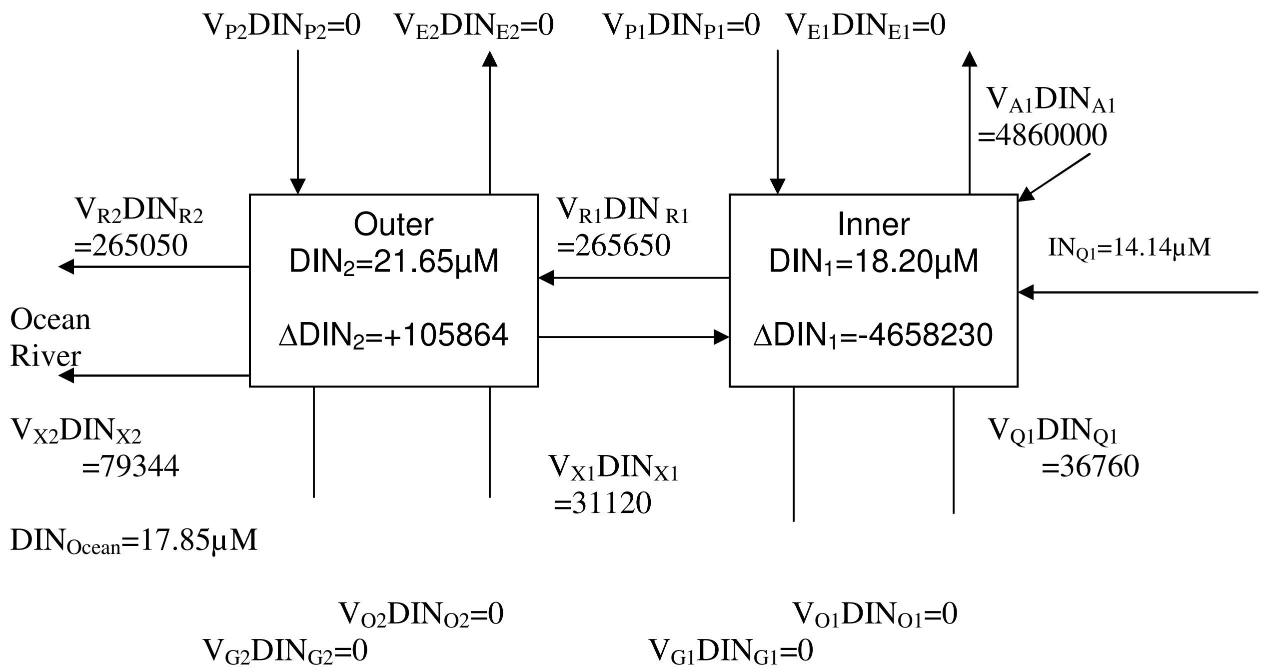

Figure 4: DIN budget for Tapi Estuary during dry season in 1984.

(Fluxes are in $mol.d^{-1}$).

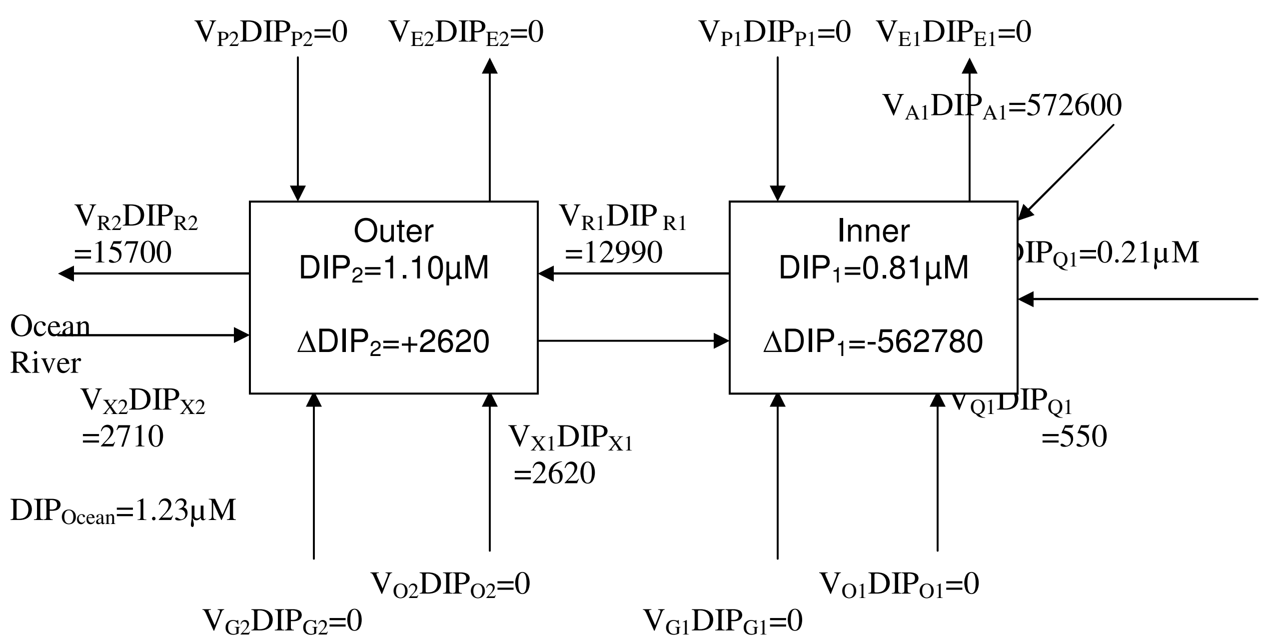

Figure 5: DIP budget for Tapi Estuary during dry season in 1984.

(Fluxes are in $mol.d^{-1}$).

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Biogeochemical Budgets For Muvattupuzha Estuary, Kerala, India

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Study Area description

The Muvattupuzha river (Fig.1) which is flowing across the Kerala state in South India is formed by the confluence of three tributaries, the Thodupuzha, the Kaliyar, the Kothamangalam. The river flows in a South-Westerly direction for about 2 km, then flows in a Westerly direction for about 13 km, again turns South-West and passes through low swampy lands. It empties into Cochin backwaters, which is subjected to the total effects through the Cochin barmouth. The length of the river is 121 km. The drainage area is 1554 km^2. During its course it passes through 45 villages of the Thodupuzha, Muvattupuzha,Vaikom, Kunnathunad, and Kanayannur talukas. The origin of the river is from Taragamkanam hills. The main sources of fresh water in backwater are two large rivers- the Periyar on the north and the Pampa on the south. Muvattupuzha river flows midway between these two.

Muvattupuzzha estuary bifurcates into two branches, Ittipuzha & Murinjapuzha at Vettikattumukku. Constant flow is maintained in the estuary during non-monsoon month also, due to the discharge of tail race water from Iddukki hydroelectric power station. The discharge through the estuary increases steadily with the onset of monsoon by the first week of June. The fresh water discharge in the Muvattupuzha river can be considered constant over a tidal cycle and the variation in the water level at various sections in the estuary are due to the tidal intrusion. Area of the estuary considered is 43.34 km^2.

Monthly observations were made at four stations (Stas. 4-7) in the estuary during 1990. A coastal station (O) outside the mouth of the estuary defines the properties of the coastal seawater. Similarly two stations in the freshwater region (Stas. 8&9) of the river define the characteristics of fresh water (Fig.1). Budget calculations were made using the data on salinity, phosphate, ammonia, nitrite and nitrate collected during these observations following the LOICZ Biogeochemical Modeling Guidelines (Gordon *et al.* 1996).

Rainfall for each season was calculated based on the daily weather report published by the India Metereology Department, for the year, 1990. Evaporation from the water surface has been calculated using the evaporation rates of 1.2m/year given by

Baumgarther and Reichel (1975). The surface runoff for monsoon season (4171.44 x 10^6 m^3) was calculated based on the monthly temperature and rainfall data for this region and using the relationship given at:
http://data.ecology.su.se/MNODE/Methods/runoff.htm.

The year has been divided into three seasons - premonsoon (Feb to May), monsoon (June to Sept) and post monsoon (Oct to Jan). All the estuarine data were pooled together season-wise and averaged to give seasonal. Similarly, the data from the riverine stations 8&9 and coastal station (O) were pooled together separately season-wise and averaged to give seasonal average for freshwater and coastal seawater.

The budget modelling done is based on the mass balance calculations of specific variables (water, salinity, DIN & DIP) for a defined geographic area and for a particular time period (monthly & annual). The rate of material delivery to the system, i.e., influx, the rate of material delivery from the system (outflux) and the rate of change of material mass within the system (storage) are calculated. A budget for coastal body should include delivery by fresh water, exchange at the seaward boundary, production-respiration, sedimentation, etc. The budgeting includes three steps, Water budgets, Salt budgets, and budgets for non-conservative materials (N, P).

Water budgets

The concept behind this budget is the conservation of water mass. It is the budget of fresh water inflow (run-off, precipitation, groundwater, others, etc.) and outflow (evaporation). The difference between inflow and outflow must be balanced by residual flow. Figures 2, 6 and 10 show the seasonal water budgets for the estuary during the pre-monsoon, monsoon and post-monsoon seasons, respectively.

Salt budgets

The exchange flow of salinity is constructed after determining the salinities of the estuary, the fresh water and the sea. These exchanges are modelled as mixing. The sea delivers salt to the system, which results in outward mixing of salt. The salt exported by the estuary to the Ocean balances this flux of salt. Figures 3,7 and 11 show the seasonal salt budgets for the estuary during the pre-monsoon, monsoon and post-monsoon, respectively.

Non- conservative budgets

All dissolved materials like, nitrogen, and phosphorous will exchange across the boundaries of the systems. Figures 4, 8 and 12 illustrate the seasonal budgets of DIN while Figures 5,9 and 13 illustrate the seasonal budgets for DIP during pre-monsoon, monsoon and post-monsoon, respectively. In general, Muvattupuzha estuary releases both DIN (74.03 x 10^6 mol/season) and DIP (5.67 x 10^6 mol/season) in the ratio of 1:13, which is close to the Redfield's ratio.

Stoichiometric calculations of aspects of net system metabolism

Table 5 summarizes the non-conservative nutrients and stoichiometrically derived net apparent biogeochemical processes. The system appears to be net heterotrophic and denitrifying during the whole year, except during pre-monsoon when it acts as net autotrophic. The system apparent net annual metabolism *(p-r)* is –38 mmolC.m^{-2}.d^{-1} indicating net regeneration within the sytem. Similarly, using the phytoplankton N:P ratio, the calculated value for annual *(Nfix-denit)* is –1.06 mmolN.m^{-2}.d^{-1}, indicating the system is net denitrifying.

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Table 1. Precipitation in the estuary during 1990

Season	**Precipitation (m)**
Pre-monsoon	0.622
Monsoon	2.43
Post-monsoon	1.01

Table 2. River runoff in the estuary during 1990

Season	**Seasonal runoff ($10^6 m^3$)**
Pre-monsoon	342.52
Monsoon	1183.6
Post-monsoon	512.92

Table 3. Surface runoff during the monsoon season (1990).
(Runoff estimates according to http://data.ecology.su.se/MNODE/Methods/runoff.htm)

Season	**Surface runoff ($10^6 m^3$)**
Pre-monsoon	Negligible
Monsoon	4171.44
Post-monsoon	Negligible

Table 4. Summary of measured variables (seasonal averages)

Parameter	**River**	**Estuary**	**Sea**
Pre Monsoon			
Salinity (psu)	3.67	13.03	34.83
DIN (μm)	33.49	18.72	11.01
DIP (μm)	0.59	1.04	0.5
Monsoon			
Salinity(psu)	0.3	3.80	35.42
DIN(μm)	32.68	19.91	10.73
DIP(μm)	0.52	1.26	2.6
Post-monsoon			
Salinity(psu)	3.29	12.42	34.44
DIN(μm)	36.9	19.01	3.53
DIP(μm)	0.65	1.59	0.74

Table 5. Non-conservative nutrients and stoichiometrically derived net apparent biogeochemical processes

Season	**ΔDIP (10^6 mole)**	**ΔDIN (10^6 mole)**	***(p-r)*** **mmolC.$m^{-2}.d^{-1}$**	***(Nfix-denit)*** **mmolN.$m^{-2}.d^{-1}$**
Pre-monsoon	-0.119	-7.15	+2.33	-1.0
Monsoon	+5.28	+73.6	-108.0	-2.1
Post-monsoon	+0.51	-7.56	-10.35	-3.0
Annual	**+5.67**	**+74.03**	**-38.0**	**-1.06**

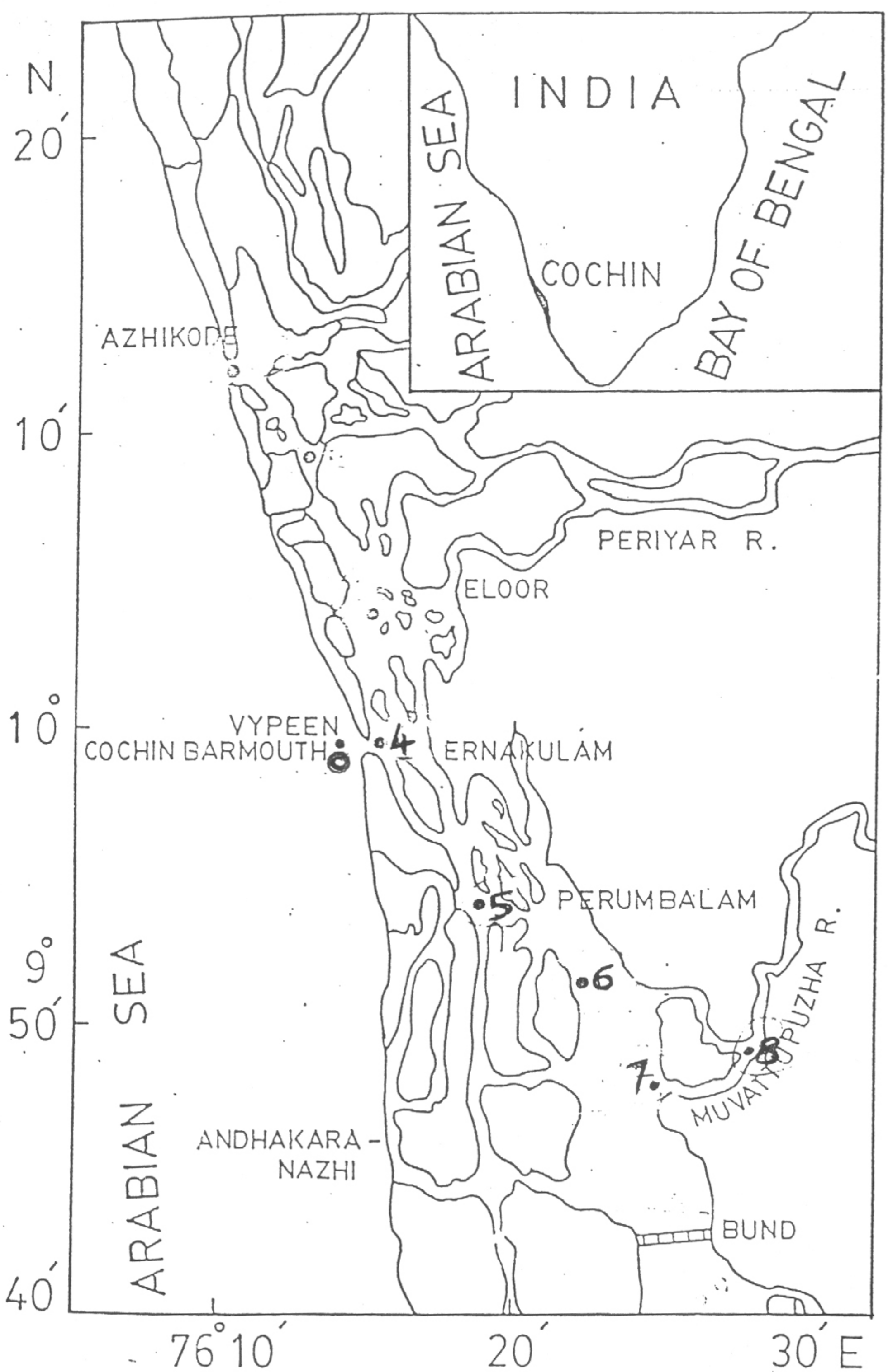

Fig. 1. Map of Cochin estuary showing location of stations.

Water, Salt and Nutrient Budgets

PREMONSOON

WATER BUDGET x 10^6 m^3

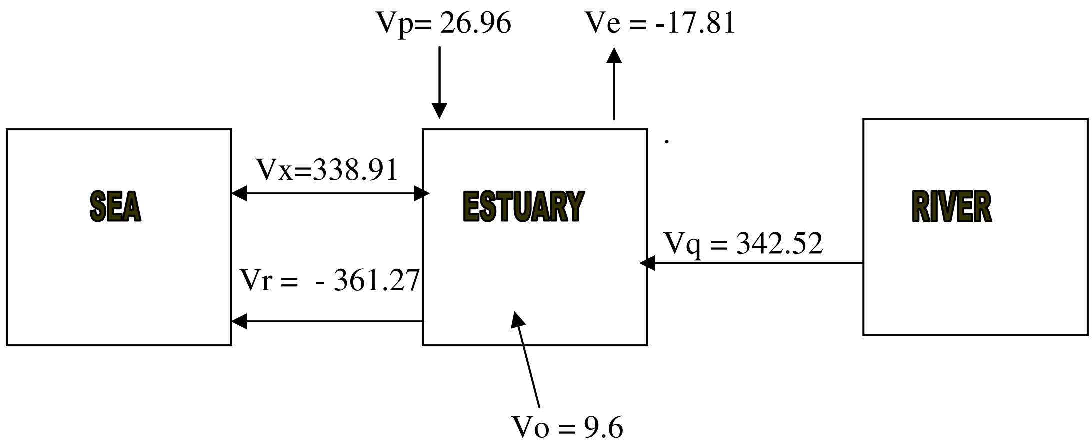

Fig. 2 – Water budget

SALT BUDGET x 10^6 psu m^3

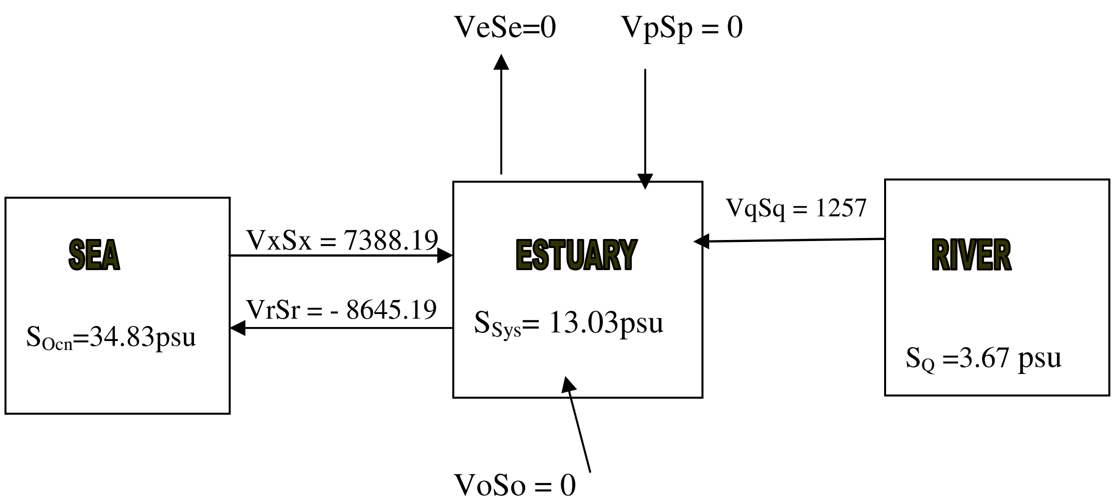

Fig. 3 – Salt budget

NITRATE BUDGET x 10^6 mmol (pre-monsoon)

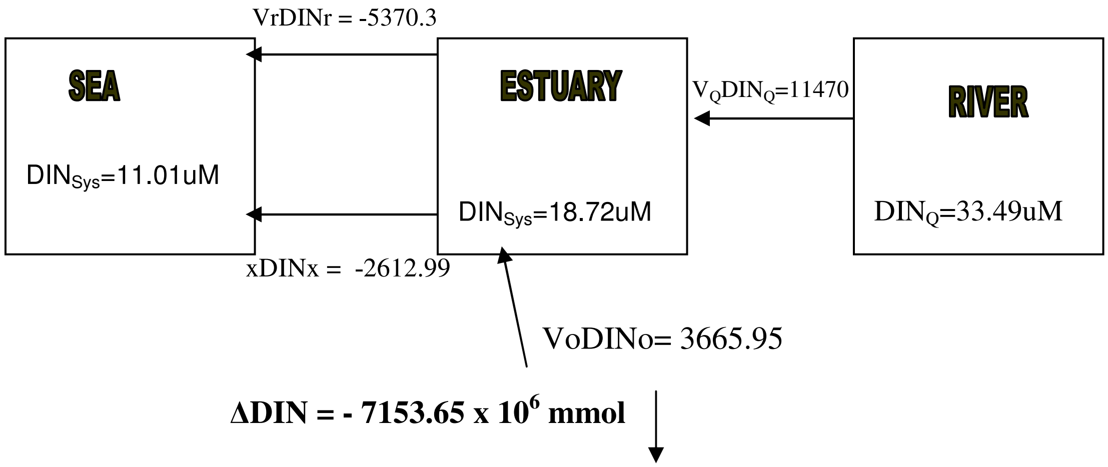

Fig. 4 – DIN budget

PHOSPHATE BUDGET x 10^6 mmol (Premonsoon)

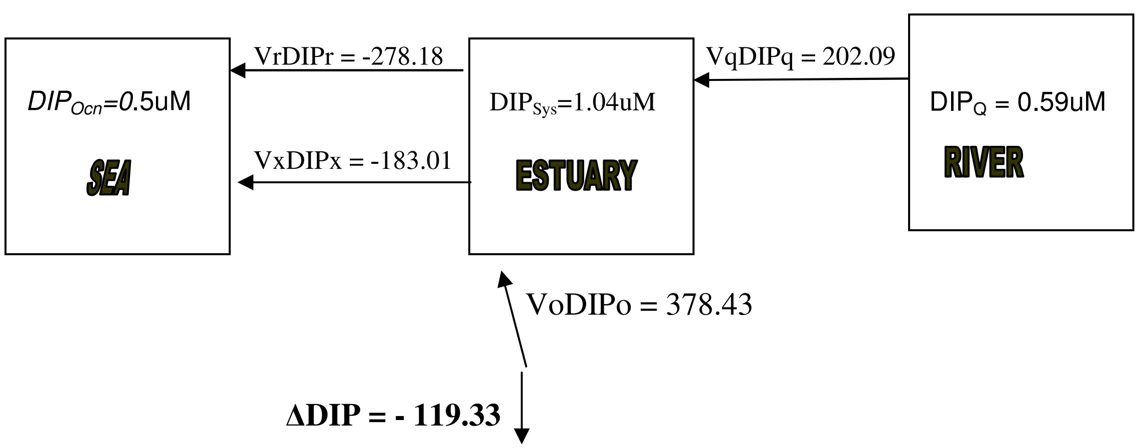

Fig. 5 - Dip budget

MONSOON

WATER BUDGET x 10^6 m^3

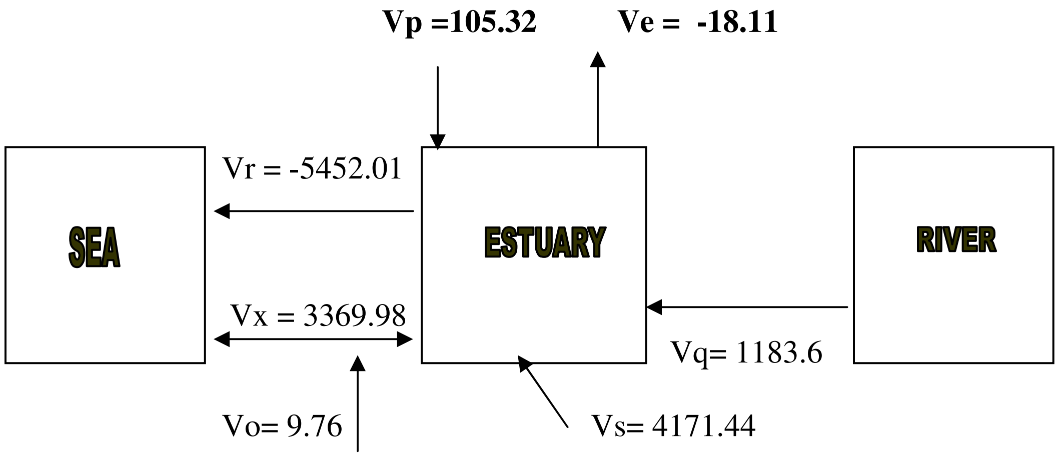

Fig. 6 – Water budget

SALT BUDGET x 10^6 psu m^3

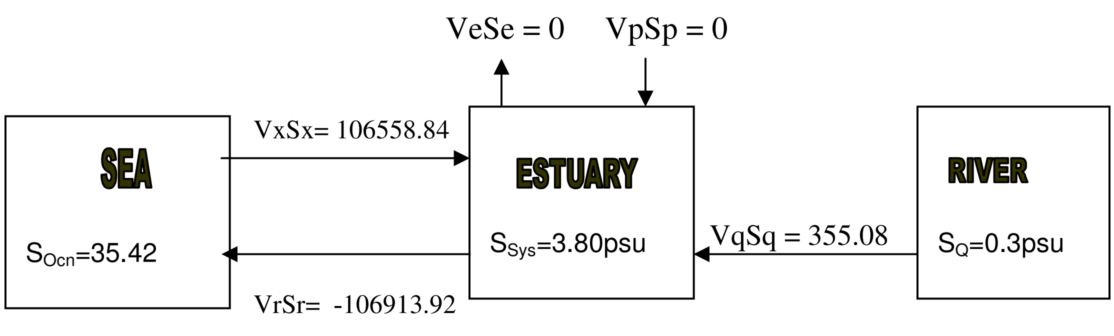

Fig. 7 – Salt budget

NITRATE BUDGET x 10^6 mmol

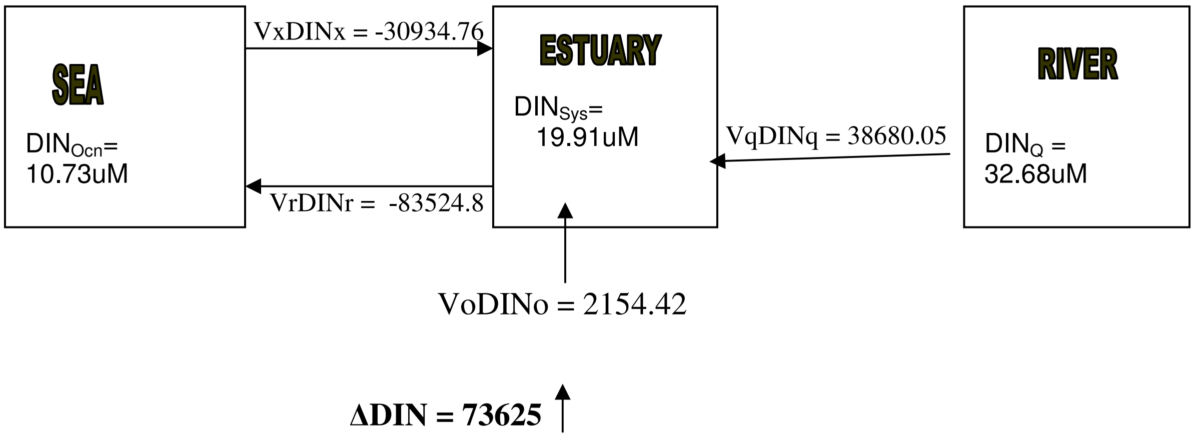

Fig. 8 – DIN budget

PHOSPHATE BUDGET x 10^6 mmol

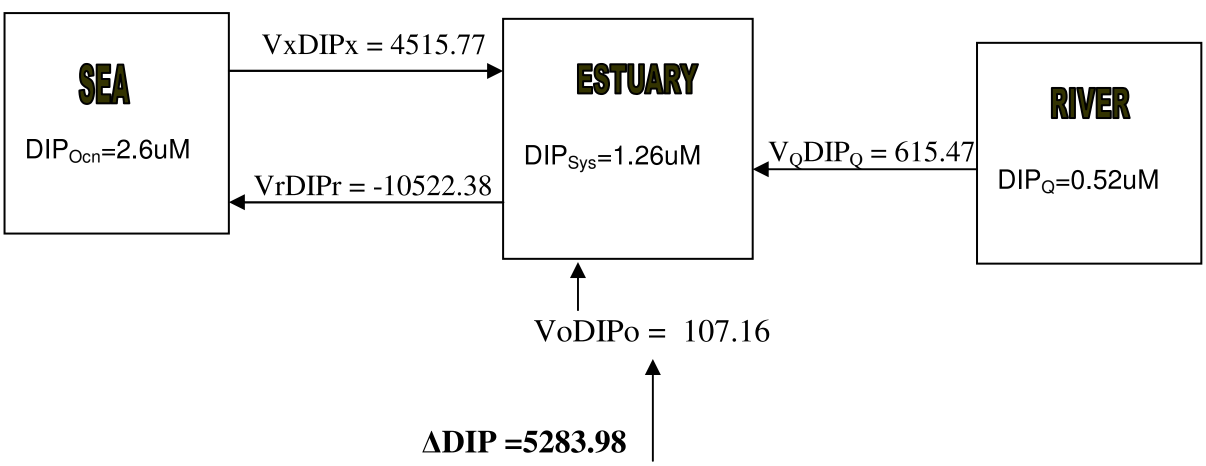

Fig. 9 – DIP budget

POST MONSOON

WATER BUDGET x 10^6 m^3

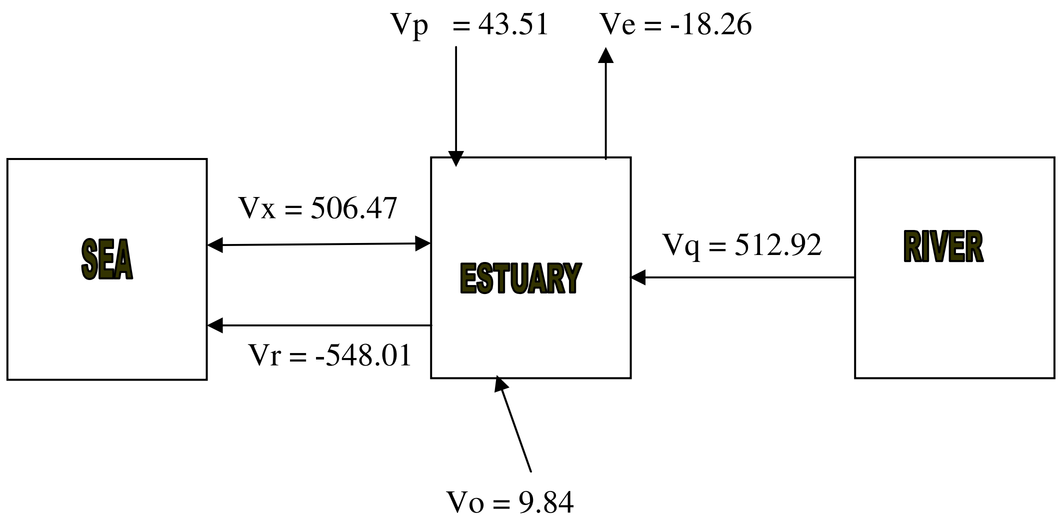

Fig. 10 – Water budget

SALT BUDGET x 10^6 psu m^3

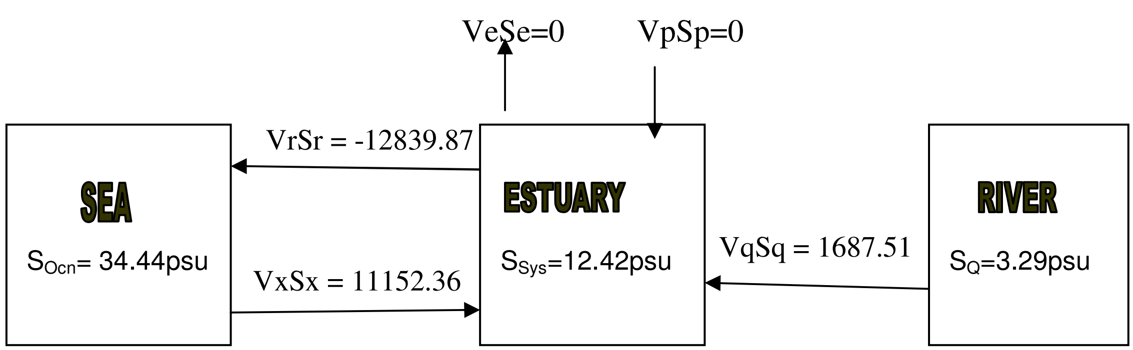

Fig. 11 – Salt budget

NITRATE BUDGET x 10^6 mmol

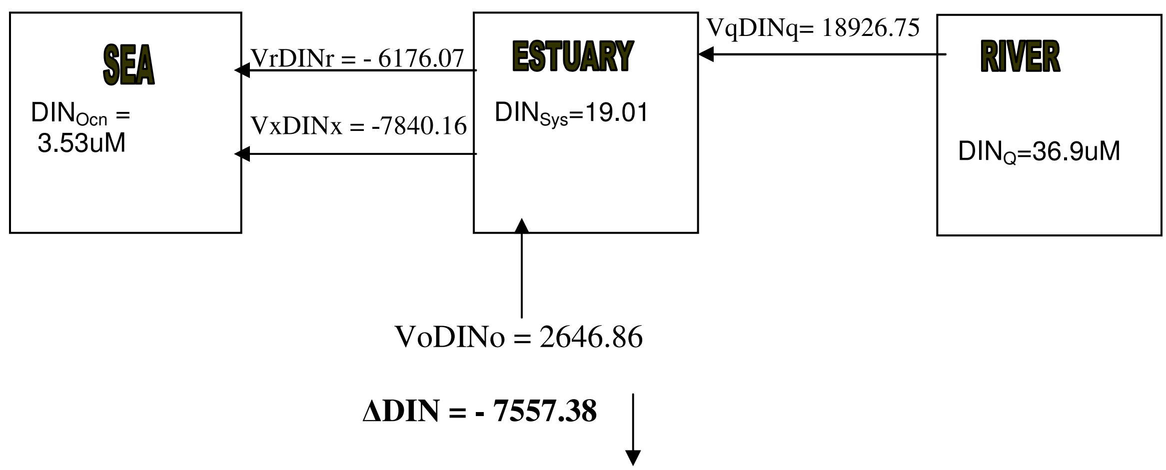

Fig. 12 – DIN budget

PHOSPHATE BUDGET x 10^6 mmol

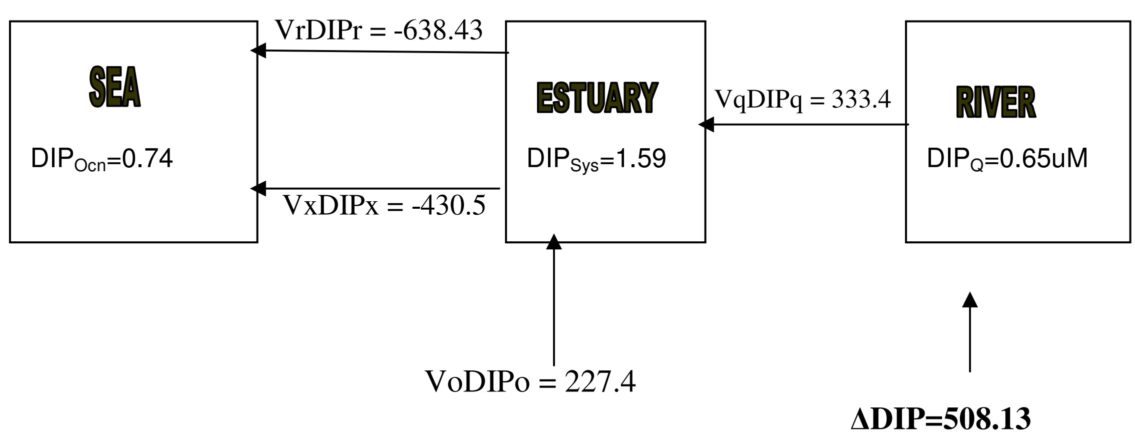

Fig. 13 – DIP budget

APPENDIX IV-C

PAKISTAN

Nutrient Budget calculated for the Indus River and Delta System

Asif Inam, M. Danish, A. R. Tabrez, Azhar Siddiqui, Shafiqur Rehman , and Rehan-ul-Haq

Nutrient Budget calculated for the Indus River and Delta System

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Shafiqur Rehman !, and Rehan-ul-Haq #

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INTRODUCTION:

The Indus River has a total length of more than 3,000 km and a drainage area of some 950,000 km^2. Almost 90% of the water in the upper portion of the river basin comes from glaciers located in the Himalaya and Karakoram mountain ranges, which border China, Pakistan and India, and the Hindu Kush, which borders Pakistan and Afghanistan.

The Indus Delta is a typical fan-shaped delta, built up by the discharge of large quantities of silt washed down from upland and mountain areas. The present Delta covers an area of about 600,000 hectares and is characterised by 17 major creeks and innumerable minor creeks, mud flats and fringing mangroves (Meynell and Qureshi 1993). The mangrove ecosystem of the Indus Delta is perhaps unique in being the largest area of arid climate mangroves in the world. As annual rainfall is so low in the region, mangroves are almost wholly dependent upon freshwater discharges from the river, supplemented by a small quantity of run-off and effluents from Karachi. The total available freshwater flow in the Indus is about 180 billion m^3, carrying with it some 400 million tonnes of silt (Meynell and Qureshi 1993). Over the last 60 years a series of dams, barrages and irrigation schemes have been built in upstream parts of the River Indus. Today, it is estimated that up to 60% of the Indus water is used to feed Pakistan's irrigation networks, and that the Indus watershed irrigates up to 80% of Pakistan's farmland (Iftikhar 2002). Pakistan's vast irrigation feeds more than 15 million hectares of farmland, with the highest irrigated to rain-fed land ratio in the world. This irrigation system is exacting a heavy toll on the environment. In particular there is concern that the abstraction of large volumes of water from rivers has, in many cases, left insufficient flow to meet the needs of downstream ecosystems.

As a result of upstream water abstraction, mainly for irrigation, by the time the Indus reaches the Kotri Barrage there is inadequate flow to maintain the natural ecosystems of the Indus Delta. It is estimated that up to 0.5 million hectares of fertile land in Thatta and adjoining areas (IRIN 2001), or about 12% of total cultivated area in the entire Province (Government of Pakistan 2001), is now affected by sea water intrusion. As well as crop losses, this has resulted in severe damage to livestock through rangeland depletion, shortage of fodder, pasture and watering areas, and a resulting mass migration of both livestock and human populations out of the area.

The status of the Delta's natural ecosystems has already become critical, and the rural economy of the region faces an emergency situation as a result. The phenomenon of sea intrusion into the Indus River Delta has become one of the most politically-charged environmental issues in Pakistan today. Competition over water allocation within river basins, especially between upstream and downstream areas, between large-scale and subsistence-level uses, and between commercial and ecosystem uses, is becoming a source of severe economic and political conflict. In many ways the Indus Delta case study epitomises a national situation which has already reached crisis point, and is likely to deteriorate still further in the future. For now, national policies have opted to allocate scarce water so as to maximise financial and commercial returns to agriculture - often at the cost of natural ecosystems, and of some of the country's poorest communities. Yet there is growing concern that the failure to factor ecological economic values, or economic losses, into river basin planning is resulting in decisions being made about water allocation that are neither ecologically nor economically optimum. As long as the economic value of ecosystem needs for freshwater flows is marginalised in national decision-making, these conflicts are likely to escalate.

SAMPLING STRATEGY:

The study area under the project was primarily Khobar Creek, which is presently the only creek that carries the fresh water of Indus River into the Arabian Sea (Figure 1 & 2). An intensive study, comprising of current metering, echo-sounding, water and sediment sampling was undertaken down stream Kotri Barrage to Khobar Creek to quantify sediment and biogeochemical budgets. However, to ascertain the baseline values of nutrients an endeavour was made to collect sediment and water samples from all the major barrages and dams on the Indus River.

Figure 1: Satellite image of the Indus Delta. Inset shows the sampling stations on the Khobar Creek.

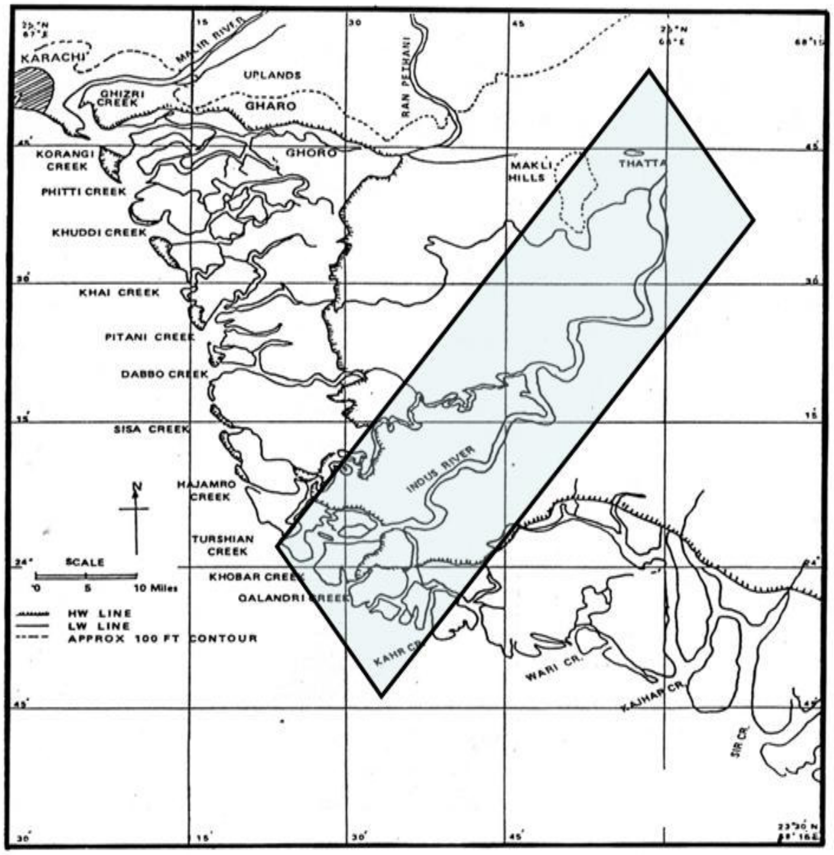


Figure 2: Map of the major creeks of the Indus Delta. The shaded portion indicates the sampling site on the Khobar Creek.

COLLECTION OF DATA AND SAMPLES:

Current Metering:

Aanderaa RCM 7 was used for recording of current speed and direction, water temperature, conductivity. Current metering was carried out at the confluence of tributaries in the Khobar Creek. Observations were obtained and recorded for continuous 25 hours (during spring tide). Water samples at one hour interval were also collected during the 25 hour continues current meter observations.

Echo-sounding:

Furuno echo-sounder (Model FE -4300) was used for the bathymetric profiling of Khobar Creek.

Navigation and Positioning:

Garmin 12 XL GPS was used for navigation and determining the coordinates of the sampling stations.

Sediment and water sampling:

Van veen type of grab sampler was used for sediment sampling. 1.2L Niskin bottle was used for water sampling. The criterion for spacing between stations was to follow a salinity gradient.

***Laboratory Analyses*:**

Sediment samples were analysed on Micromeritics Sedigraph 5100 and LECO's CR-412 Carbon Determinator for grain size and carbon content. Nutrients in water samples collected from various locations from Indus River were analysed according to standard international protocols.

SYNTHESIS OF FLUXES AND NUTRIENT BUDGETS:

The tidal, estuarine part of the Indus River at Khobar Creek covers a length of about 40 km and a basin area of 36 km^2. On the basis of physical characteristics it can be classified as partially-mixed coastal plain estuary. Hydrograhical and hydrochemical characteristics of the river exhibit seasonal variability. The water temperature reaches a maximum of 30ºC during the southwest (summer) monsoon and a minimum of 15ºC during the winter. Budgets for the estuary are therefore calculated for two seasons: wet season (July - August) and dry season (November-December). Based on the salinity variations the estuarine system has been divided into three boxes (Figure 3; Table 1)

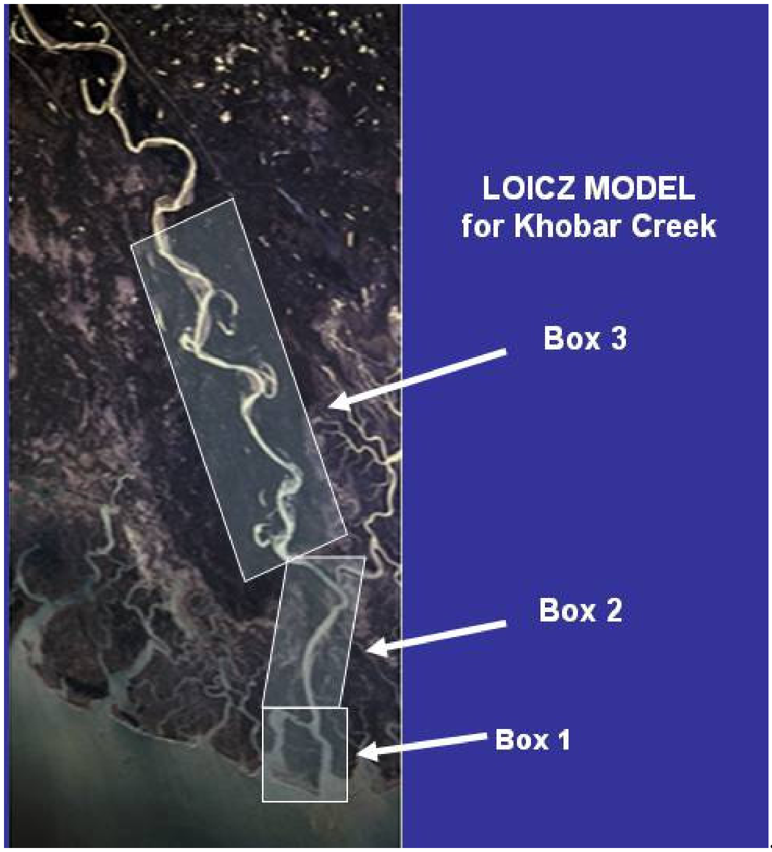


Figure 3: Location of Boxes for the nutrient budget calculations.

Nutrients:

There has been a drastic reduction in the load of nutrients brought by Indus River for the last fifty years. This reduction in Indus discharge has a negative impact on the Indus estuary and the productivity of the mangrove forest and fisheries.

Major nutrients (nitrite, ammonia, phosphate and silicate) were measured all along the Indus River water over a distance of about 1000km from Terbela Dam to Khobar Creek through which the river water discharges in to the Arabian Sea. Since the silicate were very high and in order to document the trend of Nitrite and phosphate in the transect, therefore distribution of other nutrients are omitted from the figure (Figure 4).

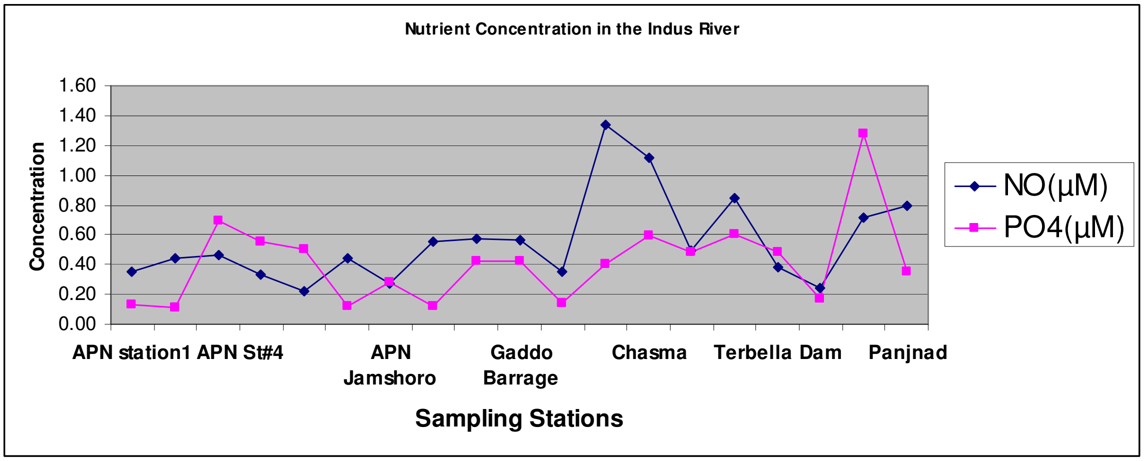


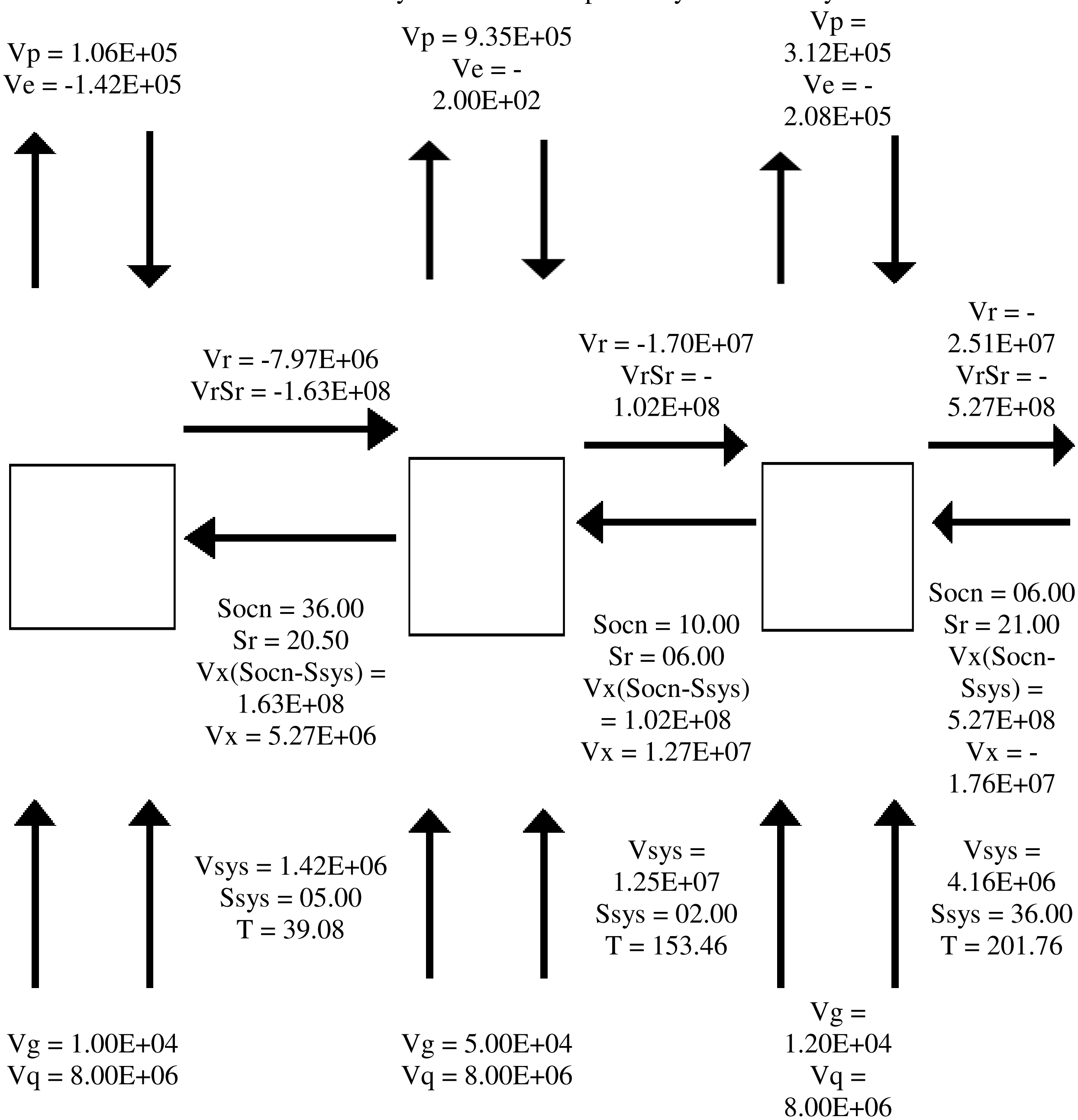
Figure 4: Nutrient concentration in the Indus River.

Table 1. Salinity and nutrient concentration in the Khobar Creek for two seasons

Seasons	Sources	Salinity (psu)	DIP (µM)	DIN (µM)
Dry	River runoff	0	0.11	0.24
	Inner	20	0.13	0.27
	Ocean	36	0.70	0.44
Wet	River runoff	0	0.12	0.21
	Inner	0	0.3	0.35
	Ocean	33	0.4	0.46

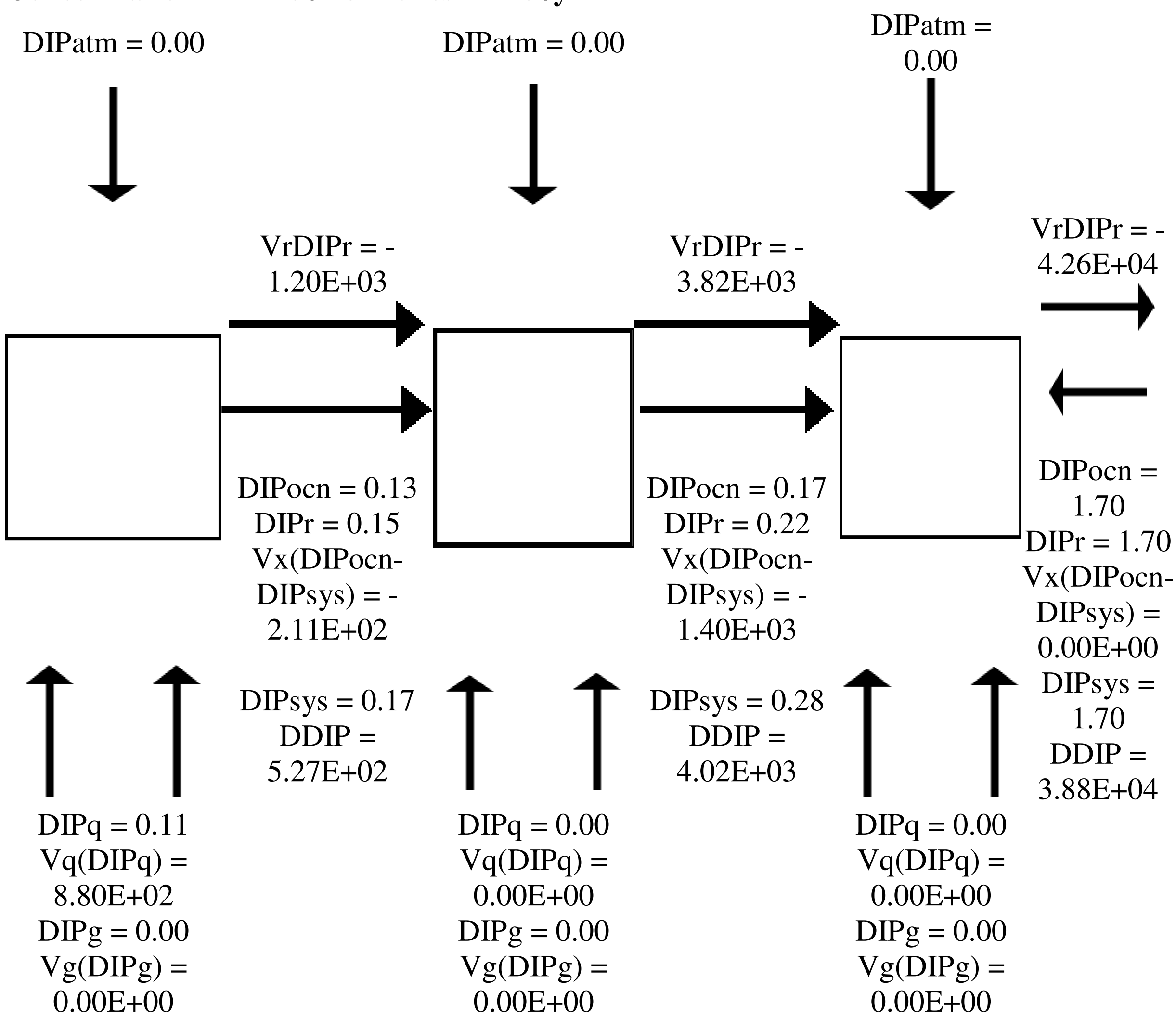
Season 1 Water and Salt Balances

Volume in m3 Water Fluxes in m3/yr Salt Fluxes in psu.m3/yr Time in days



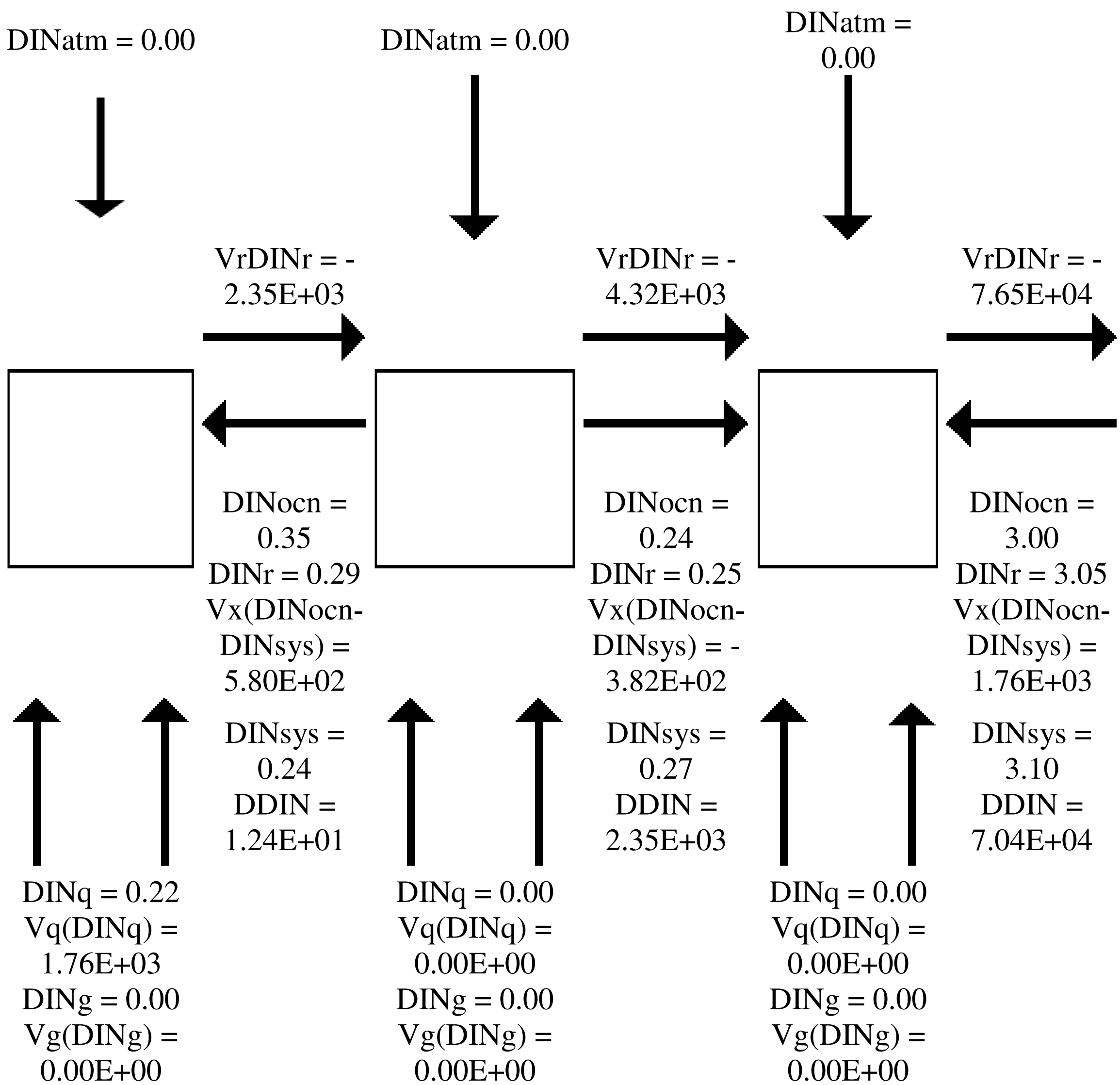
Season 1 Phosphate Balance

Concentration in mmol/m3 Fluxes in mol/yr



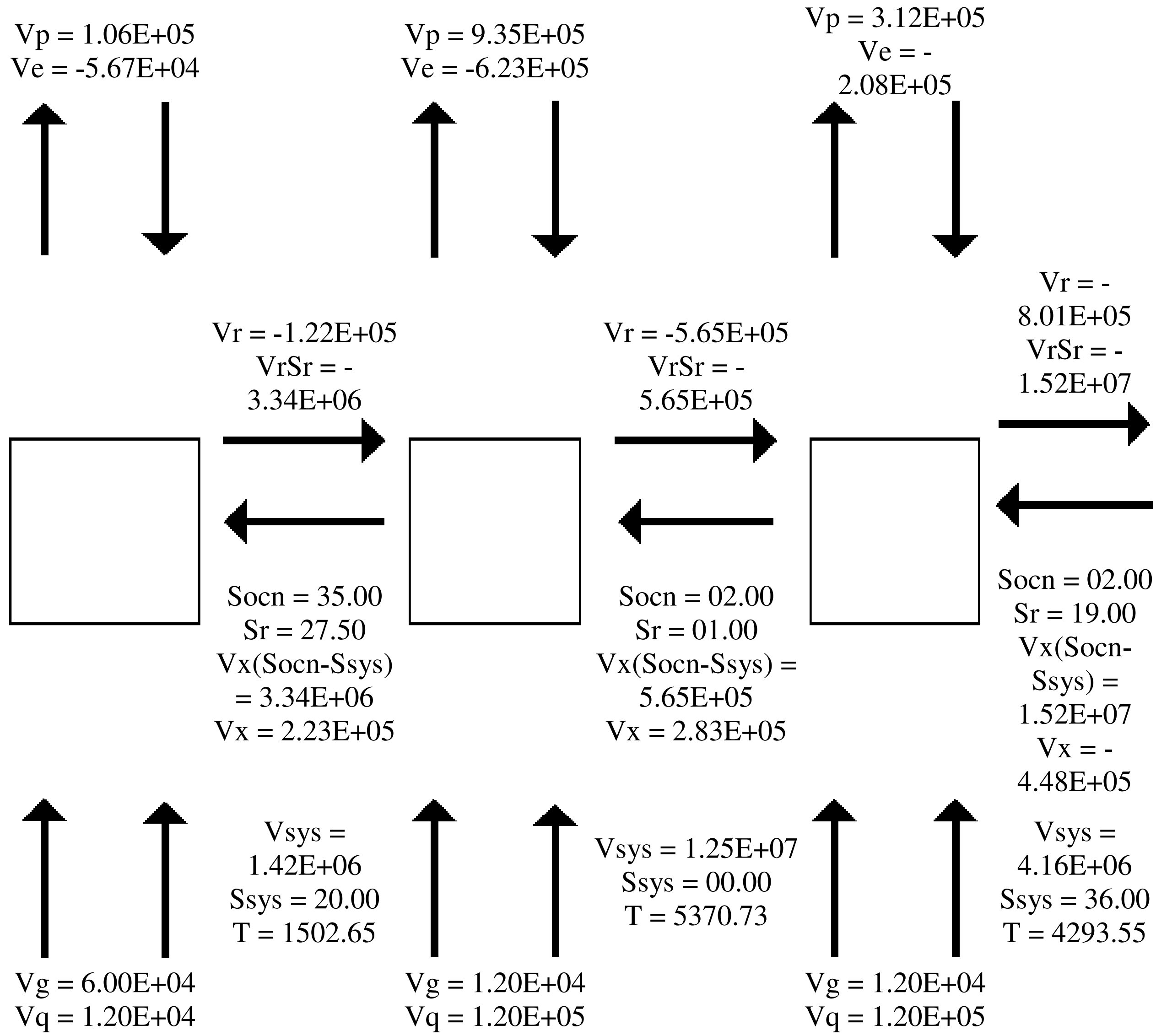
Season 1 Nitrogen Balance

Concentration in mmol/m3 Fluxes in mol/yr



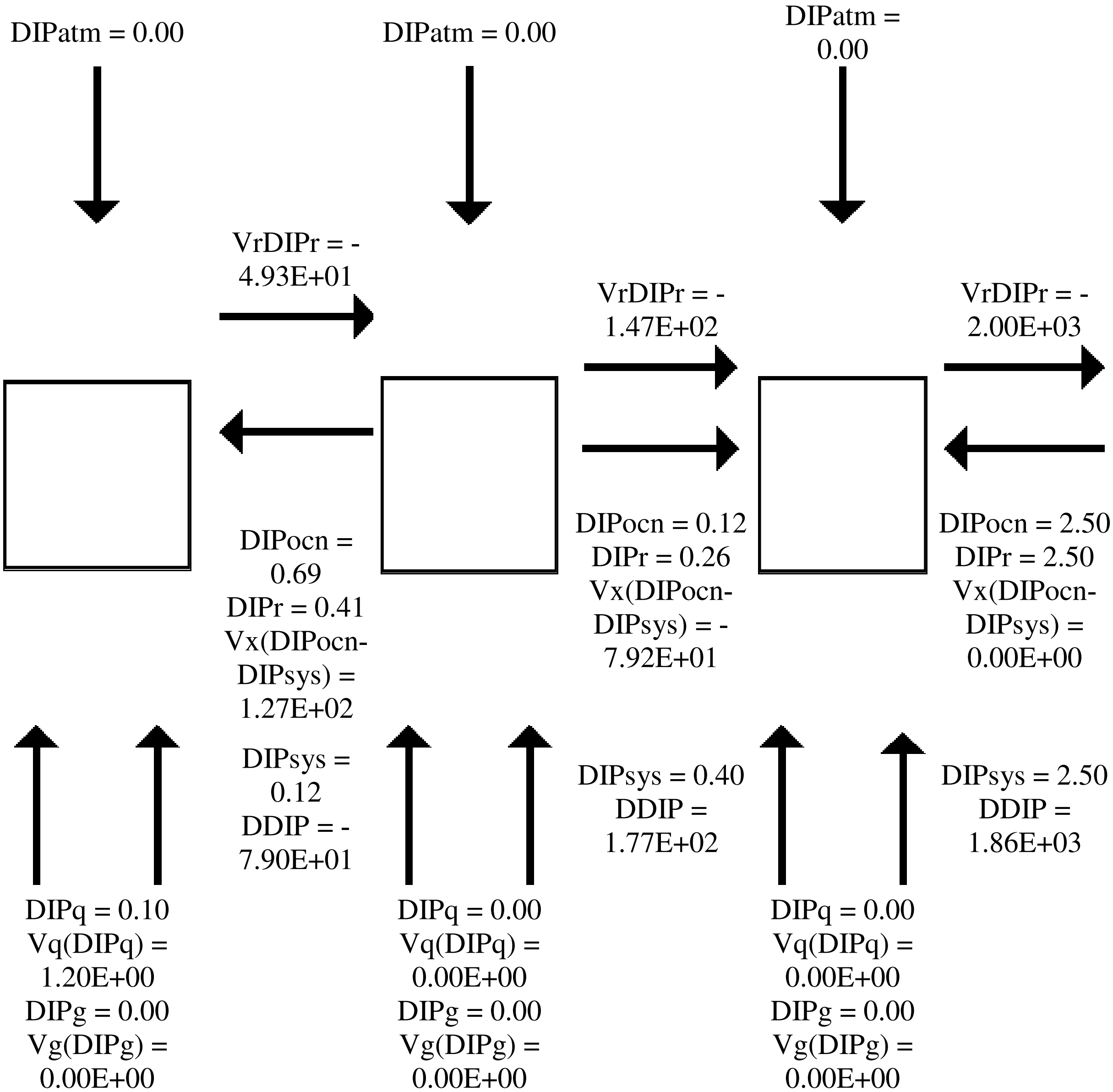
Season 2 Water and Salt Balances

Volume in m3 Water Fluxes in m3/yr Salt Fluxes in psu.m3/yr Time in days



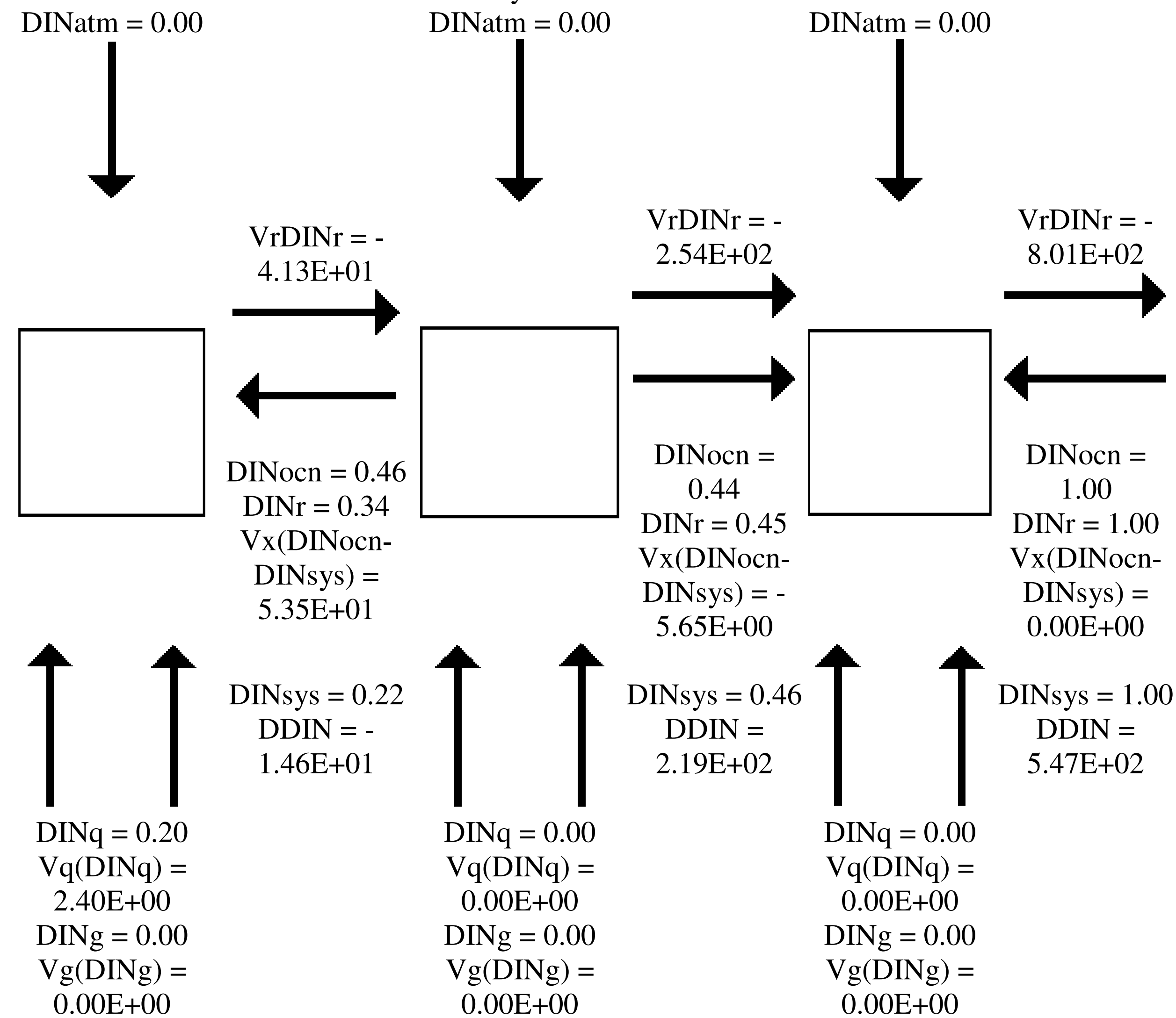
Season 2 Phosphate Balance

Concentration in mmol/m3 Fluxes in mol/yr



Season 2 Nitrogen Balance

Concentration in mmol/m3 Fluxes in mol/yr



Bathymetry:

The echo sounding of the river bed in the Khobar Creek area revealed very steep variations, specially at the confluences of tributaries in the major creek, where the river bed is much deeper (>15m) and rugged (Figure 5). The bottom topography indicates erosive phases that are characteristics of rivers with large sediment and water discharge. However the bathymetric data obtained during the present study is not sufficient to assist in the assessment of hydrodynamics of the Indus River in the Khobar Creek.

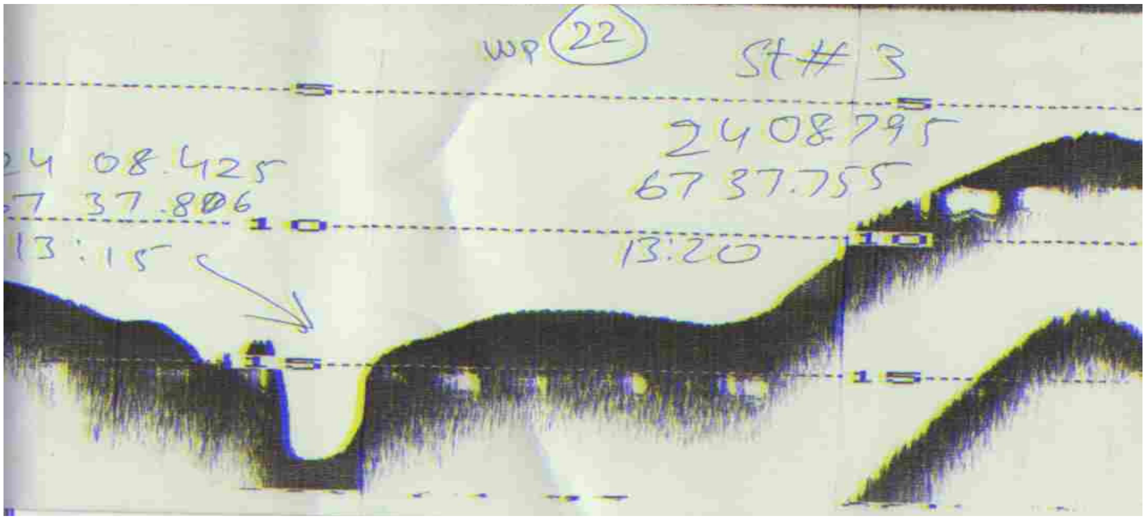


Figure 5: Echo profile of the Sajan wari (the site of 25hrs current meter observations) depicting rugged bottom topography indicative of erosional features at the confluence of tributaries.

River bed sediments:

The sediment samples collected from the area are, in general, relatively compact fine grained and mostly ranges between fine sand and clay size fraction (Figure 6).

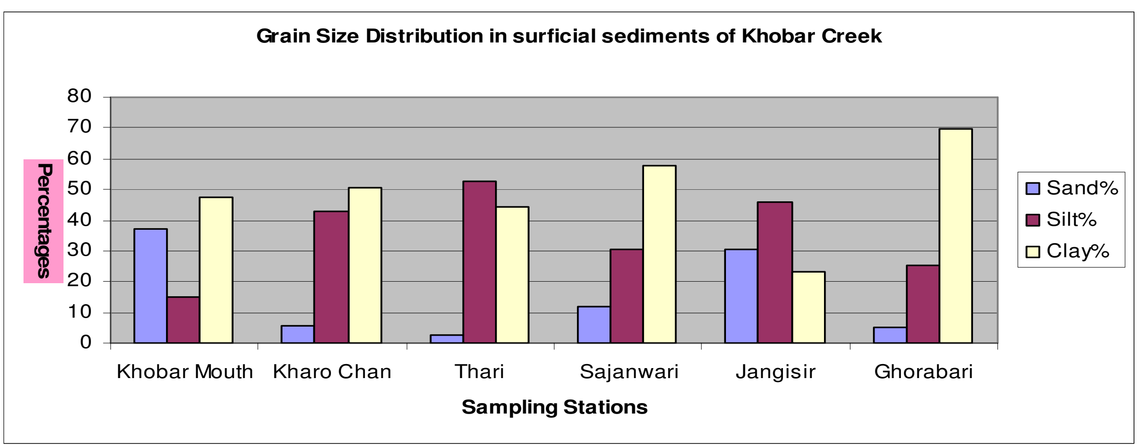


Figure 6: Grain size distribution in surficial sediments of Khobar Creek.

Sand percentage was generally low except at river mouth and at Jangisir where it was probably deposited during high flood periods. The coarseness and compactness of bottom sediments is also depicted as strong bottom echoes. In general, the mean grain size value suggests that the river flow is not strong enough to carry coarse sediments downstream to the river mouth. Whatever sediment the Indus River has carried to the delta limits itself within the Khobar Creek till the event of flood that flushes out the unconsolidated sediment to the Arabian Sea. The mineral composition of the sediments obtained from the Khobar Creek confirms that the sediment is Indus River derived. No marine component were found, this was supported by the absence of any shell fragments of marine origin. The coarse sediments at the river/creek mouth are reworked by wave and tidal processes, while the gentle slope helps sediment deposition.

Current velocity and Direction:

The analysis of 25 hours current velocity and direction data recorded in the Khobar Creek during the spring tide in July 2003 indicates that the maximum velocity was 154 cm/sec at flood and ebb stages while minimum velocity was 10 cm/sec (Figure 7). The volume of water discharged through the system can be calculated if the average velocity of water flow, average water depth and the width of the channel are known. The average depth of the Khobar Creek is ~17m; width (at the mooring site) is 1100m. Therefore the volume of water discharged through the Khobar Creek (at the time of observation) during the ebb and flood tide ranged approximately between 1870m^3/sec and 28840m^3 /sec respectively. While the average volume of water flowing at the time of observation was 13500m^3 /sec.

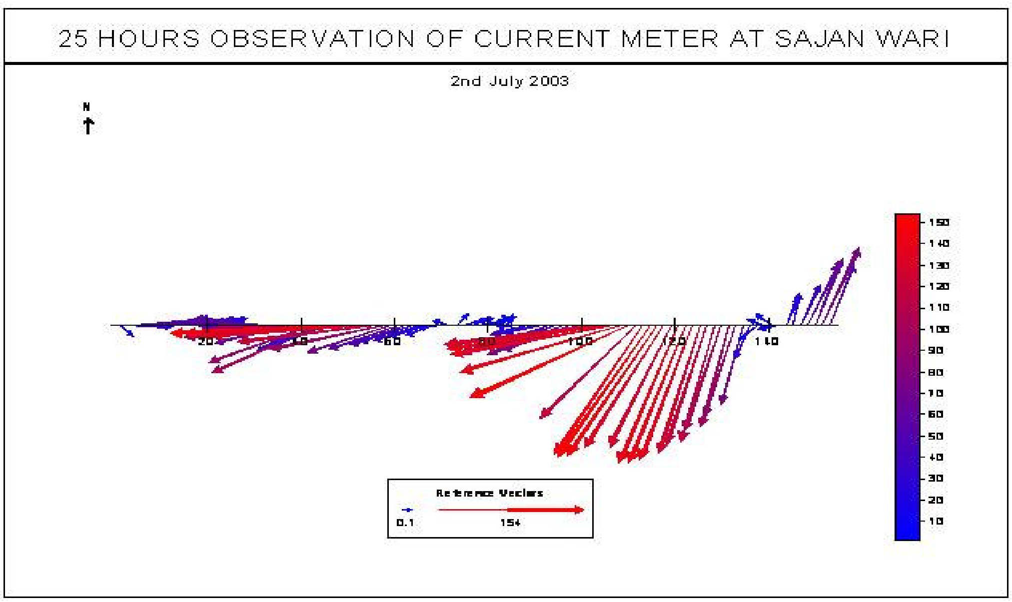


Figure 7: 25 hours current meter observations at Sajanwari, Khobar Creek.

Suspended Sediment Concentration:

The suspended sediment concentrations measured at different locations on the Indus River showed substantial variation. The concentration of suspended sediment is directly linked with the water discharge in the river. The suspended load monitored at Kotri (about 200km from the river mouth) ranged between 65 and 92ppm. Torrential rain in July 2003 in the lower Indus Basin contributed towards relatively high suspended load concentrations in the section down stream Kotri Barrage (4569ppm) to river mouth at

Khobar (3948ppm). However, since the 25hrs observation were carried out in the first week of July i.e., just prior to the onset of heavy rains therefore the data presented in Figure 8 does not show high sediment concentrations.

The suspended load measured during the 25 hour continues observation in Khobar Creek is plotted in Figure 8. Though there was substantial variation in the salinity with the diurnal variation in tide no apparent change was observed in the suspended sediment concentration (Figure 8). The apparent reason for that is the movement of relatively strong ebb and flood tide keeps the fine sediments in suspension and retards their deposition. The grain size data obtained from the Khobar Creek further substantiate this hypothesis.

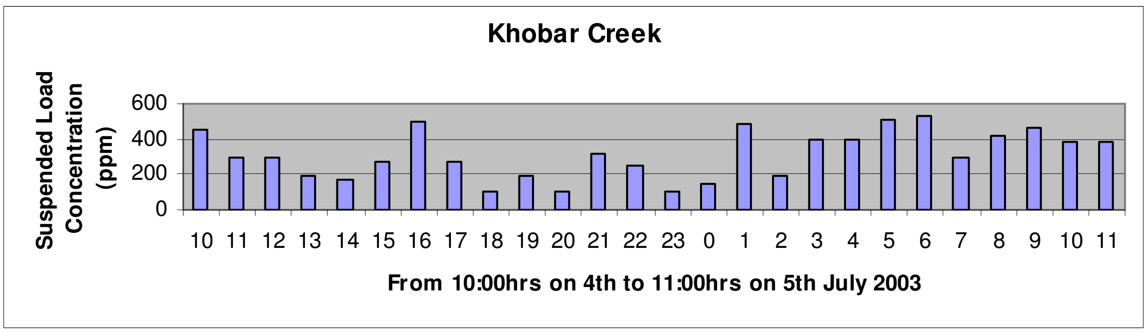


Figure 8: Suspended sediment concentration plotted with reference to salinity variations during 25 hours continues observations in Khobar Creek.

Turbidity:

In Khobar Creek the light penetration was up to a depth of <1.0 m. Turbidities are influenced by the strong tidal flux which reverses its direction during ebbing and flooding. Generally the turbidities are higher during ebb tides, particularly in the shallow creeks. The turbidities were high after the raining season of southwest monsoon.

Organic Carbon and Calcium Carbonate:

The Indus River bed sediments have relatively low values of calcium carbonate (< 10%) because sand contains relatively high concentrations of mica (36%), quartz (37%) and feldspar (11%) with very little percentage of detrital carbonate sediments. The organic carbon and calcium carbonate content in the sediment samples obtained from the area averages <1% and <15% respectively (Figure 9 & 10). Low values of the C_{org} (< 1%) were obtained for the bed samples of the Indus River. The bed sediments are generally composed of fine sand size material. Therefore, they have comparatively less $C_{org.}$

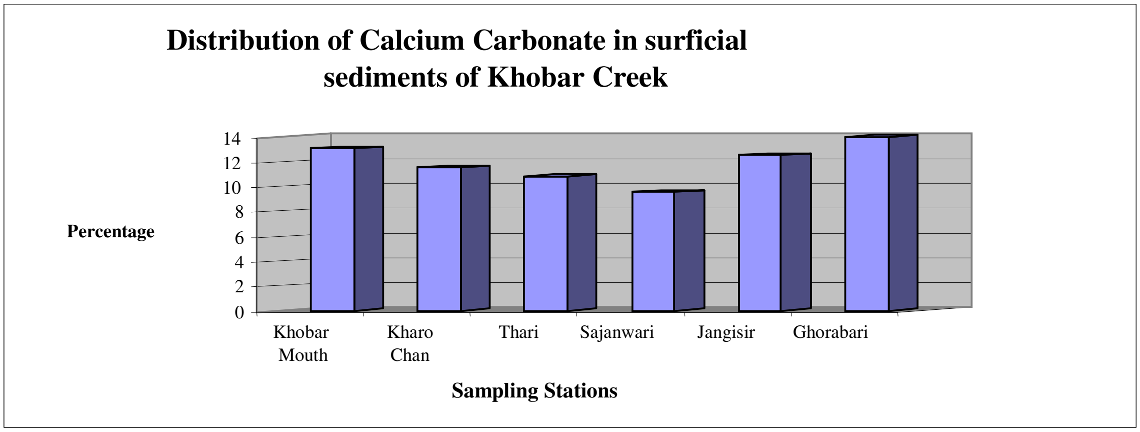


Figure 9: Distribution of Calcium carbonate in the surficial sediment of the Khobar Creek.

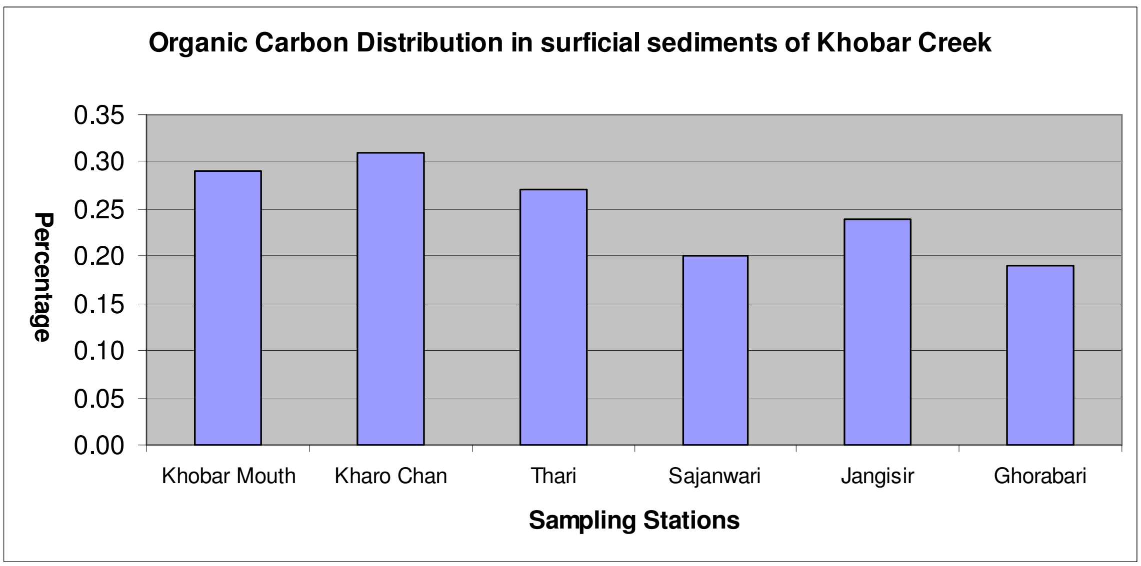


Figure 10: Organic carbon distribution in surficial sediments of Khobar Creek.

Mineralogical and elemental analyses:

Generally, quartz, albite and muscovite are the common minerals with the exception of clinochlore, anorthite sodian in the coarser river sediments. Illite, chlorite and montmorillonite are the common clay minerals.

Concentration of heavy metals in the river sand and fine-grained deltaic sediments have relatively high values of iron (Fe) that ranges between 2600 and 5000ppm, while Mn ranges from 47.43-370.90 ppm, Cu ranges from5-26.32 ppm, Zn ranges from14.51-46.38 ppm, Cr ranges from 10.7-30.70 ppm, Ni ranges from 11.26-123.56 ppm and Pb ranges from 4.2-13.52 (Figure 11).

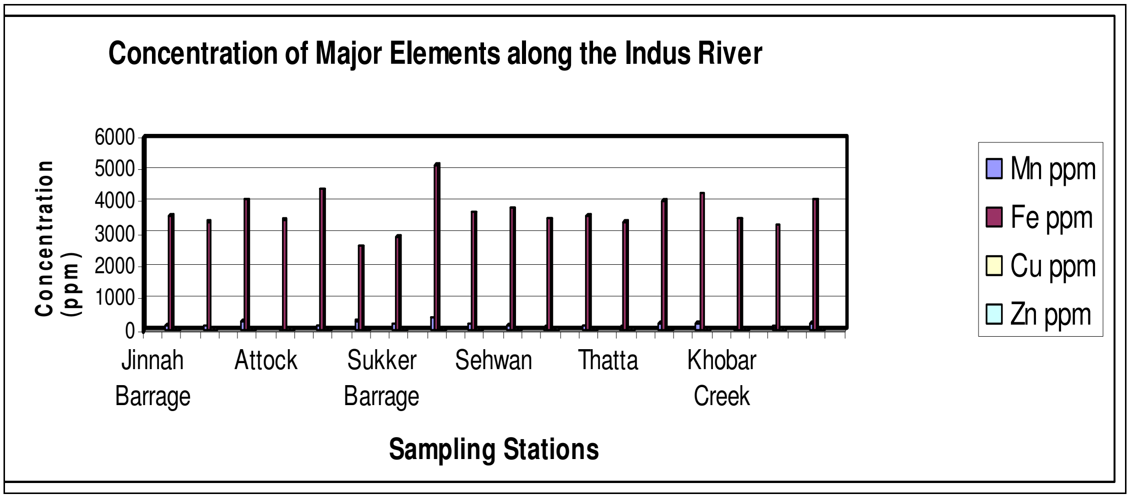


Figure 11: Distribution of major elements along the Indus River.

Socio-economy:

Pakistan had torrential rains that subsequently brought floods in the lower Indus Basin. Our scientists gave special attention to the area to document the impact of these rains and floods on the sediment and nutrient fluxes as well as on socio-economy of the area. The worst affected areas of the Sindh Province include the districts of Badin, Thatta, Larkana, Dadu, Tharparkar and Shikarpur. According to preliminary reports from the Relief Department, Government of Sindh, a total of 387,657 persons have been affected by the floods. The rains destroyed 11,699 houses while 21,063 houses were partially damaged. A total of 81 persons died as a result of the floods and 321 injured, while 9,066 heads of cattle perished and 229,754 acres of cropped area was affected.

Capacity Building

Under this project, two approaches of capacity building were adopted by the National Institute of Oceanography, Pakistan. In one approach, couple of junior scientists were attached full time with the project along with experienced scientists so that they could learn the field and laboratory techniques. On the other hand, scientists involved in this project disseminated knowledge about LOICZ approach and model to young university students.

CONCLUSION AND RECOMMENDATIONS:

The Indus River water and sediment discharge to the deltaic area and eventually to Arabian Sea is limited to few days during the months of July and August. Extensive sediment coring is proposed in the deltaic area and in the lower part of the Indus River. A hydraulic station should be established so that water and sediment input into the system can be quantified. The total sediment thickness and volume of the Holocene delta should be quantified through 3.5khz seismic surveys. On the subaerial delta a sediment facies map should be made in order to define the sedimentary sub-environments and their formative processes. It seems likely that measurements in localities strongly affected by the SW monsoon will have to be restricted to the winter months. The most dynamic period will then be missing in the data, but experience has shown that a substitute for this may be sought in the sedimentary record (box- and other undisturbed cores). In the tidal channels, and in the sub aqueous delta quantitative data should be obtained through echo sounding, by monitoring wave and tidal height, current velocity, current direction, and suspended as well as bed load. From the structures in the cores the relative importance of sediment depositing and transporting processes should be evaluated. Long term study of Indus River and delta is suggested to document the negative impacts of water and sediments starvation on the ecology and socio-economy of the area.

ACKNOWLEDGEMENT

We wish to thank Asia Pacific Network on Global Change Research, Japan & Sri Lanka Association for the Advancement of Science for funding, organising and motivating this study. The authors gratefully acknowledge the dedication, untiring commitment of Dr. Ratnasiri for sponsoring and inviting us to participate in the SASCOM-LOICZ Workshops on Estuarine Modelling and Coastal Zone Management, Colombo, Sri Lanka (April 1999 and September 2000). Under the aegis of the IGBP-START South Asia Committee (SASCOM), joint START/LOICZ/IGBP Sri Lanka workshops were held in Colombo on 28 April -1 May 1999, 18-22 September, 2000 and December 2002.

APPENDIX IV-D

SRI LANKA

An Assessment of Nutrient Budgets of Lunawa Lagoon, Sri Lanka
S.P.Samarawickrama and S.S.L. Hettiarachchi

Negombo Estuarine System: Exploratory Steady-State CNP Flux Budget
Samarawickrema S.P and U.A.P.K Dissanayake

An Assessment of Nutrient Budgets of Lunawa Lagoon, Sri Lanka

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Abstract

Lunawa Lagoon is a shallow coastal body of water located on the west coast of Sri Lanka. It has a rather elongated shape, and the water surface area is about 20 ha and the perimeter is about 4.5 km. Lagoon is surrounded by highly populated area and some heavily polluting industries. Untreated effluents have been discharged from industrial sites into the small tributaries that feed into Lunawa lagoon. In addition, domestic wash water generated by residents in the area is discharged into open ditches draining into the Lagoon. The problems are amplified by the presence of a sand bar, which blocks the connection of the lagoon to the sea, restricting water flow and exchange. This has resulted in decrease in salinity and an increase in accumulated nutrients and pollutants in the lagoon.

The paper describes the application of LOICZ budgetary model to predict the exchange of dissolved inorganic N (nitrate, nitrite and ammonium) and P (phosphate) between the Lunawa Lagoon and the adjacent ocean. This budgetary model is defined as a mass balance calculation of specific variables for a defined geographic area and time period. The model should include all major sources and sinks and usually requires a substantial amount of quantitative data for the area.

Present study was carried out with the available data for the Lunawa lagoon. It has been realized that some critical data is missing, especially in the case of Nutrients and other non-conservative components. However, as a first attempt it provides sufficient understanding of the system.

Keywords: nutrient budgets, effluents, Lunawa Lagoon

Introduction

Lunawa lagoon is a shallow coastal body of water located on the west coast of Sri Lanka. It has a rather elongated shape, and the water surface area is approximately 20 ha and the perimeter is around 4.5 km (Figure 1). The lagoon in the past served a variety of human activities such as agro business, fishing, recreation etc. and also served as a tourist attraction due to its scenic beauty. But this scenario has all changed mainly due to uncontrolled human activities leading to environmental degradation.

The lagoon is surrounded by a highly populated area and some heavily polluting industries. Untreated effluents have been discharged from industrial sites into the small tributaries that feed into Lunawa lagoon. In addition, domestic wastewater generated by residents in the area is discharged into open ditches draining into the lagoon. The problems are amplified by the presence of a sand bar, which blocks the connection of the lagoon to the sea, restricting water flow and exchange. This has resulted in decrease in salinity and an increase in accumulated nutrients and pollutants in the lagoon.

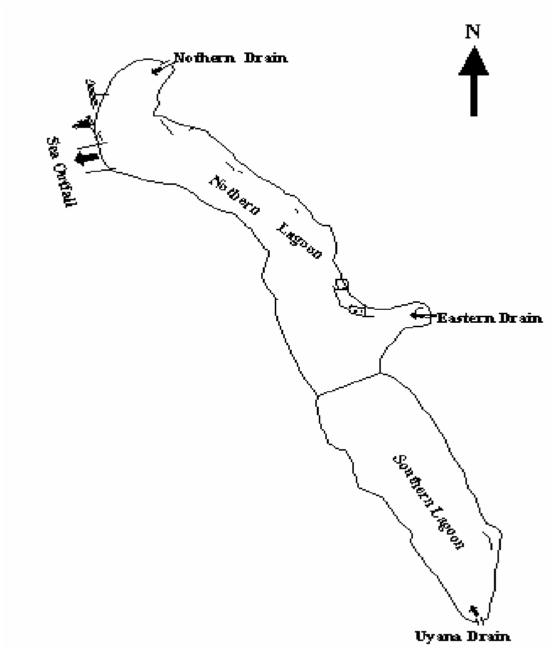

Figure 1: Lunawa Lagoon

Due to the toxic nature of some of the pollutants, most of the aquatic life have disappeared from the lagoon thus forcing the fishermen to give up their profession. The combination of the nutrient characteristics of some of the pollutants and stagnation of water within the lagoon creates an ideal environment for the phenomenon known as eutrophication or algal bloom.

The paper describes the application of Land Ocean Interaction in the Coastal Zone (LOICZ) budgetary model to predict the exchange of dissolved inorganic N (nitrate, nitrite and ammonium) and P (phosphate) between the Lunawa Lagoon and the adjacent ocean. This budgetary model is defined as a mass balance calculation of specific variables for a defined geographic area and time period. The model includes all major sources and sinks and usually requires a substantial amount of quantitative data for the given area.

The present study was carried out with the available data for the Lunawa lagoon. It has been realized that some critical data are missing, especially in the case of nutrients and other non-conservative components. However, as a first attempt it provides sufficient understanding of the system to proceed further.

Overview of LOICZ Biogeochemical Budgeting Procedure

Natural systems such as ecosystems are usually very complex, and models currently being used vary greatly in the degree of simplification in resolving these complex issues. "Budget models" are simple mass balance calculations of specific variables (such as water, salt, sediment, CNP, etc.) within defined geographic areas and over defined periods. Usually budget models are built to aggregate the vast range of individual components of a system into even smaller sets of components, which are similar to one another.

Budgeting the fluxes of materials to and from a system may be undertaken by many different procedures, but there are inherent similarities among these procedures. Basically, a budget describes the rate of material delivery to the system ("inputs"), the rate of material removal from the system ("outputs"), and the rate of change of material mass within the system ("storage"). Some materials may undergo internal transformations of state, which lead to appearance, or disappearance of these materials. Such changes are sometimes referred to as "internal sources or sinks" as shown in the Figure 2.

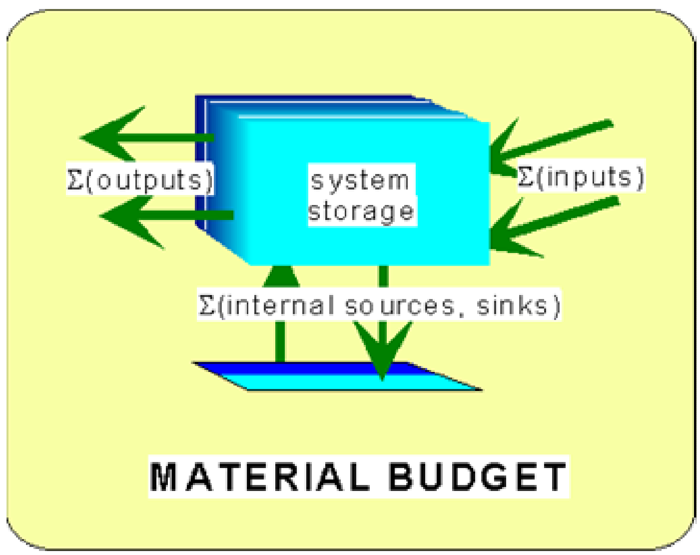

Figure 2: Generalized diagram characterizing material budgets.

It is also useful to describe such a budget in terms of a simple equation:

$$\frac{dM}{dt} = \sum inputs - \sum outputs + \sum[sources - sinks] \qquad (1)$$

where "*dM/dt*" represents the change of mass of any particular material in the system with respect to time. It is often assumed that *dM/dt* = 0; that is, the system mass is assumed to be at steady state.

LOICZ system contains three budgetary models which are introduced below.

ONE Box Model : This model is used when the system is both horizontally and vertically uniform such as when there is only a small freshwater input compared to the volume of the system and/or when there is through mixing of the water column.

TWO Layer Model: This model is used when the system is vertically stratified such as when there is high amount of freshwater input into the system.

Multi-Box Model: This model is used when the system is vertically heterogeneous such as when there is a significant freshwater input into the system but an otherwise thoroughly mixed water column.

The LOICZ ONE Box Model, which is used in the present study is described in greater detail.

Water (and Salt) Budget

The rate of water exchange between that of a coastal water body which is of interest (system) and adjacent systems is estimated by one of several procedures. The simplest procedure to describe water exchange in many coastal marine systems is the construction of combined water and salt budgets for those regions. This combined water and salt budget does not provide a dynamic, quantitative understanding of the processes controlling the characteristics of water exchange in a particular system, but it is often a quick and simple way to describe the exchange. Figure 3 shows the generalized diagram of water and salt budgets in coastal water bodies.

Water and salt have no internal inputs or outputs, so that allows simplification of this equation. A second simplification, for the presentation here, is to consider that the mass of the system stays constant through time; that is, *dM/dt = 0*. We may thus simplify equation (1):

$$0 = \sum inputs - \sum outputs \qquad (2)$$

In the case of a coastal system, river inflow (V_Q) and perhaps direct precipitation on the system (V_P) are likely to be the major freshwater inputs to the system. Groundwater (V_G) and other freshwater sources (V_O) are likely to be lesser of importance, but can be included if preliminary calculations suggest them to be a significant fraction of the freshwater volume. Evaporation (V_E) may be a significant freshwater output, and because it is an outflow it has a negative sign.

The residual flow (V_R) can be either to or from the system. It is algebraically treated as an input, although this "input" has a negative value (like V_E) in most coastal systems.

$$V_R = -\left(V_Q + V_P + V_O + V_G - |V_E|\right) \qquad (3)$$

There are additional, potentially large (often dominating) terms of water flow: the inflow and outflow of seawater from outside the system. In the simple budgeting procedure used here, these are all grouped together into a single term described as "exchange flow" (V_X), where there is an inflowing volume V_X exactly matched by an outflowing volume (also V_X). V_X is not known at this point. The equation (3) can be re-written to describe the water budget of the system as:

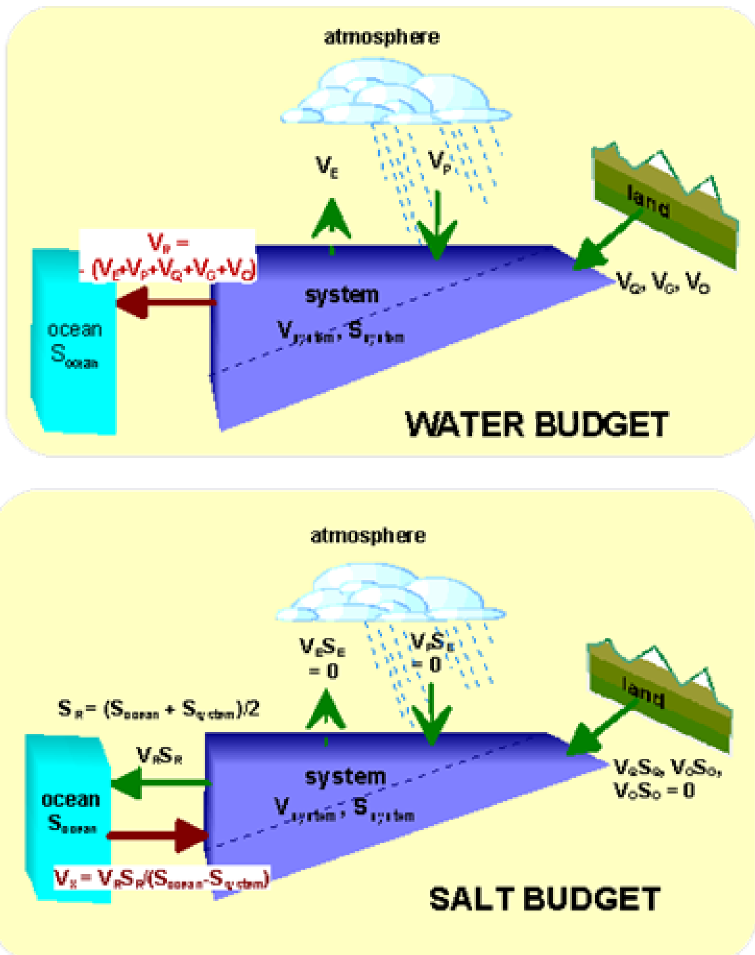

Figure 3: Generalized diagram illustrating the calculation of water and salt budgets in coastal water bodies.

$$0 = \sum(V_Q + V_P + V_G + V_O + V_R + V_X) - \sum(|V_E| + V_X) \qquad (4)$$

This equation describes the water budget for the system of interest. For the salt budget, an average salinity is assigned to each one of the water inputs and outputs. The inputs and outputs then become the volume flow (the V's in the above equation) multiplied by the appropriate salinities (designated as S's). For most of the terms (S_Q, S_P, S_E, S_G and S_O) it is sufficiently accurate to assume their salinity to be 0. This leaves S_R and S_X of both the inflowing water and outflowing water to assign. S_X of the outflowing water is usually treated as the average salinity of the system of interest (S_{system}) and S_X of the inflowing water is the adjacent (oceanic) salinity (S_{ocean}). S_R is the salinity near the boundary between the ocean and system of interest; often it is adequate to assign this salinity as the average of the oceanic water and the system water. Re-writing equation (4) for a salt budget by leaving out those terms with salinity likely to be near 0:

$$V_X = \frac{V_R S_R}{(S_{syst} - S_{ocn})} \qquad (5)$$

The value V_X is a relatively unsophisticated, but surprisingly robust, estimate of water exchange. V_X will prove critical in calculating **nutrient budgets**. It is often useful to estimate water residence time for a system; this is defined as the average length of time water stays in the system. Both residual flow and exchange account for the water residence time, so the system volume (V_{syst}) divided by the sum of V_X plus the absolute value of V_R is an estimate of water residence time.

Nutrient Budgets

$$\sum[sources - sinks] = \sum outputs - \sum inputs \qquad (6)$$

Equation (6) defines the role of any particular budgeted system as a net source or sink for any particular material. Materials which enter or leave the system with water and which undergo no net transformations within the system (salt is an example) are said to exhibit "conservative behavior." For any material Y, the term $\sum$ [*sources-sinks*] can be denoted ΔY. This term is sometimes called the "nonconservative behavior" of the system, because the flux of Y is not the same as (that is, is not conserved with respect to) the fluxes of water and salt. The water and salt fluxes are described by the hydrographic budget, so ΔY is not conservative with respect to hydrography.

Figure 4. shows the generalized budget for any material, Y, within a coastal marine system. ΔY represents the sum of internal sources and sinks and is calculated from the system inputs and outputs. All dissolved N and P will exchange between the system of interest and adjacent ocean according to the criteria established in the water and salt budgets. Deviations are attributed to net no conservative reactions of N and P in the system. In the case of a coastal system, concentration of dissolved inorganic N (nitrate, nitrite, ammonium) and P (phosphate) in the system (DIN_{sys}, DIP_{sys}), in the adjacent ocean (DIN_{ocn}, DIP_{ocn}) and in the inflowing river water (DIN_Q, DIP_Q) are likely to be the major nutrient inputs to the system. If important concentration of dissolved inorganic N and P in ground water (DIN_G, DIP_G) and some estimate of nutrients (or at least BOD) loading from sewage or other waste discharges (DIN_O, DIP_O) can be included

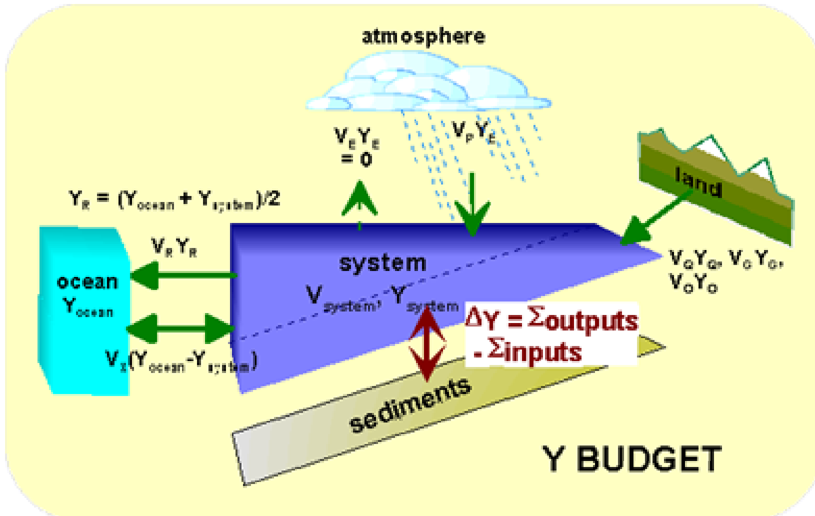

Figure 4: Generalized budgets for any material, Y, within a coastal marine system.

$$\Delta DIN = flux_{out} - flux_{in}$$
$$\Delta DIN = -\left(V_X DIN_X + V_R DIN_R + V_G DIN_G + V_O DIN_O + V_Q DIN_Q\right) \qquad (7)$$

DIP is calculated similarly.

Stoichiometric relationships

It is assumed that the non-conservative flux of DIP with respect to salt and water is an approximation of net metabolism (photosynthesis and respiration) at the scale of the system. The non-conservative flux of DIN approximates net nitrogen fixation minus denitrification.

(p-r) is photosynthesis minus respiration

$$(p - r) = -\Delta DIP(C:P)_{part}$$

(nfix-denit) is N fixation minus denitrification

$$(nfix - denit) = \Delta DIN - \Delta DIP(N:P)_{part}$$

where $(C:P)_{part}$ and $(N:P)_{part}$ are the ratios of organic matter reacting in the system. The organic matter with the "Redfield CNP ratio" of 106:16:1 is probably an adequate description for plankton-based systems, but systems dominated by benthic organisms such as seagrasses, benthic algae, or mangroves may not be well-described by this ratio.

Budget for the estuarine system of the Lunawa lagoon

Available Data

Precipitation

Daily rainfall data for Lunawa region was available for year 2000. Average daily rainfall figures used in the study is given in the table 1.

Evaporation

Average daily Evaporation for Colombo was obtained from the Meteorological Department for the year 2000 and is given in the table 2.

Dissolved Inorganic Phosphate (DIP) and Dissolved Inorganic Nitrate (DIN)

DIN and DIP data were available from the Lunawa Environmental Improvement and Community Development Project (2). The values for the months of May, 2000 and June, 2000 were not available and corresponding values from year 2001 were used to obtain a full years (2000) record. Data from the measuring point at the Outfall of the Lunawa lagoon is taken as the values for *outside system* and the average of the three measuring points inside the lagoon is taken as the values for the *system*. Table 3 gives the DIP and DIN values used for the study.

Table 1: Average daily Rainfall for the year 2000

Month	Average Daily Rainfall (mm)
January	4.2
February	5.8
March	6.6
April	12.6
May	6.2
June	7.8
July	2.1
August	5.4
September	10.3
October	19.3
November	8.1
December	6.6

Salinity

No salinity measurements were available for the Lunawa lagoon but conductivity measurements were available on monthly basis. Those conductivity data was used to calculate the average monthly salinity of the lagoon. Monthly average temperatures for

Ratmalana area together with monthly averaged conductivity was used for calculations due to the unavailability of temperatures at Lunawa measured points.

Table2: Average daily Evaporation for the year 2000

Month	Average Daily Evaporation (mm)
January	3.01
February	3.32
March	3.85
April	3.71
May	3.53
June	3.15
July	3.80
August	3.43
September	3.18
October	3.47
November	3.07
December	3.22

Table 3: DIN and DIP values for year 2000

Month	In the system		Outside the system	
	DIN ($mmol/m^3$)	DIP ($mmol/m^3$)	DIN ($mmol/m^3$)	DIP ($mmol/m^3$)
January	1.29	26.32	1.52	10.53
February	7.72	5.26	0.52	2.63
March	0.53	6.14	0.05	11.05
April	0.35	9.65	4.03	2.63
May	1.84	8.53	0.65	7.89
June	7.19	24.91	1.13	30.74
July	4.60	10.53	5.48	5.26
August	2.22	8.77	2.58	15.79
September	1.58	3.16	0.45	5.26
October	3.38	14.04	2.58	15.79
November	3.60	17.54	0.00	21.05
December	0.79	17.54	0.52	21.05

The conductivity measurements for the months May and June of the year 2000 were missing and corresponding figures from year 2001 was used in the study. The salinity of the ocean (outside the system) was taken as 30ppm. Average monthly Conductivity, Temperature and Salinity are given in the Table 4.

Table 4: Conductivity, Temperature and Salinity for year 2000

Month	Conductivity (ms/cm)	Temperature (^{0}C)	Salinity (ppm)
January	1.58	27.4	15.3
February	1.34	27.8	18.4
March	2.96	28.2	08.1
April	3.53	29.0	06.8
May	3.42	29.0	07.0
June	3.06	28.3	07.8
July	2.74	28.4	08.7
August	1.18	27.9	21.5
September	1.08	27.5	24.1
October	1.96	28.0	12.2
November	2.83	27.6	08.4
December	2.39	27.4	09.9

Discussion of Results

LOICZ ONE Box Model was run on monthly basis for the year 2000 and Table 5 (and Figure 5) presents the model results. The results indicate that in the months of July, August and September there is net removal of DIP from the Lunawa lagoon whereas in all other months there is a net production of DIP. In the months of April and July there is net removal of DIN from the Lunawa lagoon where as in all other months there is a net production of DIN. On average the budgetary results show that the Lunawa lagoon is a net source of DIN and DIP.

Table 5: ΔDIP and ΔDIN for the year 2000

Month	**ΔDIP (mmol/d)**	**ΔDIN (mmol/d)**
January	10.2	0.2
February	4.7	9.5
March	2.4	0.4
April	20.8	-1.3
May	4.7	1.2
June	19.0	7.7
July	-4.3	-1.4
August	-3.6	0.5
September	-7.8	8.8
October	40.6	12.4
November	16.3	5.0
December	10.7	0.6
Annual Average	**9.5**	**3.6**

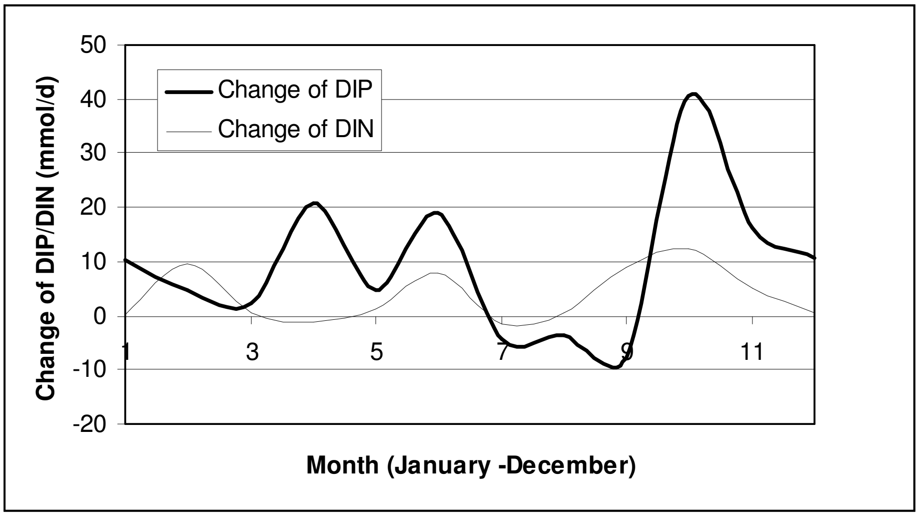

Figure 5: Monthly variation of ΔDIP and ΔDIN for the year 2000

Using $(C:P)_{part}$ = 106 and $(N:P)_{part}$ = 16, (p-r) = -1007 mmol/d and (Nfix-denit) = -148.4 mmol/d. The negative *(p-r)* indicate that the Lunawa lagoon is apparently net heterotrophic. Results of the *(Nfix-denit)* calculation show that the system is net denitrifying.

Summary and Conclusions

The paper describes the application of Land Ocean Interaction in the Coastal Zone (LOICZ) budgetary model to predict the exchange of dissolved inorganic N (nitrate, nitrite and ammonium) and P (phosphate) between the Lunawa lagoon and the adjacent ocean. Present study was carried out with the available data for the Lunawa lagoon. It has been realized that some critical data is missing, especially in the case of Nutrients and other non-conservative components. However, as a first attempt it provides sufficient understanding of the system to proceed with further investigations.

The results indicate that in the months of July, August and September there is net removal of DIP from the Lunawa lagoon where as in all other months there is a net production of DIP. In the months of April and July there is net removal of DIN from the Lunawa lagoon where as in all other months there is a net production of DIN. On average the budgetary results show that the Lunawa lagoon is a net source of DIN and DIP.

The negative *(p-r)* indicate that the Lunawa Lagoon is apparently net heterotrophic. Results of the *(Nfix-denit)* calculation show that the system is net denitrifying.

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http://data.ecology.su.se/MNODE/Methods/TOC.HTM

Negombo (Sri Lanka) Estuarine System: Exploratory Steady-State CNP Flux Budget

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The Negombo Lagoon ($7^0 4'$-$7^0 12'$ N: $79^0 47'$- $79^0 51'$ E) is situated in the west coast of Sri Lanka. The estuary receives water from Attanagalu Oya (Ja-Ela and Dandugam Oya) drainage basin and performs a dominant morphological feature of the watershed. The brackish water mass is 32.39 km^2 with an average depth of 1m and considered to be the estuarine part of the contiguous wetland system of the Muthurajawela Marsh Negombo Lagoon. The main fresh water source, Attanagalu Oya empties at Ja-Ela and Dandugam Oya at the southern tip of the estuary. In addition the Hamilton canal is the connecting watercourse of the Kelani estuary and the Negombo Lagoon running parallel to the west coast from the north to the south along the Muthurajawela Marsh.

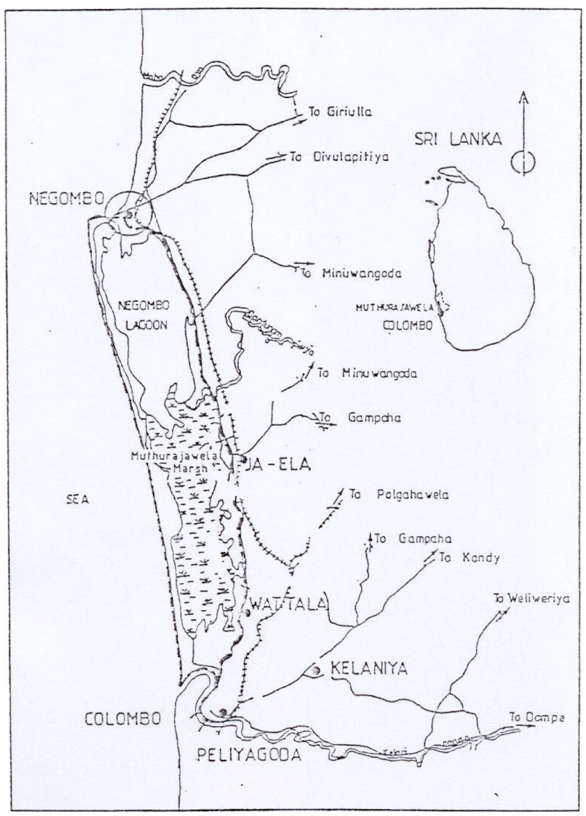


Figure 1: Muthurajawela Marsh – Negombo Estuary

LOICZ one Box one Layer, two box one layer and three box one-layer models were applied to generate budgets for the Negombo Estuary. The period starting from

February to September (2002/2003) is considered as the Dry season and the period from October to January (2002/2003) is considered as the Wet season.

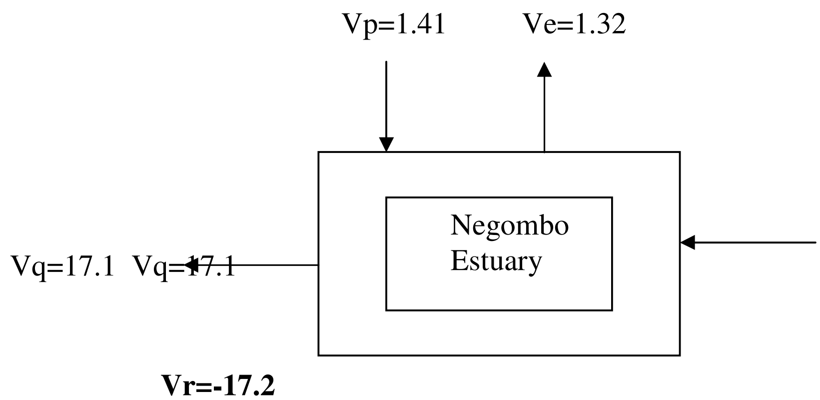
1. BUDGET ANALYSIS 1-1 Box 1 layer

(a) Water and Salt Balances

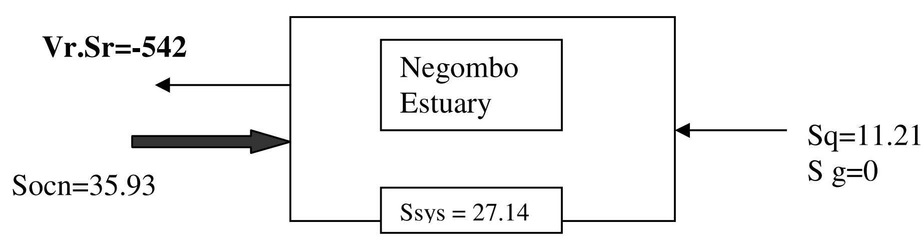
1. ***(i) Salt & Water Budget for Dry Season***

The estuary (volume= 31,742,200m^3) is considered as a single well-mixed system receiving inputs from river discharge and precipitation, losing water to evaporation, exchanging water with the ocean. Figure 2 illustrates the steady state water and salt budgets for the Dry Season. The precipitation is 1.41 m^{3}s^{-1} (121,824 m^3 day^{-1}). The ground water inflow Vg is assumed to be zero. The river discharge brought into the estuary is 17.1 m^{3}s^{-1} (1,477,440 m^3 day^{-1}). Evaporation is 1.32 m^{3}s^{-1} (114,048 m^3 day^{-1}).

According to the Budgetary Analysis there is net fresh water out flow of 17.2 m^{3}s^{-1} (1,486,080 m^3 day^{-1}). The hydraulic residence time of the system is 21.35 days and the total exchange time for the system is 8.26 days.



Water Budget (fluxes in m^{3}s^{-1})



Salt Budget (fluxes in ppt)

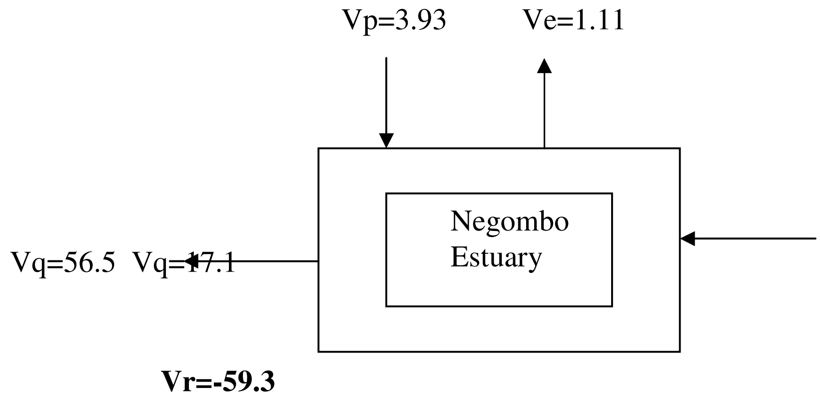
Figure 2: Steady-state water and salt budgets for the Dry Season when the Negombo Estuary is considered as a 1 Box 1 Layer system.

Quantities estimated from data independent of the budgetary calculations are shown in light typeface; quantities calculated within the budget are shown in bold typeface.

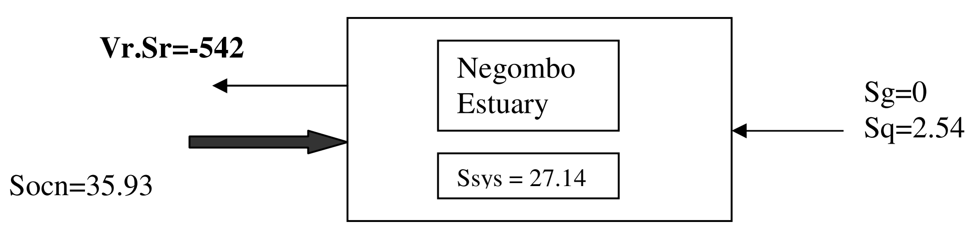
2. *(ii) Salt & Water Budget for Wet Season*

The estuary (volume= 31,742,200m^3) is considered as a single well-mixed system receiving inputs from river discharge and precipitation, losing water to evaporation, exchanging water with the ocean. Figure 3 illustrates the steady state water and salt budgets for the Wet Season. The precipitation is 3.93 m^{3}s^{-1} (339,552 m^3 day^{-1}). The ground water inflow Vg is assumed to be zero. The river discharge brought into the estuary is 56.5m^{3}s^{-1} (4,881,600 m^3 day^{-1}). Evaporation is 1.11 m^{3}s^{-1} (95,904 m^3 day^{-1}).

According to the Budgetary Analysis there is net fresh water out flow of 59.3 m^{3}s^{-1} (5,123,520 m^3 day^{-1}). The hydraulic residence time of the system is 6.19 days and the total exchange time for the system is 2.65 days.



Water Budget (fluxes in m^{3}s^{-1})



Salt Budget (fluxes in ppt)

Figure 3: Steady-state Water and Salt Budgets for the Wet Season when the Negombo Estuary is considered as a 1 Box 1 Layer System. Quantities Estimated from Data Independent of the Budgetary Calculations are Shown in Light Typeface; Quantities Calculated Within the Budget are Shown in Bold Typeface.

Table 1: Non-conservative Dissolved Inorganic P and N Fluxes in Negombo Estuary Considering as a 1 Box 1 Layer System.

1. **Process**	**Dry Season RATE ($mmolm^{-2}d^{-1}$)**	**Wet Season RATE ($mmolm^{-2}d^{-1}$)**
Area	32.39km^2	32.39 km^2
DDIP	+0.052	+0.008
DDIN	-0.104	-0.837
DIN:DIP	13	18
2. **Stoichiometric Analysis**		
(nfix-denit)phytoplankton$^{(1)}$	-0.936	-0.965
(p-r) phytoplankton$^{(2)}$	-5.512	-0.848
(nfix-denit)sea grass$^{(1)}$	-1.664	-1.077
(p-r)sea grass$^{(2)}$	-28.6	-4.4
nfix-denit)mangrove$^{(1)}$	-0.676	-0.925
(p-r)mangrove$^{(2)}$	-67.6	-10.4

1) $(N:P)_{part}$ assumed to be 16 (plankton), 11(mangrove) and 30 (sea grass)
2) $(C:P)_{pa\ rt}$assumed to be 106(plankton), 1300 (mangrove) and 550 (sea grass)

The DDIP >0 in both seasons. This system with DDIP>0 is producing DIC via net respiration (p-r) and is net heterotrophic. The negative signs of the (p-r) calculated for phytoplankton, sea grass and mangrove support this assumption if phytoplankton, sea grass and mangrove dominate the input of organic matter from outside the system respectively. The estuary has areas dominated by mangroves, sea grass as well as phytoplankton.

The (nfix-denit) is negative in the case of phytoplankton as well as for sea grass and mangroves indicating that the denitrification is the main process taking place. The denitrification rates are in the range of -0.676 to -1.664 for Dry Season and -0.925 to -1.077 in the Wet season.

2. BUDGET ANALYSIS 2-2 Box 1 layer

(a) Water and Salt Balances

3. *(i) Salt & Water Budget for Dry Season*

The estuary (volume= 31,742,200m^3) is considered as a 2 box 1 layer system receiving inputs from river discharge and precipitation, losing water to evaporation, exchanging water with the ocean. The steady state water and salt budgets for the Dry Season is given in Table 2. The precipitation is 1.41 m^3s^{-1} (121,824 m^3 day^{-1})$^{.}$ The ground water inflow Vg is assumed to be zero. The river discharge brought into the system box 1 is $17.1 m^3 s^{-1}$ (1,477,440 m^3 day^{-1}). Evaporation is 1.32 $m^3 s^{-1}$ (114,048 m^3 day^{-1}).

4. *(ii) Salt & Water Budget for Wet Season*

The estuary (volume= 31,742,200m^3) is considered as a 2 Box 1 Layer system receiving inputs from river discharge and precipitation, losing water to evaporation, exchanging water with the ocean. The steady state water and salt budgets for the Wet Season is given in Table 2. The precipitation is 3.93 $m^3 s^{-1}$ (339,552 m^3 day^{-1}). The ground water inflow Vg is assumed to be zero. The river discharge brought into the System Box 1 is 56.5 $m^3 s^{-1}$ (4,881,600 m^3 day^{-1}). Evaporation is 1.11 $m^3 s^{-1}$ (95,904 m^3 day^{-1}).

Table 2: Steady-state Water and Salt Fluxes for the Dry and Wet Seasons When the Negombo Estuary is Considered as a 2 Box 1 Layer System

	Dry Season		**Wet Season**	
	Box1	**Box2**	**Box1**	**Box2**
V_p $m^3 s^{-1}$	1.41	1.41	3.93	3.93
V_e $m^3 s^{-1}$	1.32	1.32	1.11	1.11
V_q $m^3 s^{-1}$	17.10	17.10	56.50	56.50
V_r $m^3 s^{-1}$	-17.2	-34.4	-59.3	-119
S_{ocn} ppt	26.73	35.93	23.49	27.64
S_{sys} ppt	24.80	26.73	17.75	23.49
V_x $m^3 s^{-1}$	229	117	213	731

Table 3: Hydraulic Residence Times (HRT) and Total Exchange Times (TET) When the Negombo Estuary is Considered as a 2 Box 1 Layer System

Box No	**Dry Season**		**Wet Season**	
	HRT days	**TET days**	**HRT days**	**TET days**
Box1	16.22	1.32	4.70	0.74
Box2	2.57	1.07	1.81	0.14
Total	**18.79**	**2.39**	**6.51**	**0.88**

Denitrification is the main process in both Box 1 and Box 2 in Dry and Wet Seasons. The denitrification rate (if phytoplankton dominate the input of organic matter) of Box 1 is greater than that of Box 2 in the Dry Season. Due to the longer residence time in Box 1 anoxic conditions can develop which enhance denitrification. The denitrification rate (if phytoplankton dominate the input of organic matter) of Box 2 is greater than that of Box1in the wet season. In the wet season the sediments are more prone to have anaerobic conditions due to the large volume of water in the system. Therefore oxygen depletion in the sediment is possible and this will promote denitrification to take place.

If phytoplankton dominate the input of organic matter from outside the system. The estuary is net heterotrophic in the Wet Season. In the Dry season the system box 1 is net autotrophic while system box 2 is net heterotrophic.

Table 4: Non-conservative Dissolved Inorganic P and N Fluxes in Negombo Lagoon Considering as a 2 Box 1 Layer System.

Process	Dry Season RATE Box 1 ($mmolm^{-2}d^{-1}$)	Dry Season RATE Box 2 ($mmolm^{-2}d^{-1}$)	Wet Season RATE Box 1 ($mmolm^{-2}d^{-1}$)	Wet Season RATE Box 2 ($mmolm^{-2}d^{-1}$)
Area	24.59km²	7.80km²	24.59 km²	7.80 km²
DDIP	-0.002	+0.080	+0.047	+0.184
DDIN	-1.200	+0.479	-0.421	-0.768
DIN:DIP ratio	12	17	11	15
3. Stoichiometric Analysis				
(nfixdenit) phytoplankton	-1.228	-0.802	-1.173	-3.712
(p-r) phytoplankton	+0.212	-8.480	-4.982	-19.504
(nfix-denit) sea grass	-1.14	-1.921	-1.831	-6.290
(p-r)sea grass	+1.100	-44	-25.85	-101.2
(nfix-denit)mangrove	-1.178	-0.401	-0.938	-2.792
(p-r)mangrove	+2.6	-104	-61.1	-239

1) $(N:P)_{part}$ assumed to be 16 (plankton), 11(mangrove) and 30 (sea grass)
2) $(C:P)_{pa\ rt}$assumed to be 106(plankton), 1300 (mangrove) and 550 (sea grass)

3. BUDGET ANALYSIS 3-3 Box 1 layer

(a)Water and Salt Balances

5. (i) Salt & Water Budget for Dry Season

The estuary (volume= 31,742,200m^3) is considered as a 3 Box 1 Layer system receiving inputs from river discharge and precipitation, losing water to evaporation, exchanging water with the ocean. The steady state water and salt budgets for the Dry Season is given in Table 5. The precipitation is 1.41 m^3s^{-1} (121,824 m^3 day^{-1}). The ground water inflow Vg is assumed to be zero. The river discharge brought into the system box 1 is 17.1m^3s^{-1} (1,477,440 m^3 day^{-1}). Evaporation is 1.32 m^3s^{-1} (114,048 m^3 day^{-1}).

6. (ii) Salt & Water Budget for Wet Season

The estuary (volume= 31,742,200m^3) is considered as a 2 Box 1 Layer system receiving inputs from river discharge and precipitation, losing water to evaporation, exchanging water with the ocean. The steady state water and salt budgets for the Wet Season is given in Table 5. The precipitation is 3.93 m^3s^{-1} (339,552 m^3 day^{-1}). The ground water inflow Vg is assumed to be zero. The river discharge brought into the System Box 1 is 56.5 m^3s^{-1} (4,881,600 m^3 day^{-1}). Evaporation is 1.11 m^3s^{-1} (95,904 m^3 day^{-1}).

Table 5: Steady-state Water and Salt Fluxes for the Dry and Wet Seasons when the Negombo Estuary is Considered as a 3 Box 1 Layer System

	Dry Season			**Wet Season**		
	Box1	**Box2**	**Box3**	**Box1**	**Box2**	**Box3**
V_p m^3s^{-1}	1.41	1.41	1.41	3.93	3.93	3.93
V_e m^3s^{-1}	1.32	1.32	1.32	1.11	1.11	1.11
V_q m^3s^{-1}	17.1	17.1	17.1	56.5	56.5	56.5
Vr m^3s^{-1}	-17.2	-34.4	-51.6	-59.3	-119	-178
S_{ocn} m^3s^{-1}	27.55	26.73	35.93	20.95	23.49	28.16
S_{sys} m^3s^{-1}	19.86	27.55	26.73	12.74	20.95	23.49
V_x m^3s^{-1}	53.00	-1140	176	122	1040	984

Table 6: Hydraulic Residence Times (HRT) and Total Exchange Times (TET) when the Negombo Estuary is Considered as a 3 Box 1 Layer system

Box No	**Dry Season**		**Wet Season**	
	HRT days	**TET days**	**HRT days**	**TET days**
Box1	6.38	3.06	4.70	1.75
Box2	4.92	0.15	0.74	0.14
Box3	1.76	0.71	0.50	0.11
Total	**13.06**	**3.92**	**5.94**	**2.00**

Photosynthesis is the dominant process in Box 1 and 2 in the Dry season. Nitrogen Fixation is the dominant process in Boxes 1 and 2 in the Dry season and Nitrogen Fixation in Box 2 is higher than that of Box 1. The System Box 3 is net heterotrophic and denitrification is dominant in the Dry Season.

In the Wet season the system boxes 1 and 3 are net heterotrophic while system box 2 is net autotrophic. Nitrogen fixation is the dominant process in Box 2 but the rates are lower than the rates of the Dry season. In box 1 and 3 denitrification is dominant.

When the estuary is considered as a 1 Box 1 Layer system the estuary does not exhibit nutrient pollution problems. When it is considered as a multiple box system it was identified that there are certain regions in the estuary which exhibit nutrient pollution problems. Therefore, it is more suitable to use a multiple box system to understand the nutrient pollution problems in the estuary. It can be concluded that the 3 Box 1 Layer system used best describes the biogeochemical processes in the estuary.

The Negombo Estuary has sea grass and mangrove dominant areas. In such areas the input organic matter to the system is from sea grass and mangroves rather than from phytoplankton. Therefore, in the stoichiometric analysis the CNP ratios of sea grass and mangroves were also used in addition to Redfield ratio of phytoplankton. The sea grass or mangrove nutrient status reflects sediment nutrient availabilities (months to years). Similarly, tissue nutrient content of macro algae can be used to infer nutrient concentrations integrated over time periods of up to weeks.

Table 7: Nonconservative Dissolved Inorganic P and N Fluxes in Negombo Lagoon Considering as a Three Box One Layer System

Process	**Dry Season RATE Box 1 (mmolm^{-2}d^{-1})**	**Dry Season RATE Box 2 (mmolm^{-2}d^{-1})**	**Dry Season RATE Box 3 (mmolm^{-2}d^{-1})**	**Wet Season RATE Box 1 (mmolm^{-2}d^{-1})**	**Wet Season RATE Box 2 (mmolm^{-2}d^{-1})**	**Wet Season RATE Box 3 (mmolm^{-2}d^{-1})**
Area	9.67km^2	14.92km^2	7.80km^2	9.67 km^2	14.92km^2	7.80 km^2
DDIP	-0.034	-0.223	0.111	0.046	-0.180	0.302
DDIN	0.020	7.040	0.725	-0.658	-0.121	-0.852
DIN:DIP ratio	25	9	16	11	21	15
Stoichiometric Analysis						
(nfix-denit) phytoplankton	+0.546	+10.608	-1.051	-1.394	+2.759	-5.684
(p-r) phytoplankton	+3.604	+23.638	-11.766	-4.876	+19.08	-32.012
(nfix-denit) sea grass	+1.04	+13.73	-2.605	-2.038	+5.279	-9.912
(p-r) sea grass	+18.7	+122.65	-61.05	-25.3	+99	-166.1
(nfix-denit) mangrove	+0.394	+9.493	-0.496	-1.164	+1.859	-4.174
(p-r) mangrove	+44.2	+289.9	-144.3	-59.8	+234	-392.6

1) $(N{:}P)_{part}$ assumed to be 16 (plankton), 11(mangrove) and 30 (sea grass)
2) $(C{:}P)_{pa\ rt}$assumed to be 106(plankton), 1300 (mangrove) and 550 (sea grass)

Nitrogen is typically the nutrient that controls primary production in marine coastal ecosystems and as such, is commonly implicated in the eutrophication of coastal waters. Denitrification is probably the most important nitrogen cycling pathway because it is one of the few natural processes that is capable of counteracting the process of eutrophication. Upto 60% to 80% of the external nitrogen load delivered to coastal ecosystems may be lost to coupled sediment nitrification-denitrification. Despite its importance, sediment denitrification has rarely been measured in Sri Lankan coastal ecosystems.

Worldwide denitrification studies in tropical and sub-tropical estuaries where N_2 fluxes have been directly measured are also rare, with most work having been carried out in temperate West European and North American systems. There are distinct biogeochemical differences between tropical/ sub-tropical and temperate estuaries.

Differences in tropical/ sub-tropical estuaries most likely to influence denitrification rates include:

- generally low water column nitrogen concentrations,
- different temperature and light regimes,
- differences in benthic infauna,
- shallower so benthic processes that interact with denitrification such as benthic productivity are more important, and
- episodically driven resulting in differences in the quality, timing, and delivery rates, of carbon inputs to the sediments.

From the studied estuarine coastal systems of East and SouthEast Asia region, trends of the CNP fluxes suggest that the net increase in terrestrial loading may be driving systems towards net autotrophy. But the rate of primary production is very low in Box 1 in the Dry Season. Extreme values of net production, however, indicate other sink mechanisms of terrestrially derived nutrients (ex: sediment sorption). The autotrophic-heterotrophic nature of an estuary is determined by three primary factors; the ratio of inorganic to organic matter inputs, water residence time and the overall lability of allochthonous organic matter inputs

APPENDIX V

Gap – Filling Studies - Bangladesh

Contents

PREFACE

Being one of the participating countries under the Regional project APN 2001-20 (A study of nutrients, sediment and carbon fluxes to the coastal zone in South Asia and their relationship to human activities), the activities of Bangladesh Chapter were started in July 2001. Although objective of this programme involved two types of activities, i.e., (1) Collection and assessment of existing data, and (2) a gap filling research work; some extra research works were done by postgraduate students of the Institute of Marine Sciences (IMS), University of Chittagong making good use of field work facility provided under the activity 2. This compilation presents abstracts of those by-product research work.

An Assessment of Material Budget along with some Physico-chemical parameters of the lower Meghna River-estuary, Bangladesh.

M. M. Uddin

KEYWORDS: Material Budget, Primary Productivity, Lower Meghna River-estuary.

ABSTRACT

An investigation between September 2001 and May 2002 (covering an annual cycle) on micronutrients and primary productivity with relation to some physico-chemical parameters was carried out in the lower Meghna River-estuary, Bangladesh. Material (Salt, water, DIP and DIN) budgeting exercise was done following LOICZ Biogeochemical modeling guidelines of Gordon *et al.* (1996) using collected and calculated data to understand the nature and extent of change in the estuary, and associated impact towards the Global Change for the first time in Bangladesh. Inorganic nutrients showed irregular seasonal and spatial fluctuation and the peak were found during premonsoon at station-1 (Chandpur), and decreasing trends towards the sea in almost all the seasons. Highest productivity was also recorded at the upper reach of the estuary during premonsoon following the peak of transparency with more sunshine, low water movement and higher nutrients. Salinity records reveal that the study area attains the characteristics of a fresh water body except being saline at the mouth of the estuary during premonsoon and postmonsoon. Budgeting exercise indicated that Hatiya Channel, the system produces net amount of DIP and DIN in almost all the seasons i.e. source of nutrients, and the production of nutrients were higher during monsoon. Residual water volume and mixing volume of showed extensively high values during monsoon and a quick exchange of residual water takes place during monsoon which takes more time during premonsoon. Result of stoichiometric calculations reveals the system as an apparently net heterotrophic and denitrifying estuary; and the system metabolism rate was very high during monsoon in comparison with the rest of the year.

Seasonal distribution of Phytoplankton in the Meghna River-estuary of Bangladesh with notes on Biodiversity.

M. S. Ullah

KEYWORDS: Biodiversity, Phytoplankton, Secchidepth, Meghna River-estuary.

ABSTRACT

This report gives the first information on biodiversity with reference to occurrence and distribution of Phytoplankton in the Meghna River-estuary following three exploratory trips during premonsoon, monsoon and postmonsoon. Samples were collected from five different stations: Sandwip, Hatiya, Bhola, Barisal and Chandpur. The result of the observations on Phytoplankton with some selected water parameters was also studied. In the study area, the occurrence and distribution of Phytoplankton was influenced strongly by Secchidepth. It was also observed by using Shannon-Wiener index (H'), Evenness Index (J), Margalef Index (Ma) between the stations that highest biodiversity occurred at Bhola and then step by step decreased at Barisal, Chandpur, Hatiya and Sandwip stations. During the observation period, 23 genera of 13 families under *Bacillariophyta*, 19 genera of 4 family under *Chlorophyta* and 13 genera of 5 family under *Cynophyta* were identified from the study area. Being the annual cycle *Nitzschia* was common genera at all 5 stations. In all three seasons, *Nitzschia, Schrodella, Thalassiothrix* and *Triceratium* were recorded from Sandwip; *Coscinodiscus, Navicula, Nitzschia, Schrodella* and *Triceratium* were recorded from Hatiya; *Biddulphia, Cymbella,Nitzschia, Plurosigma*, *Thalassiothrix* and *Triceratium* were common to Bhola; *Biddulphia, Cymbella, Nitzschia, Pleurosigma*, *Thalassiothrix* and *Triceratium* were frequently recorded from Barisal and *Biddulphia, Nitzschia, Nostoc* and *Rhizosolenia* were recorded from Chandpur. The common genera at all 5 stations- in the premonsoon *Coscinodiscus, Nitzschia, Rhizosolenia,* and *Triceratium* were recorded, in the monsoon *Nitzschia, Thalassiothrix* and *Triceratium* were recorded, in the postmonsoon *Coscinodiscus, Nitzschia* and *Thalassiothrix* were recorded in the whole investigated area.

Macrozoobenthos of the Meghna River-estuarine bed with special reference to Polychaete faunal biodiversity

M. B. Hossains

KEYWORDS: Macrozoobenthos, Polychaete Faunal Diversity, Meghna River-estuary.

ABSTRACT

The macrozoobenthos of the Meghna River-estuary were collected from five different stations during premonsoon (May 2002), monsoon (September 2002) and postmonsoon (February 2003) using a Peterson grab and were studied quantitatively. The fauna comprise 20 taxa of which only polychaetes were identified up to species level and other groups up to generic or family level wherever possible. A total of 10 polychaetes, *Nephtys polybranchia, N. oligobranchia, N. sp., Glycera prashadi, Glycera sp., Lumbrinereis sp., Namalycastis sp., Perinereis cultifera,* Sabillidae, Maldanidae have been firstly recorded from the study area. *Nephtys polybranchia,., Glycera prashadi, Namalycastis sp., Perinereis cultifera,* were identified for the first time in Bangladesh coastal waters. Macrozoobenthos were chiefly composed of Oligochaetes (53.75%), Polychaetes (33.31%) and Mesogastropods (4.94%). These three groups together contributed about 90% of the total population. Population density varied from 112 to 9410 ind/m^2. The maximum and minimum incidence was found during postmonsoon and monsoon at Chandpur and Hatiya respectively. A rapid decline of faunal density during monsoon and subsequent colonization during postmonsoon were observed. Of the polychaetes, *Nephtys sp.* was dominant and constituted 56.72% followed by *Namalycastis sp.* (13.36%), *Glycera sp.* (9.15%), *Lumbrinereis sp.* (7037%), *Nephtys oligobranchia* (5.3%), *Nephtys polybranchia* (2.35%), Maldanidae (2.17%), Sabillidae (1.04%) and *Perinereis cultifera* (0.30%). The highest SR value (4) was observed at Sandwip and Barishal during postmonsoon and lowest SR value (1) was recorded from Vola. Species diversity index (H') of polychaetes varied from 0 to 1.36. Highest incidence of benthic fauna at Chandpur and Barishal indicate that .the areas are suitable for aquaculture practices. The information generated here can be used to measure the impact of pollution, if any, in future, and also to conserve the biodiversity of the area.

A comparative study on Plankton and benthos of the Meghna River-estuary during monsoon and postmonsoon

A.S.M. Sharif

KEYWORDS: Benthos, Plankton, Meghna River-estuary.

ABSTRACT

This report gives the first information on occurrence and distribution of Phytoplankton, Zooplankton and macrobenthos in the Meghna River-estuary following two exploratory trips during monsoon (4^{th} to 6^{th} October 2001) and postmonsoon (21^{st} to 23^{rd} February 2002). Samples were collected from five different stations: Sandwip, Hatiya, Bhola, Barisal and Chandpur. The result of the observations on Plankton and Benthos with some selected Water and Soil parameters have been also documented. A total 22 different genera of Phytoplankton, 32 major taxa of Zooplankton and 11 major taxa of macrobenthos occurred in the study area during monsoon. During postmonsoon 21 different genera of Phytoplankton, 23 major taxa of Zooplankton and 20 major taxa of macrobenthos were recorded from the study area. Occurrence of Phytoplankton from Chandpur to Barisal had close similarity during the two seasons, where as the occurrence was not similar at Hatiya and Sandwip. *Coscinodiscus spp*. was common in all the stations during both the seasons. In monsoon, higher density was recorded at Bhola (55.93%) and at Sandwip (88.89%) during postmonsoon. During the both seasons, occurrence of Phytoplankton decreased from Chandpur towards Sandwip. Both diversity and abundance of Zooplankton at Chandpur had similarity during both the seasons but at Sandwip and Hatiya changes occurred. Occurrence of Salinity indicating Zooplankters such as *Lucifer, Sagitta* etc along with the physical parameters like salinity indicated that during monsoon salinity reached up to Sandwip and in postmonsoon up to Hatiya. Among the Macrobenthos Amphipoda was common in all stations during monsoon and Nemertina during postmonsoon. Abundance of benthos was found to be rich in stations having finer particles (Clays) where Organic Carbon contents were also found to be high.

Study of Zooplankton of the Karnafully River-estuary from the Biodiversity and Environmental points of view

M. E. Islam

KEYWORDS: Zooplankton, Biodiversity, Karnafully River-estuary.

ABSTRACT

The study was carried out in the Karnafully River-estuary. Samples were collected from the 7 different stations of Karnafully river-estuary in monsoon (September), postmonsoon (January) and premonsoon (May 2003). A total of 22 major taxa of zooplankton were identified during the study period. Further 6 genera of Cladocera were also identified, namely *Daphnia, Diaphanosoma, Moina, Ilyocryptus* and *Penilia*. Highest peak of Zooplankton (654.91 indivs./m^3) was obtained during the postmonsoon at station-5 and the second seasonal highest peak (437.38 indivs./m^3) was found during premonsoon at station-7. Abundance of Zooplankton showed higher values at stations-5, 6 and 7 in all three seasons than stations-1, 2, 3 and 4. Copepoda comprised the bulk of total Zooplankton individuals and highest composition (89.31%) was found during postmonsoon at station-5 and lowest composition (22.69%) was found during premonsoon at the same station. Next to Copepoda, Cladocera occupied the dominant group during monsoon and premonsoon and greatly reduced during postmonsoon. The composition of Cladocera varied between 1.657% and 47.40% during monsoon, 0.86% and 42.40% during premonsoon and 0% and 0.47% during postmonsoon. The highest composition (42.40) was found during premonsoon at station-5. *Daphnia* and *Diaphanosoma* were the two major genera representing Cladocera population. A significant relationship was found between Cladocera (%) and Salinity (‰) in all three seasons. Only TDS (mg/l) during monsoon and Salinity during postmonsoon showed the significant relationship with total organisms (indivs/l) among the environmental parameters. Diversity was measured by using Shannon-Wiener index (H’), Evenness Index (J) and Margalef Index (Ma). The highest diversity values (H’ for 2.974216, J for 5.969948 and Ma for 8.147617) were found during premonsoon at station-3. The lowest diversity values (H’ for 0.535972 at station-3, J for 3.190217 at station-4 and Ma for 1.715803 at station-7) were found during postmonsoon.

Composition, distribution and abundance of Periphyton from different habitats and locations in the Karnafully River-estuary.

M.K.U. Chowdhury

KEYWORDS: Periphyton, Habitat, Karnafully River-estuary.

ABSTRACT

Qualitative and quantitative studies of Periphyton of the Karnafully river-estuary have been conducted during the postmonsoon (December 2002) and premonsoon (April 2003). Samples were collected from different stations: Station 1 (Jetty no. 15), station 2 (Jetty No. 11), Station 3 (Ichinnar ghat), Station 4 (Coast Guard), Station 5 (Gridge ghat), Station 6 (Near Chaktai Khal) and Station 7 (Mouith of the Halda River). A total of 30 genera of Periphyton were recorded. Among them 28 genera were recorded during postmonsoon and 19 genera were recorded during premonsoon. During postmonsoon Periphyton genera were found to be about three times more than premonsoon. The *Bacillariophyta spp*. was the dominant species in the total Periphyton population. Periphyton count was found to be higher (2421.549 ind/cm^2) in station 1, Jetty No. 15 during postmonsoon from rock habitat and the lowest (594.472 ind/cm^2) were found in station 6, near Chaktai Khal from wood habitat. In premonsoon the highest (772.435 ind/cm^2) and the lowest (359.712 ind/cm^2) values were found at station 1, Jetty No. 15 and at station 7, mouth of Halda River respectively. Comparatively (both in postmonsoon and premonsoon) average Periphyton was attached abundantly in Rock substrate and it was moderate in the Brick and Tyer. They were poorly represented in other type of habitats like Styrofoam and wood. During postmonsoon *Coscinodiscus sp. , Fragilaria sp., Pleurosigma sp*. and *Spyrogyra sp.* were found almost all stations. During premonsoon, *Fragilaria sp* and *Frustulia sp.* were found in many stations. The target habitats of Periphyton were Rock, Styrofoam, Brick, Tyer and Wood. Among the different habitats Periphyton were dominant in the Rock substrate and poorly found in Styrofoam and Wood. Identification and taxonomic accounts of Periphyton genera are given.

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APPENDIX VI

Gap – Filling Studies - Nepal

1. Monitoring sediment transport – Gaps in information

2. A Study of Sediment Fluxes to the Coastal Zone in South Asia and their Relationship to Human Activities

MONITORING SEDIMENT TRANSPORT – GAPS IN INFORMATION

Keshav P Sharma and Suresh Maskey

SYNOPSIS

This report reviews in brief the existing sediment monitoring system in Nepal. It discusses the problems in monitoring sediment transport on the Himalayan rivers. The report also recommends some simplified procedures, which could provide reliable data with less effort and time. This study and the recommended procedures are based on some experiments carried out for a few days on the Narayani River at Narayanghat during the monsoon of 2001 and the low-flow period of 2002. The report also summerizes the observations made using simplified procedures on other three rivers: the Bagmati River at Noonthar, the Kosi River at Chatara and the Kankai River at Mainachuli.

BACKGROUND

Among several objectives of the project on "A Study of Nutrient, Sediment and Carbon Fluxes to the Coastal Zone in South Asia, and their Relationship to Human Activities." One of the major objectives was to "Identify critical gaps in information and knowledge of processes and undertake some regional studies to address these needs." This report assesses the information gap in sediment considering some major river basins in Nepal.

Sediment information for most of the river basins in South Asia is scant and not readily available. The available information has been described in another paper submitted to the same project (Sharma, 2002).

INTRODUCTION

Soil loss and sediment transportation from the Himalayas are often reported as environmental disasters related to natural as well as human factors in the upstream mountainous areas of the basins. Similarly, the large-scale deposition of the sediment in the downstream plains is considered to be a major reason behind the notorious behavior of the Himalayan rivers in the Nepalese Terai (plain area) and the Gangetic plains in India.

Study of sediment load of any river is an essential aspect for the evaluation of environmental impacts in any river basin. The characteristic of sediment transport by a river is not only important to understand the soil loss characteristics in the upstream catchment areas but also in the assessment of the environmental impacts in the downstream region. Monitoring of the quantity as well as the quality of sediment must hence be an essential aspect of any river basin development and environmental monitoring and conservation program. The importance of such activities is more important especially for the rivers of the Himalayan origin where the climatic and physical conditions are highly conducive to the erosion and sedimentation processes. Large-scale mass wasting processes, such as, landslides, landslide lake (temporary damming of river or stream by landslides) outbursts and glacial lake outburst floods bring further complications in the sediment monitoring programs.

SEDIMENT MONITORING

The history of sediment data collection in Nepal goes back to 1963 in the Karnali River basin, which was started as a part of the feasibility studies on Chisapani run-of-river project carried out by the Nippon Koei Co. of Japan (1966). The study team continued the collection of data till the end of 1964.

DHM is the sole agency in Nepal responsible for maintaining a nationwide network for monitoring sediment transport by the rivers in Nepal. Systematic collection of sediment data by DHM was initiated on the Bagmati River at Chovar. The program was extended to include the Trishuli River at Betrawati in 1969. The sediment-monitoring network was expanded to cover most of the major river basins in Nepal by installing other 19 stations during 1973 to 1979. Figure 1 depicts the stations established by DHM in Nepal, where sediment was sampled for some periods. Sediment sampling work has been conducted on irregular basis by DHM. The sediment sampling of the Kosi River at Barahkshetra was, however, carried out on regular basis by the Central Water Commission (CWC) of the Government of India for the purpose of hydrological investigation of the potential Kosi High Dam Multipurpose project. Regular data for this location are available from 1948 to 1977.

Most of the DHM stations are equipped with US DH-59 or US D-49 depth integrating samplers. The sediment samples are usually collected once a day at noon at the mid-section of the river during high flow season (June - September). It is done once or twice a week during low flow season. A cable car or a boom is used to take the samples.

The bottles containing samples are sent to the basin office located in the far-west, mid-west, central, and eastern region of Nepal for necessary laboratory analyses and data processing. The bottles are either carried by porters or by public transport in most of the instances. The samples are then analyzed by evaporation method following USGS procedures based on evaporating the collected samples after decantation (Guy, 1977).

SEDIMENT DATA

Despite the setup described in the last section, no sediment data have been published by DHM so far due to several gaps and poor quality of the sediment data. Some of the major reasons behind it are:

- Lack of trained manpower
- Inadequate management of laboratory activities
- Inadequate laboratory equipment and power supply facilities
- Lack of logistic supports and unavailability of the facilities for maintaining sophisticated laboratory equipment in Nepal
- Lower priority for sediment monitoring activities as compared to other hydrological and meteorological activities

In addition to these general problems, the quality of data is also effected by the procedures and the condition of the equipment. The existing system of taking one sample a day during flood seasons at a single depth may not represent the actual rate of sediment transport in many cases when the stations are not properly calibrated. The effects of frequent debris flows and changing catchment erosion patterns bring complications in the sediment rating curve of the station making the data processing job a tricky one.

EXPERIMENT PRINCIPLES

In the background of the major problems described in the last section, experiments were carried out to find an alternative simple procedure of sediment sampling that could be practiced with minimum effort and minimum skill so that continuous sediment transport data could be obtained for the Himalayan rivers.

Some experiments were carried out by collecting the sediment samples from the Narayani River at Narayanghat (Figure 2). The method evaluated for the site is a filtration-based method with sampling taken on the bank of the river at a suitably selected easily accessible location with manual dipping of sampling bottle.

Filtration method is one of the most standard methods used in determining sediment concentration of the sample. It has distinct advantages over evaporation method and has higher practical applicability in a country like Nepal because the filtration equipment can be easily installed at a sampling site with minimal cost. The filtered sediment can then be easily transported to a regional or a central laboratory.

The apparatus needed for this method at the sampling station are a Buchner funnel, a Pyrex vacuum flask that can be connected to a vacuum pump and filter papers (Finlayson, 1981). The instrument set up used in this experiment is depicted in Figure 3.

The sample is filtered by using filter paper (Whatman filter paper) and then the filtered sediment is dried on a solar dryer (Figure 4). The suspended sediment concentration is calculated by using the following relationship.

$$concentration(ppm) = \frac{W_2 - W_1}{V} * 10^6$$

Where, W_1 = Initial weight of the filter paper (mg)

W_2 = Weight of the filter paper with sediment (mg)

V = Volume of water Sediment mixture (m^3)

This relation is found to be applicable up to the concentration of about 16,000 ppm(Gordon et al, 1992). Conversion from ppm to mg/l is required for larger concentrations.

EXPERIMENTAL OBSERVATIONS

Some of the results obtained in the experiments are presented in Figure 5, Figure 6, Figure 7 and Figure 8.

- Figure 5 shows that the results obtained by evaporation method and filtration method provide close results. The average for seven days (14 samples) presented in this figure shows the average of 227 ppm in the case of filtration method and an average of 210 ppm in the case of evaporation method.

- Figure 6 shows that the variation of sediment can be significantly high even during the same condition of river flows.

- Figure 7 and Figure 8 indicate consistently high sediment discharges in the mid-section of the river compared to the concentration on bank. The overall average difference computed for the Narayani River at Narayanghat shows that the average value based on mid-section sample is almost four times higher than the average value obtained from the sample taken near the bank.

The data obtained from the simplified method at four locations (Figure 4 during 2001 are as follows (Table 1).

Table 1. Sediment transport based on simple filtration method with dip sample near the bank – results of 2001 experiment.

	Sediment transport (million tonnes)					
	July	August	Sept.	Oct.	Nov.	Dec.
Narayani at Narayanghat (31100 km^2)	13.4	24.6	9.03		1.64	0.67
Bagmati at Noonthar (2700 km^2)	0.076	0.091	0.051			
Kosi at Chatara (54100 km^2)	3.86	10.36	7.32			
Kankai at Mainachuli (1148 km^2)	0.109	0.187	0.173	0.55	0.032	0.011

CONCLUSIONS AND RECOMMENDATIONS

General assessment of the sediment monitoring system of Nepal has led to the conclusion that there is an urgent need to strengthen the existing system with proper instrumentation and simplified working procedures. This can be achieved only with simple procedures that can be followed with minimum knowledge, as unavailability of qualified manpower and sophisticated laboratory system are the facts in most of the areas of interest. The studies carried out indicated that there are distinct advantages in replacing the existing sediment monitoring system with a simplified system such as the filtration technique, which can be easily applied at the site or field station. While developing sediment-sampling system, it is also advisable to pay more attention to representativeness of samples than the accuracy of the lab procedures.

Sedimentation and sediment transport are extremely complex for theoretical treatment. Empirical approach needs to be encouraged extensively in the region for obtaining better picture of continental sediment flux. The methods tested in this study are a primary step in that direction that needs to be extended to rivers of different sizes and characteristics. Similarly, a major recommendation would be the testing of several simple methods at the four sites used in this study with emphasis on practical applicability. Examples of other simple methods could be: rising-stage sampler and Emhoff cone sediment decantation. For instance, the rising-stage sampler can provide sediment information even during the time a station is unattended. Similarly, it may be possible to read sediment data directly from an Emhoff cone allowing certain time for decantation.

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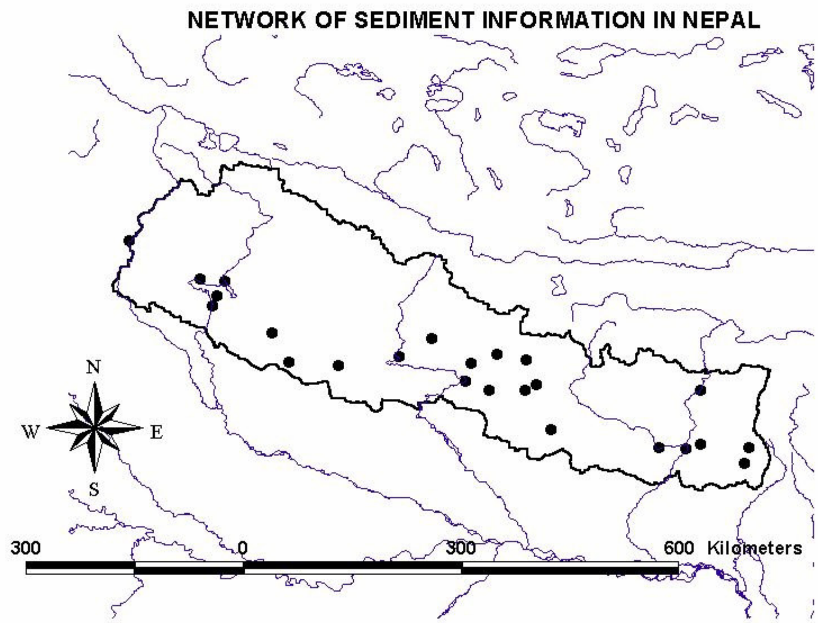

Figure 1. Hydrometric stattion network in Nepal with sediment records for some period.

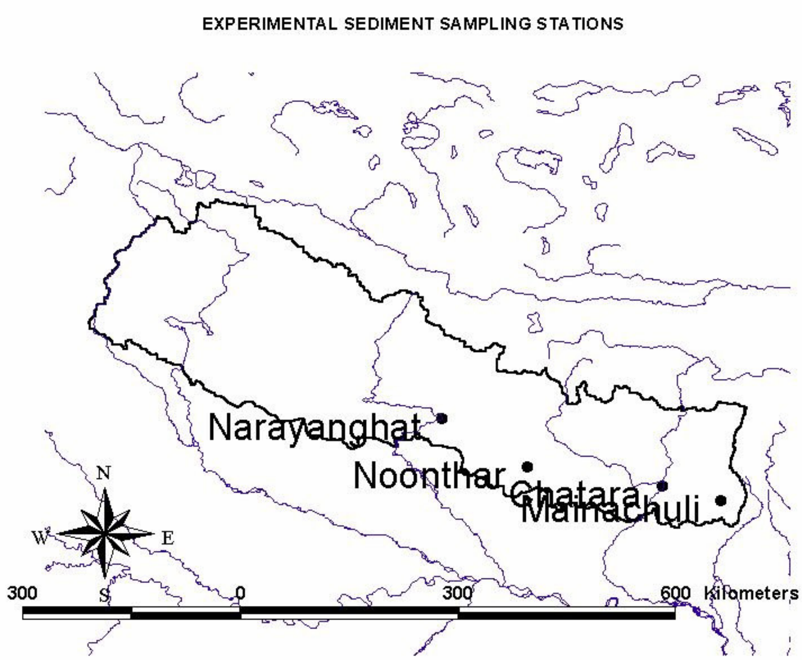

Figure 2. Sediment samling stations considered for experiments under the APN project.

Figure 3. Set-up for a simple system for the filtration of sediment used at Narayanghat. The method uses a Buchner funnel, a pyrex vacuum flask and a filter paper.

Figure 4.The inner view of a solar dryer used to dry sediment in a filter paper at Narayanghat.

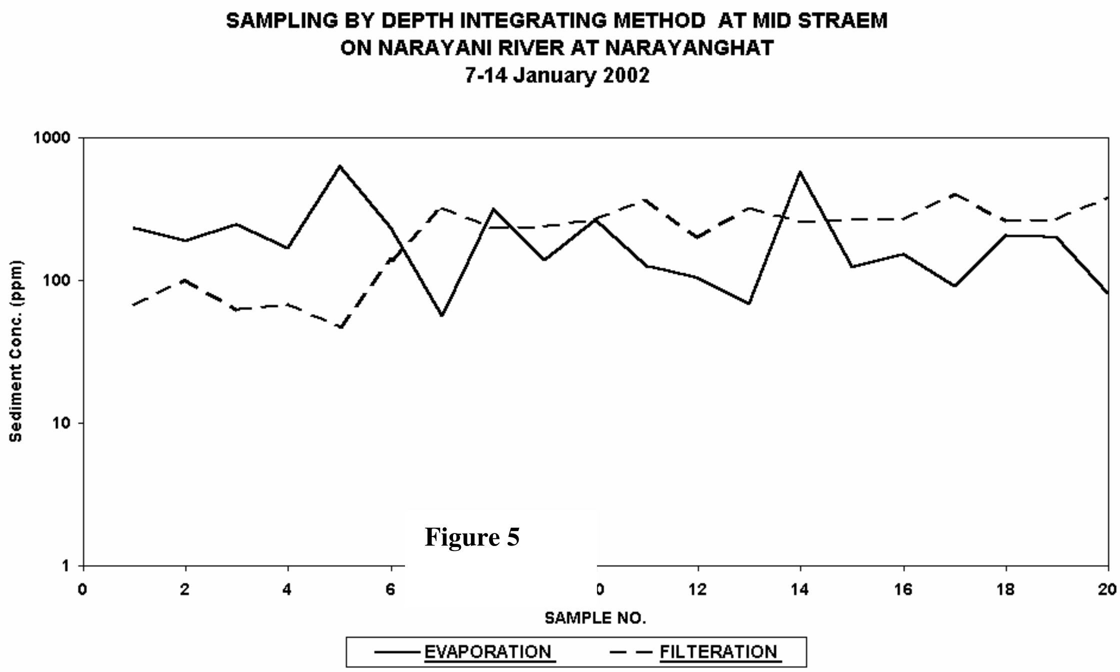
SAMPLING BY DEPTH INTEGRATING METHOD AT MID STRAEM
ON NARAYANI RIVER AT NARAYANGHAT
7-14 January 2002
1000
100
10
1
Sediment Conc. (ppm)
0
2
4
6
0
12
14
16
18
20
SAMPLE NO.
EVAPORATION
FILTERATION

Figure 5

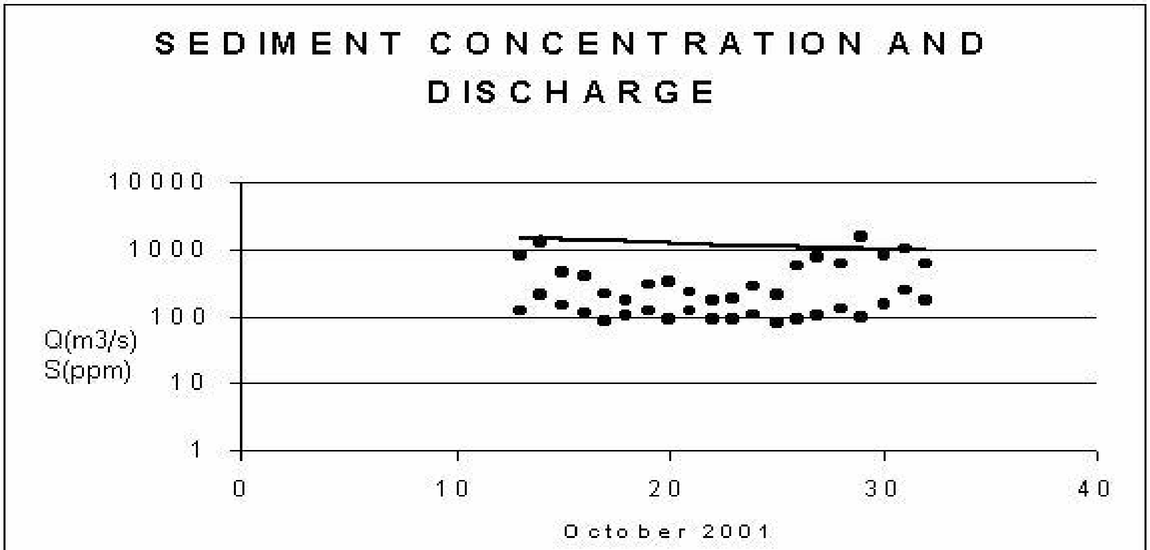

Figure 6. Sediment concentration taken two samples a day during recession period of flood plotted along with discharge indicated by a line.

Figure 6

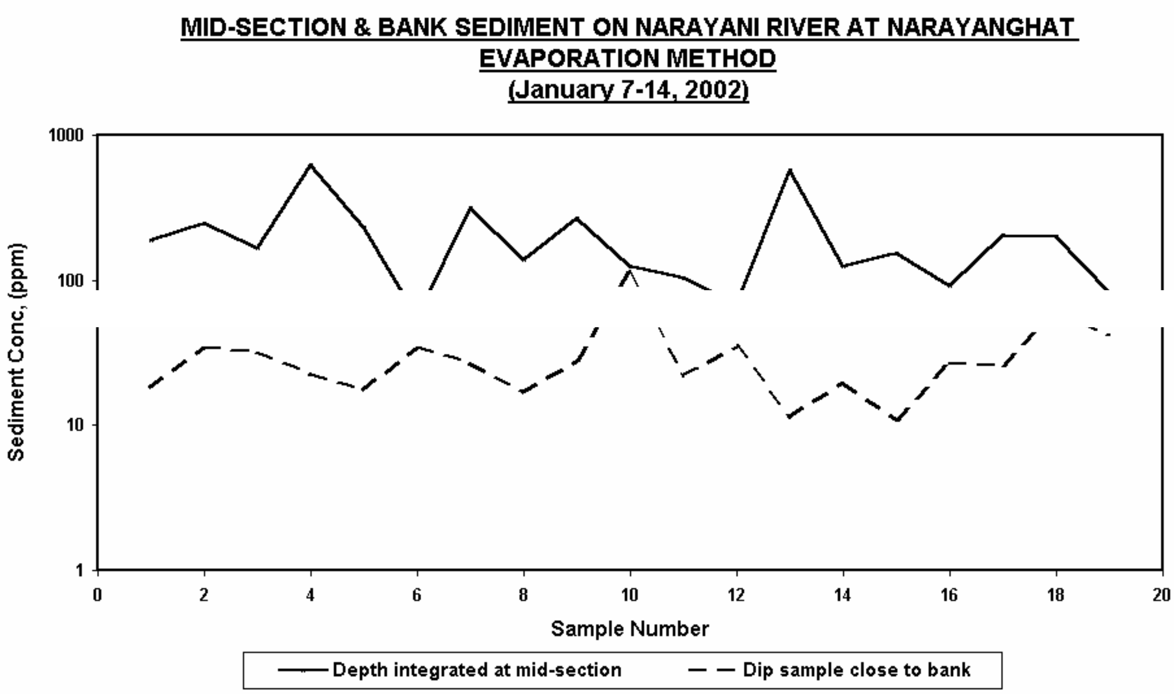

Figure 7

Sediment Conc. (ppm)

A Study of Sediment Fluxes to the Coastal Zone in South Asia and their Relationship to Human Activities

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Introduction

South Asia is the most diverse region of the world not only in terms of natural diversities but also in terms of human activities. The Himalayas are the steepest and the youngest mountain region of the world whereas the Deccan Plateau is made of ancient hard rock. Table 1 contains the basic socio-economic and physiographic information influencing the soil conservation, soil erosion and sediment transport about the countries in South Asia. Besides the area covered by Table 1, the South Asian Rivers include some parts of Afghanistan and China. The Kabul is one of the major tributaries of the Indus coming from Afghanistan. Out of the total area of the Indus, 75,628 km^2 lies in Afghanistan and 93,000 km^2 lies in Tibet (China). Similarly, 43,000 km^2 of the Ganga 393,000 km^2 of the Brahmaputra basin and 101,250 lie in the Tibetan Autonomous Region of China.

The South Asian region accommodates the population of 1.4 billion people, which is more than one fifth of the global population. The Ganga, Brahmaputra, Indus, Narmada, Krishna, Godavari, Padma, Irrawadi and Salween are the major rivers in the region. Most of these rivers are well known for high sediment concentration during the months of summer monsoon. In particular, the rivers originating from the Himalayas are known as some of the highest sediment laden rivers of the world. These large rivers along with other medium and small rivers of the region transport a significant amount of sediment in addition to other riverine materials towards oceans. The region contributes almost 15% to 20% of the global sediment flux towards the oceans (Milliman & Meade, 1983; Milliman & Syvitski, 1992; UNEP, 1996). The sediment received by the oceans at river mouths has created some of the largest deltas of the world (Coleman, 1969) such as the Ganga-Brahmaputra delta (50,000 km2) and the delta formed by the Irrawadi River in Myanmar (30,000 km^2).

The studies of sediment transport by rivers have been a major component for the understanding of biogeochemistry of fresh-waters and water quality (Meybeck, 1988; UNEP 1995). In addition, proper understanding of the sediment delivery pattern of a basin has enormous economic value in the development of water resources and agriculture (Khan, 1985; Crowder, 1987). Although Reservoir sedimentation has been a global concern for the development of water resources, it is one of the most critical aspects of reservoir design in South Asia. The average rate of more than one per cent storage loss by reservoirs in South Asia (Khan, 1985; Narayana & Ram Babu, 1983) is almost five times the average rate observed in the USA (Crowder, 1987). Lack of understanding of the sediment delivery pattern of the rivers in the region has resulted either in the failures of several reservoir designs (Bhargava et al., 1987; Ahmad & Chaudhry, 1988) or in the loss of expected economical gains (Tejwani, 1987).

Study Area

The study area considered in this study includes all the drainage areas that drain to the ocean through the South Asian region. The study area is bordered in the west by the Kirtar and Suleiman range. The Hindu Kush, Karrakoram, and Nyenchentanglha are the mountainous areas in the northern boundary of the region. Eastern part of the South Asian Region can be delineated close to the mountains lying at the Thai-Myanmar border.

South Asia, considered in this study includes seven countries: Pakistan, India, Nepal, Bhutan, Bangladesh, Myanmar, and Srilanka. The study area also includes some areas of Afghanistan drained by the Kabul River. Besides the South Asian countries from Afganistan to Burma, the study area also includes some parts of China that drain to the Indus, Ganga, and Brhmaputra. The total area considered in this study, is about 5.5 million square kilometres which is about 3.5% of the global land-surface area and 12% of Asia. The region consists of high extremities in physiographic, geologic and soil characteristics. The high elevated Tibetan Plateau, high rise Himalayan mountains, and the great plains of the Ganga-Brahmaputra-Indus directly influence the sediment production, dispersion, and ultimate delivery to the oceans. All the areas considered in this study drain to the Indian Ocean. An area of about 200,000 km^2, lying in the Great Indian Desert are either dry or are inland draining areas that do not contribute to the oceanward sediment flux.

Due to the physical and geological heterogeneity, different factors dominate the sediment yield in different regions. Geological characteristics dominate the sediment delivery in the Deccan Plateau (Biksham & Subramanian, 1988) whereas topography dominates the sediment dynamics of the Himalayan region (Carson, 1985; Bruinzeel and Bremmer, 1989).

The precipitation pattern in the study area is highly influenced by the monsoons. The monsoon trough that steers the summer monsoon activities lies almost along the Indo-Gangetic plain. The duration of the summer monsoon activities varies from more than five moths at the southern tip of India to less than three months in Pakistan. Pakistan lies almost at the western margin of the monsoon. Besides the monsoons, the other aspects that govern the climate of the region includes: latitude and altitude. The region is spread from tropics to high latitude (6^o N to 37^o N). Mixed with the altitudinal and latitudinal effects, the region experiences all types of climates possible on the earth surface. Such variations in climate are not only limited to the temperature characteristics but also to the precipitation pattern.

The north-east part of the study area are well known for recording the highest annual precipitation of the world whereas some parts in the west such as the Thar desert, precipitation amount is almost negligible. Topography has strong influence on precipitation distribution in the Hindu- Kush-Himalayan region. For example, within a distance of less than 100 km in Annapurna area, annual precipitation amount varies from 250 mm to more than 5000 mm.

Vegetative cover in the region is primarily governed by the climatic conditions. In western part of the study area, the climate is too dry for forest except in the northern hills. Since a significant area of the Hindu Kush-Himalayan region is occupied by the scattered population, human activities have influenced the forest in the region.

Data

Various available publications are used to compile the sediment data for the region. The publications include various institutional reports and published articles. The details of the compiled data including source of information are given in Annex I to the paper on Literature Survey on Nepal's previous work (see Appendix II). There are some variations in the reported values in different sources of information. The main reasons for such variations were the different periods of records used in computation of statistics and the influence of reservoirs. For the regional assessment of the sediment delivery pattern of the South Asian rivers, the data have been carefully compiled to adopt the updated information and to avoid the reservoir impacts.

Most of the available data do not provide information about the impact of reservoir; but some data indicate strong impacts. For example, Narayana and Ram Babu (1983) report the sediment flux of the Cauvery River amounting to 32 million tonnnes each year whereas the latest information given by UNEP (1996) shows the figure as low as 0.04 million tonnes. The sediment load decreases from 15 million tonnes to 1.5 million tonnes within a short distance of about 150 km between Mettur dam and Musiri stations on Cauvery river. Although it was possible to update the data considering the published dates and the available information on period of records, consideration of human impacts, such as the reservoir trapping, seems difficult for all the basins.

Regarding the quality of data, almost all the literature reports about the poor quality of sediment data throughout the globe (Jansson, 1988). The database of the region can be considered poorer than many parts of the world as the region is shared by developing countries only. Considering the evaluation of Milliman and Meade (1983), the database for the Ganga-Brahmaputra, Irrawadi, and Godavari is inadequate and the database for the Indus is sufficiently adequate or good. Some assessment of data quality for particular areas in the Hindu-Kush Himalayas are more pessimistic such as "notoriously poor" (Ferguson, 1982) and "inconsistent and unreliable" (Galay, 1987) suffering the limitations of station operation and data processing in addition to technical problems related to measurement procedures and rating curve techniques (Walling, 1981). Some of the rivers have been well gauged for example the Narmada River, where sediment observations are conducted six times a week using Punjab type bottle sampler at 0.6 depth along with discharge from boat or wading (Char et al, 1995). In general, sediment data have received less priority compared to river discharge data in terms of density of network, frequency of observations and processing of data in the region.

Sediment data are available neither for the global flux of sediment to the ocean nor regional flux. Estimation of global flux based on some measured data varies from 8.3 billion tonnes to 58 billion tonnes (Walling, 1987). The most recent estimates of global and regional sediment flux to the ocean obtained from the surveys of major rivers are listed in Table 2 for selected basins with basin area exceeding 10,000 km^2. The table shows that the region with about twelve percent of the global area delivers more than quarter of the recently estimated (Milliman and Syvitski, 1992; Maybeck, 1988, Ludwig & probst, 1996) global sediment flux.

Regional Sediment Pattern

Since most of the study area consists of mountainous environment, high extremities exist in sediment delivery rate, particularly at the micro catchment level. The extremities are further enhanced by the monsoons, the seasonal precipitation that dominates the whole region. Regarding, annual variation in sediment transport, more than 90% of the transport occurs during the monsoons. The reported percentage of sediment transport during monsoon season exceeds 97 % in some studies of the Hindu-Kush Himalayan rivers (Ferguson, 1982). The findings of Chakrapani and Subramanian (1990) for the south Indian rivers and the findings of Goswami (1985) for the Brahmaputra River are also close to 95% sediment transport during summer monsoon season.

Due to the influence of heavy precipitation in some days during monsoon and due to the likely effects of landslides and debris flow in mountainous rivers, the daily sediment transport may significantly influence the annual amount. Mahmood (1987; quoted in Bruinzeel & Bremmer, 1989) reports a June 1980 event on Tamor River in Nepal during which 36 % of the average annual load of the river was transported in a single day. Several examples of large-scale sediment transport are available for a single event. One of the noteworthy examples is the sediment inflow in the Kulekhani reservoir (basin area = 126 km^2; reservoir capacity = 85 million cubic meters) in Nepal during the historic flood of 1993 (Nippon Koei, 1994). Primarily due to the result of the sediment flow triggered by the heavy rainfall of 19-20 July 1993 (24-hour basin rainfall at 395 mm with maximum recorded point rainfall at 540 mm), the reservoir lost six percent of its capacity. The survey indicated a sediment yield rate of 53,000 t km^{-2} during 1993 against the average annual rate of about 2,000 t km^{-2}.

The massive sedimentation of the Ichari dam (11.5 million cubic meters) in India during 1978-79 is another example of extreme sediment event in a medium catchment of the Tons River (basin area = 4,913 km^2). Sediment inflow to the dam exceeded 29 million cubic meters (8,300 t km^{-2}) during the year of 1978-79 against the average annual rate of 0.65 million cubic meter (Bhargava, Narain, Tiagi, & Gupta, 1987; CWC, 1991). Significant contributions of sediment transport during few selected days to the annual amount have also been documented for the rivers originating in the Deccan Plateau (Chakrapani & Subramanian, 1990). The catchment response to sediment delivery during events is less significant in the areas with lower monsoonal influence and higher snowmelt contribution such as the high mountainous areas of the western Himalayas and the Hindu-Kush range (Ferguson, 1982).

Considering the homogeneity of basin and climatic characteristics, we can divide the study area in the following seven regions:

1. Sulaiman-Kirthar Range
2. Hindu Kush-Himalayas
3. Indo-Gangetic Plain (Brahmaputra, Indus, and Ganga)
4. Deccan Plateau and adjoining high lands
5. Desert or inland draining basins
6. Islands

1. Sulaiman-Kirthar Range:

The Sulaiman mountains and the Kirthar hills form the western boundary of the lower Indus plain. Takht-i-Sulaiman at 3443 m is the highest peak in this 1000 km long hills and mountains chain. These mountains lying south of the Kabul River have west-east strike unlike the Hindukush-Himalayan range with north-south strike. These mountain and hill ranges are traversed by the Kurram, Tochi, Gomal, Hab and Lyari rivers. This is a relatively dry area with precipitation in the range of 100 to 200 mm. This area does not have a significant role in the overall delivery of oceanward sediment flux because of significantly low precipitation.

2. Hindu Kush-Himalayas.

The 2500 km long high-rise mountainous range is shared by Afghanistan, China, Pakistan, India, Nepal, Bhutan, and Myanmar. These mountain ranges separate Central Asia from South Asia. This region is the source and headwater area of the three major rivers, namely, – the Ganga, Brhmaputra, and Indus. The Karrakoram Glacier, which is the largest glacier of the Hindu Kush-Himalayan region is a part of the Indus river basin in its headwater area. The Ganga originates from the Gangotri glacier in the Garhwal Haimalayas and the Brhamaputra drains the northern side of the Great Himalayas. High elevation and steep slope are the main characteristics of these mountains that abruptly end at the Brahmaputra-Indus-Ganga plain. Geologically, the Hindu-Kush Himalayan range is believed to be the product of collision between a part of Gondawana land and the Asian landmass and hence these mountain ranges are considered geologically young. Annual precipitation in this region varies from more than 4000 mm in the eastern Himalayas to less than 500 mm in the Far West. Some locations in the East have recorded some of the world’s highest precipitation rates. These physiographic, geologic, and climatic characteristics make these mountains highly susceptible to landslides and erosion. The region is the source of about ten percent of the global continental sediment flux.

Depending on the severity of the monsoon activities and heterogeneity, wide ranges of temporal as well as spatial extremities exist within the region. Although the sediment delivery rate in the eastern Himalayas is relatively higher than the western Himalayas at macro scale, the rates at micro catchment level can be similar in several parts of the region. For instance, Ferguson (1982) reports the sediment transport rate of 4,800 t km^{-2} on the Hunza River (13200 km^2) in the western Himalayas (Karakoram) which is comparable to the rates found in some parts of eastern Himalayas (Ferguson, 1982). The Kosi, Narayani, Karnali, Ganga, Yamuna, and Indus are the major rivers draining the Himalayan region. Due to high sediment content and highly damaging floods, the Kosi River is often compared with the Huang He in of China. Large scale sediment deposit in the Ganga plain by the Kosi river has also changed its river course extending up to 120 km during the last century (Gole & Chitale, 1966).

Naga hills and Myanmar mountains are the eastern end of the Great Himaayan range representing the extreme east of the Asian land-mass draining to the Indian Ocean. The Irrawadi, and Salween are the two major rivers draining this area to the Bay of Bengal. Annual precipitation in this zone varies from 1000 mm to 4000 mm. Although hydrological information of the Irrawadi and Salween have been documented (UNEP, 1996), sediment transport information is available only for the Irrawadi. Since only the average value is available for a single location, no description on spatial characteristics can be made for this region. The average value available for the Indrawati River, however, indicates that the sediment transport rate is moderate compared to the Himalayan region.

Tibetan Plateau, north of the Himalayas, is shared by all the major rivers of the region including Indus in the far west and the Huang He in the far east. More than 40 % the Brahmaputra basin lies in this plateau. The plateau is mostly dry with annual precipitation mainly within the range of 200 mm to 500 mm. Low precipitation, relatively flat lands and the existence of permafrost and glaciers influence the sediment movement in this zone. Few data available for the Brahmaputra River and its tributaries in Tibet shows the sediment yield varying from 34 to 192 t km^{-2}.

3. Indo-Gangetic Plain (Brahmaputra, Indus, and Ganga):

The Indo-Gangetic Plain with about one million square kilometer area (334,000 km^2 in the Indus and the rest in the Ganga) is the immediate deposition zone for the Hindu-Kush Himalayan sediment. In addition, the plain also receives sediment from the northern part of the Deccan Plateau. The plain consists of about 2000 m deep alluvial deposits (Ahmad, 1964). The plain has gentle slope towards the sea with an average gradient of one metre to five kilometres. Annual precipitation varies from more than 1000 mm in the Ganga-Brahmaputra plain to less than 200 mm in the Indus plain in the western part. Although no reliable assessment is available about the annual deposition rate in the plain, it can be expected that the basins retain more than 50 % of the total sediment received. Available information of the Kosi basin shows that almost 40% of the sediment deposition occurs within about 100 km between Barahkshetra (before the Kosi River enters into the plain) and Baltara, India in the Ganga plain (Upreti & Dhital, 1995). Since the plain acts as a transit zone for the sediment flux originating in the northern and southern mountains, it is difficult to assess the erosion rate within it. The annual rate is found to vary from about 200 t km^{-2} (Gomti) to 2400 t km^{-2} (Burhi Gandak).

4. Deccan Plateau and adjoining highlands:

This area represents all the southern part of the Indian subcontinent, south of the Indo-Gangetic plain. This region is believed to be a part of Gondwanaland, which is geologically much older than adjoining Indo-Gangetic plain and the Himalayan range. Annual precipitation in most of the area within this zone varies from 400 to 1500 mm. Some areas in the Western Ghat, however, receive precipitation exceeding 3000 mm. Unlike the Himalayan region, all the rivers in Deccan Plateau are rain-fed and hence many tributaries of the mainstem rivers are non-perennial.

Out of about 1,960,000 km^2 area covered by the region, about 16 % of the area drains to the Ganga river system. A major portion the basin area (about 80 %) drains to the Bay of Bengal, the remaining four per cent draining toward the Arabian Sea. The Betwa, Chambal, and Damodar are some of the major tributaries of the Ganga River system. The Krishna, Mahanadi and Godavari, draining towards the Bay of Bengal, are some of the major river systems of the world with each river draining more than one million square kilometer area. Narmada and Tapi are the two major rivers draining towards Arabian Sea. The region consists of volcanic areas and ancient rocks with less than two percent recent deposit areas. Biksham and Subramanian (1988) and Chakrapani and Subramanian (1990) indicate that the geological formation within the region is the major controlling factor of sediment transport.

5. Desert or inland draining basins:

The Indian Desert at southern part of the Indo-Pakistan border behaves different from the rest of the region in terms of sediment delivery. This region does not contribute to the oceanward sediment flux. This area, extending to about 200 thousand square kilometer, consists of relatively dry lands or deserts with annual precipitation less than 100 mm. A few lakes in this zone are inland drainage; hence, contain saline water or water with high chemical concentration.

6. **Islands**:

Sri Lanka is the only major island of South Asia that has noticeable contribution to the sediment flux in the Indian Ocean. Other islands including Laksdweep and Andman and and Nicobar islands have insignificant area when compared to the area of the remaining South Asian region. The south-central highland massif governs the drainage pattern of Sri Lanka. Most of the major rivers radiate from centre toward sea. Geology of Sri Lanka is dominated by Precambrian rocks of more than 2500 million years. Under the strong influence of summer monsoon (May to September) and topographic variations, precipitation varies from less than 1000 mm in northwestern and southeastern low lands to more than 5000 mm in southwest mountain slopes of the country.

Modeling Sediment Transport

Out of the considered 5.4 M km^2 area, 0.2 M km^2 of the area is either desert or inland drainage. The remaining area, accounting about 5.2 M km^2, contributes to the oceanward sediment flux. Macro-scale sediment yield of the region contributing to the continental sediment flux varies significantly within the region from less than 100 t km^{-2} in Tibetan Plateau to more than 5000 t km^{-2} in the eastern Himalayan region. The reported sediment yields for relatively small watersheds varies from almost nil (267 km^2 Muneru catchment in Deccan; CWC, 1991) to as high as 53,000 t km^{-2} (126 km^2 Kulekhani Basin in 1993 in Nepal). Overall assessment of the regional pattern of sediment yield in the South Asia region is explained in Sharma (1999).

The temporal and spatial variation of basin-wide sediment movement depends on several variables and factors including: climate, hydrology, topography, geology, land-use, soil characteristics, and channel characteristics. Satisfactory results from a modeling exercise, hence, primarily depend on availability of such data. Due to the role of several variables and factors, the best modeling approach would be the statistical approach in the form or regression analysis or principle component analysis to find out the best predictors. Modeling based on physical principle and conceptual formulations are less likely to yield reasonable outcome as the erosion and sediment transport and sediment deposition process are highly area specific with different controlling factors in different region. For example the sediment movement is primarily influenced by topography and rainfall intensity in the Himalayas, and geology in the Deccan Plateau.

Although laws are available in literature that describes the sediment processes, they do not have adequate practical values. For example, the Boyce law, which states that the steepest areas of the basin are the main sediment producing zones, implies the role of topographical gradient in controlling sediment transport. On the contrary, sediment yields in the highest zones of the Himalayas are much lower than the sediment produced in the lower elevation zones as the high elevation areas with steep slope are dominated by rocky landscapes and shallow soil layers. Furthermore, permanent snow also controls the widespread erosion and movement of sediment. Even in the snow-free areas of Kenya, the studies based on 61 catchments indicate lack of topographical effects on sediment transport (Degens et al, 1991).

Based on a review of approaches, Onstad (1984) divides the sediment yield models in five classes: sediment delivery ratio, sediment rating curve, statistical equations, deterministic model, and stochastic approaches. A review of all these approaches, however, indicated that basically there are only two approaches: Universal Soil loss Equation (USLE) and statistical equations. The others are either the modified form of one of them or the combination. USLE, developed for the computation of plot erosion in the USA needs several climatic and land-use data and has little application value for large catchments. Besides, the evaluation of soil erodibility factor, used in USLE, for a given area or region requires additional research.

Statistical approach relating the sediment with land-use, physiographic, and climatic data is probably the only practicable method for large-scale catchments or regions. Since the controlling factors of sediment transport can be different for different regions, statistical methods need to be developed using such data. Database on climate, geology, land-use, soil and physiography is hence necessary for the whole region to develop statistical models for each region considered in this study.

As an initial step, we used the database developed in this project with additional data obtained from the digital elevation model (DEM) and available atlas. ArcView3.2a along with Spatial Analyst was used to derive several physiographic information of different basins. Derivation of all the physiographic variables was not possible for all the basins due to unavailability of DEM at required resolution. The available DEM at 30 arc-sec (about 1 km grid) used in this study was found to be fairly adequate for spatial analysis in mountainous environment such as the Himalayan region but was inadequate for most part of South Asia. Primarily due to unavailability of suitable DEMs and maps at appropriate scale, our attempt to obtain a database with complete data was not possible. The estimated sediment loads from each river is given in Annex I.

Data in Annex I was used for the statistical analysis in this project for obtaining a most suitable model for south Asia or some specific areas in the region. Figure 1 shows the location of the data points. Selected independent variables in this study were: basin area, river discharge, river length, average elevation of the basin, elevation difference within the basin, and slope of the basin. The analyses were carried out using linear model with linear scale and logarithmic scale.

The analysis showed that the sediment yield of a basin is significantly related to the basin area, river discharge and river length. Since river length is significantly related to basin area and since the data for discharge is not complete in the database, we used basin area as the best independent variable to predict sediment yield. Although it was found that the relation between basin area and sediment yield can be improved with the introduction of elevation difference in the watershed, such addition of a variable was not considered at this stage as the improvement was marginal (improvement of R^2 from 76% to 80%) and that the accurate elevation data was not available for several basins.

The relationships obtained by using the data described above (Annex I) and also for different regions are produced in Figure 2, Figure 3 and Figure 4. The figures also present the basic statistics of the derived regression equation for prediction. The statistics indicated the suitability of power equation instead of linear equation as the residual plot showed the normality in the case of regression using logarithmic transformation. The equation for the estimation of sediment yield based on the regression equations presented in Figure 2, Figure 3, and Figure 4 can be summarized as:

2. For the whole of South Asian Region

$$S_y = 1260A^{0.93}, \quad (1)$$

3. For the Hindu Kush-Himalayan Region

$$S_y = 6310A^{0.83}, \quad (2)$$

4. For the South and Central region of the Indian Subcontinent

$$S_y = 930A^{0.95}, \quad (3)$$

where Sy is the annual sediment yield in tonnes and A is the basin area in square kilometres.

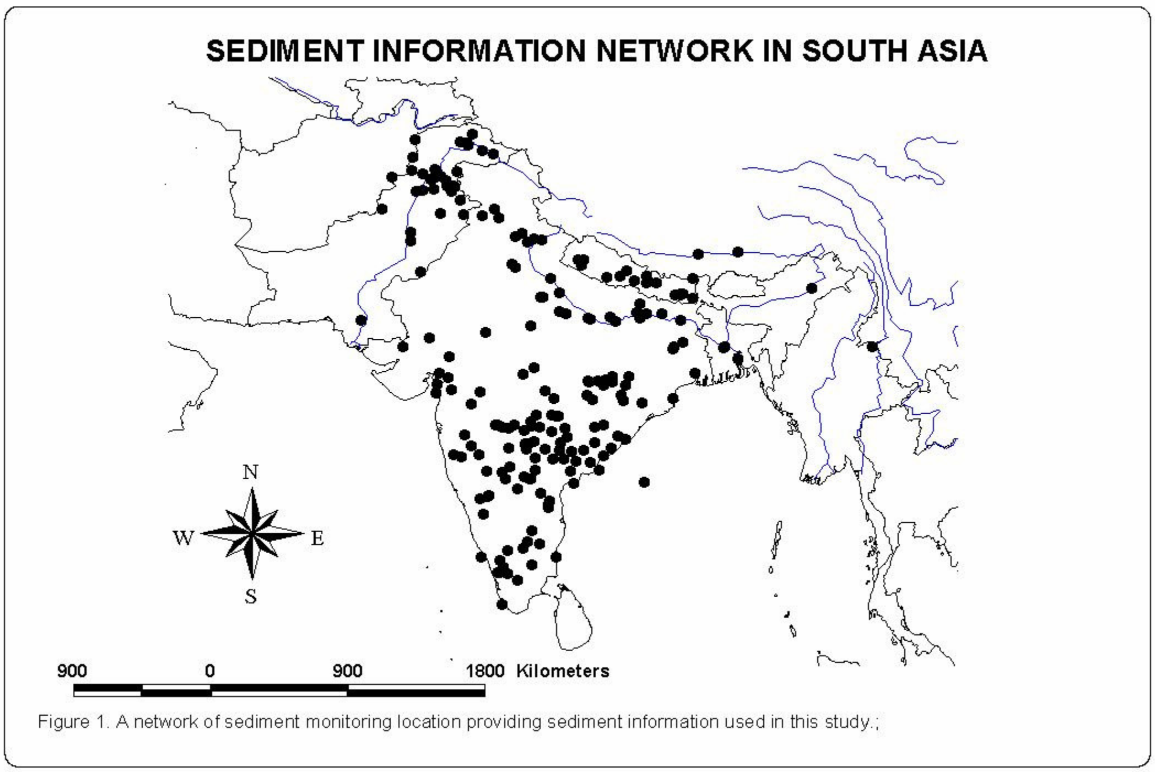

Figure 1 Network of Sediment Monitoring Stations in South Asia

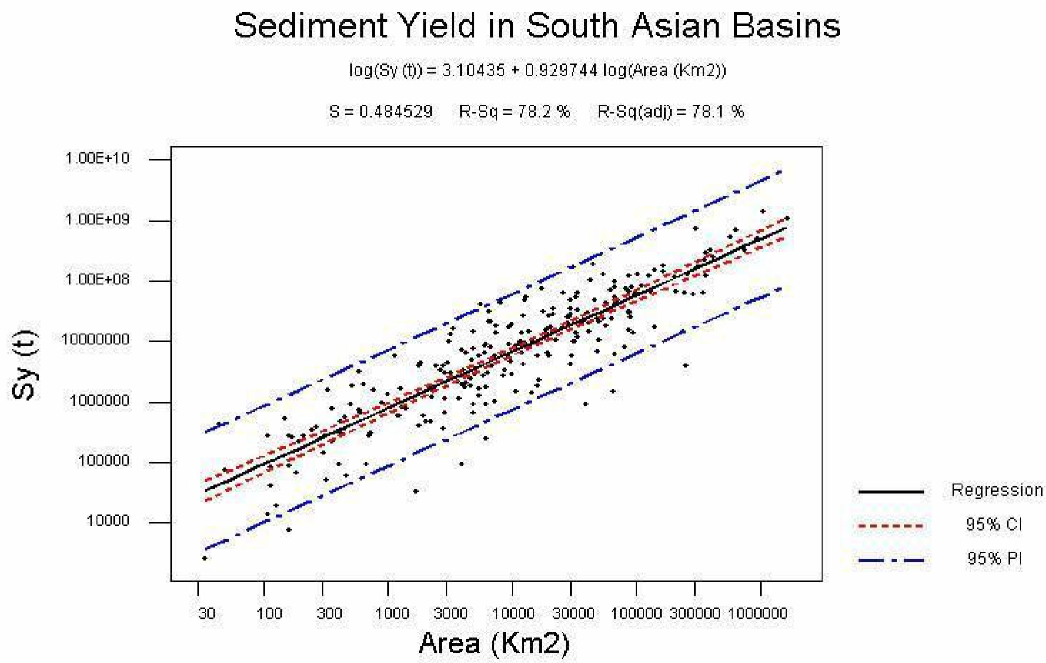

Figure 2. Regression between the annual sediment yield and area of basin considering the whole of South Asia as a single region.

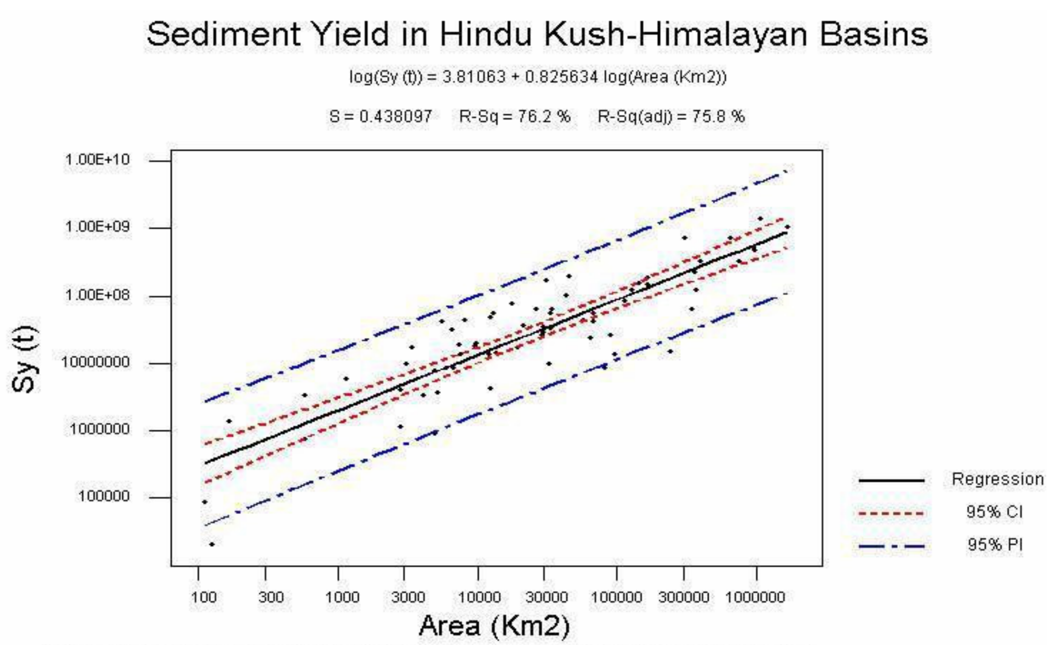

Figure 3. Regression between the annual sediment yield and area of basin considering the Hindu Kush-Himalayan region.

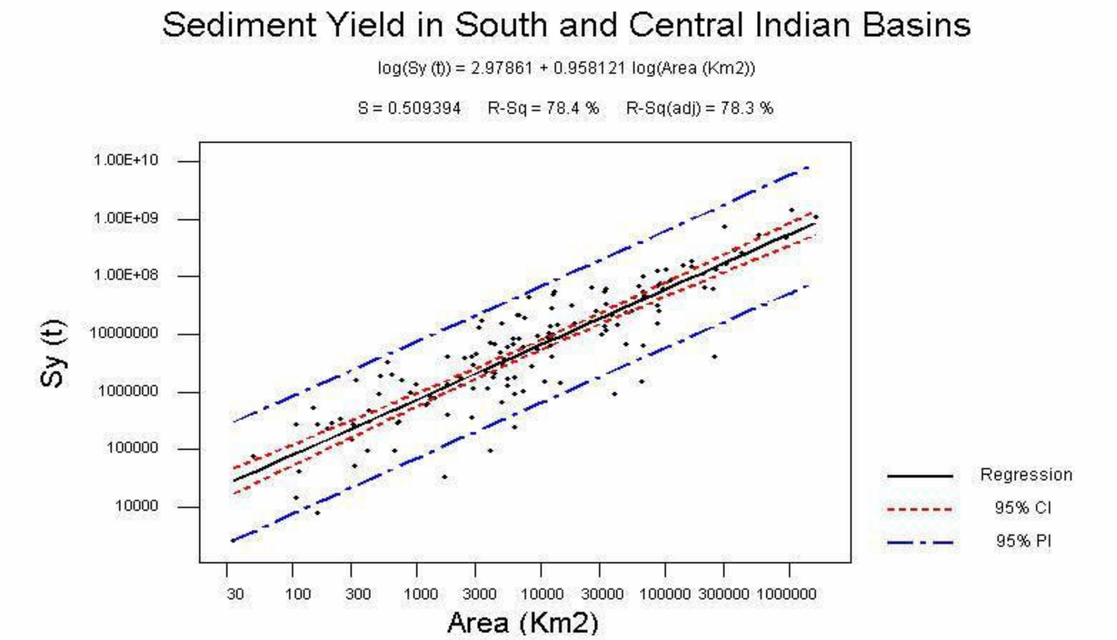

Figure 4. Regression between the annual sediment yield and area of basin considering the South and Central region of the Indian Subcontinent.

Sediment Flux

Table 2 presents the oceanward sediment flux through the major and minor (accumulative value) river systems. The table shows the flux in the Bay of Bengal side as well as the Arabian Sea side of the Indian Peninsula. The assessment of the total sediment flux based on reported data and regression approach showed that South Asia annually contributes more than three billion tonnes of sediment every year.

Table 2. Sediment flux from the South Asian rivers towards Ocean

No.	**River**	**Area (km^2)**	**Sediment Flux (Mt)**	**Reference**
Bay of Bengal				
	Ganga-Brhmaputra	1648000	1100	Appendix I
	Damodar	20000	28	’’
	Mahanadi	132000	68	’’
	Godavari	310000	170	’’
	Krishna	250000	64	’’
	Pennar	48700	7	’’
	Cauvery	87900	32	’’
	Irrawadi	419000	260	’’

	Salween	325000	168	Using regional value (Fig 1)
	Other rivers	734000	360	Using regional value (Fig 3)
	Total	3959600	2257	
Arabian Sea				
	Indus	958000	481	Appendix I
	Mahi	37600	22	’’
	Narmada	98800	61	’’
	Tapi	66900	100	’’
	Other west flowing rivers	580700	278	Using regional value (Fig 3)
	Islands	65000	35	
	Total	1807000	976	
	Grand Total		**3233**	

The countrywise sediment flux in South Asia from rivers in India, Pakistan, Bangladesh, Mynmar and Sri Lanka, is presented in Table 3.

Table 3**. Oceanward sediment flux from South Asian countries**

Country	Soil Erosion (Mt)	Reference	Sed. Flux towards ocean (Mt)	Reference
Pakistan	430	Ahmad & Chaudhary, 1988	481	Ahmad & Chaudhary, 1988
India	5300	Singh (1990)	990	**Estimated**
Bangladesh			1100	Ludwig & Probst, 1996
Myanmar			524	Estimated
Sri Lanka			35	Estimated
Total			**3236**	

Sediment Retention

A major portion of the eroded sediment is usually retained within the watersheds along channels or flood plains as a natural process. Available information in literature is not adequate for estimating the retention of sediment by river basins in the region. Some of the available information indicates that about 65 % of the transported sediment is retained in the Mahanadi River basin (Chakrapani & Subramanian, 1990); 70 % in Brahmaputra River basin (Goswamy, 1985), 57% in the Indus River basin (Ahmad and Chaudhary, 1988). Due to the complexities involved in natural as well as human induced processes in sediment retention, it is difficult to make reliable estimates. Since the only source of information is the sediment transported by the rivers, the estimates of erosion within a catchment are likely to be underestimates. For instance, a detailed study of Potomac River basin (area = 38000 km^2, sediment yield = $2.3X10^6$ t) shows that only about 5 % of the products of erosion exits the river basin (Holeman, 1968). Even for a small basin (area = 360 km^2) in Wisconsin, a similar study indicates the yield as low as 5.5 % of the watershed erosion (Walling, 1983).

Influence of Human Activities

Modeling the human impacts on sediment transport is another complex aspect in sedimentology. Such impacts are not site specific but propagate throughout the downstream areas.

Human activities are responsible for two opposite types of effects on sediment flux.

1) Construction of Dams*:* Although the objective of reservoir construction is to store water, the reservoirs act as human made retention system for the sediment transported by rivers. A huge amount of sediment is retained by reservoirs every year. The average amount of 305 million tonnes of sediment trapped by the three reservoirs (Tarbela, Mangla, and Bhakra) in the Indus basin (Khan, 1985; CWC, 1991) far exceeds the estimated annual sediment flux of Indus towards ocean. Sediment trapped by the Indian reservoirs is estimated at 480 million tonnes (Narayana & Ram Babu, 1983), which is almost half of the direct sediment flux from India to the Oceans (Table 1). The sediment trapped by the Indian reservoirs is almost 20% of the sediment eroded in India (Singh 1990).

The nature of sediment trapping by reservoirs is found to be changing with the age of reservoir. Long term impacts of reservoir are reported to be lesser than the impacts observed during the initial years of construction either due to engineering improvement (Xuemin, 1992) or natural development of balance on sediment budget of reservoirs (CWC, 1991). The other major human induced impacts on sediment movement are the influence due to land-use changes. A great debate exists regarding the land-use effects on sediment in the regional context (Ives & Messerli, 1989). A survey of some available information in the Himalayan region led Bruinzeel and Bremmer (1989) to conclude that, "The frequently voiced claim that upland reforestation will solve downstream siltation problems does not pertain to the Himalayan situation." On the other hand, studies made by Milliman, Yun-Shan, Mei-E, and Saito (1987) in the Huang He indicate strong human influence on the regional sediment delivery.

2) Loss of Vegetative Cover*:*

One effect is to increase sediment flux induced soil erosion resulting from clearing of vegetative cover and improper agricultural practices. Since more than 70% of the population in the region are engaged in agricultural activities, clearing of forest for agriculture land is a regular process. The forest clearing although takes place in almost every habitable area of the region, the activities are severe in some areas. For example, most of the dense forest of Nepal south of the Siwaliks has disappeared during the last 50-year period.

Denudation of a catchment through human activities by the way of improper agricultural practices, deforestation, extensive grazing etc has been blamed for accelerating soil erosion. Several studies at plot scale and micro-catchment scale demonstrate the impacts of such human activities in accelerating soil erosion. Studies show the increase in soil erosion from 100 to 1000 times as a result of transforming the forest into row crops. (Leeden, et al, 1990). Similarly, road construction activities in mountainous areas are believed to contribute significant to soil loss mainly in the form of induced landslides and increased socio-economic activities. Some estimates in the Himalayan region show the production of debris from 400 m3 to 700 m3 per linear kilometer.

What are the impacts of human activities in the basin scale delivery of sediment? Adequate information and data are not available for such assessment. Very few long-term time series are available for assessing the sediment transport trend of major river basins in relation to human activities. Available data for the Kosi, which is one of the major Himalayan basins are plotted in Figure 5 and some basic statistics of trend are presented in Table 3. The figure presents the data of total annual sediment load available for the Kosi River at Chatara (Drainage area = 54,100 km2) from 1948 through 1977. Almost half of the basin upstream of Chatara drains the relatively dry areas of the Tibetan Plateau and the rest of the area lies in the Nepalese portion of the Himalayan mountains and hills. The patterns of sediment load, although very high in some years, did not show any distinct trend.

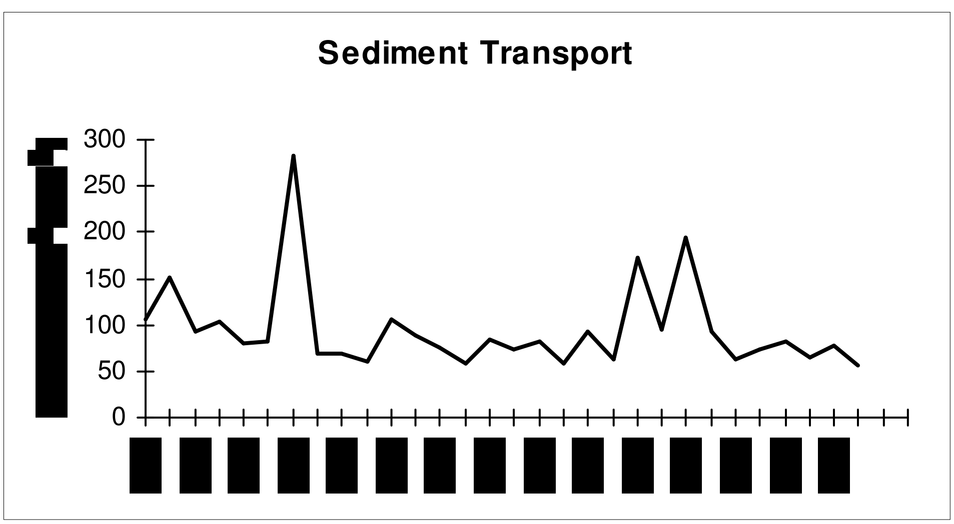

Figure 5. Annual sediment load measured on the Kosi River at Chatara.

Table 3 presents the statistics of parametric and nonparametric tests applied to the time series of suspended sediment load presented in Figure 5. The table shows a slightly negative trend of sediment over the period of record; but the trend is insignificant in terms of parametric statistics as well as nonparametric statistics.

Table 3. Parametric and nonparametric trend of sediment load on the Kosi River at Chatara.

	Nonparametric			Parametric			
Sediment Load	*Z-statistics*	*Z-critical*	*p-value*	*Slope*	R^2	*F-statistics*	*p-value*
Normal Scale	-1.80	0.964	0.072	-1.18	0.05	1.4	0.25
Logarithmic Scale	-1.93	0.973	0.054	-0.005	0.07	2.0	0.17

The figure and table presented here do not support the theory of accelerating erosion in the Himalayan region as a result of human activities. One of the reasons behind such observation could of the scale of impacts. Since the Kosi River basin is one of the highly sediment laden rivers of the world, the sediment transport as a result of human activities could have been insignificant compared to natural processes. The other reason could be the human activities itself, which are probably well planned considering the soil conservation aspects. The third possible reason could be the negligible increase in human activities that could induce sediment movement. All of these reasons might be playing role in explaining the observation made in Figure 5 and Table 3.

Conclusions And Recommendations

The sediment delivery patterns within the South Asia region represent all scales from lowest to the highest possible within the globe mainly because of the diversities in climatic, geologic, physiographic, topographic and land-use factors that influence the movement of sediment particles. Assessment of the spatial sediment delivery pattern indicated strong influences of geographical factors depending on the local conditions of soil erodibility and climatic conditions.

Quality and quantity of available sediment data were inadequate in the region for obtaining a satisfactory conceptual model that could provide sediment delivery pattern on the basis of basin characteristics and climatic conditions. Statistical modeling approach was adopted, as it is probably a better approach in view of the nature of available data. As an initial attempt, regression analysis was carried out with sediment yield as a dependent variable and basin area as a predictor. The result showed a significant correlation between these two variables. The regression equations developed for different region were used to compute sediment yield for the basins for which no sediment yield data were available.

Based on these computations, the total oceanward sediment flux from South Asia was estimated at 3.2 billion tonnes per year.

Regarding the human activities, several critical issues were realized that could influence the pattern of sediment flux. Several studies were found that could relate human activities to sediment movement at micro-catchment or at plot level. Our attempt to quantify such impacts for large basins did not yield noticeable conclusion that could be stated with high degree of confidence; however, the impact of reservoir construction on sediment transport was distinctly clear. Such impacts were found highly significant on central and south Indian rivers. Excluding the Indus, the impacts of reservoir construction on oceanward sediment flux was not found to be significant, as there are only few dams on the tributaries of the Ganga and Brahmaputra rivers.

Since most of the areas except the Ganga and Brahmaputra basins in South Asia are highly influenced by the construction of reservoirs, the Himalayas are the ideal zones for the studies of natural sediment yield characteristics in the region. Since several high dams have been planned and several schemes of water resources development are being developed in the Himalayan region, we recommend initiating sediment studies in region with extensive network. Such studies will not only contribute towards the understanding of sediment characteristics of high sediment yield areas of the world under natural environment, but also help for the better implementation of planned projects and schemes in the region.

Information on sediment in the region is far less than adequate and significant uncertainties lie in the proper understanding of its behaviour. Educational and research activities must be promoted in the field of soil erosion, soil conservation, sediment transport, and river morphology. Similarly, methods for monitoring sediment transport must be standardized for obtaining reliable and standard data for the assessment of sediment flux.

Major sources of sediment data were the publications on reservoir sedimentation; however, there was inadequate information about the trapping efficiency of the reservoirs. Besides, the data on reservoir sedimentation do not provide other essential information such as the hydrological and geographical data. Inclusion of such information would provide a lot of scope for the assessment of sediment transport characteristics.

There are several hydrometric stations in the region, where sediment observations are made either regularly or for certain duration during high flow periods. The number of reported sites in India alone is given as 318. The author’s attempt to obtain these data from India, Pakistan, Bangladesh and Myanmar did not yield much result mainly because the data are either classified or are too costly. This fact has been a major bottleneck in the present study and is likely to be a stumbling block for future studies at regional scale. A major recommendation in this respect is to make the data available to scientific community for research purpose.

Basically sediment problems are considered with three different types of objectives: a) control of sediment to increase reservoir life, b) management of flood plain, and c) control of sediment for soil conservation. Since all these three objectives are complementary to each other, there is an urgent need to have an integrated method, which considers watershed as a unit. Besides, the strategies of sediment management in source areas should also give adequate importance to the downstream areas and overall sediment flux towards oceans.

Acknowledgement

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Item	**Pakistan**	India	**Nepal**	**Bhutan**	**B'desh**	**Myanmar**	***Sri Lanka***
Land Area, km^2	778,720	2,973,190	143,181	46,500	133,910	657,740	65,525
Mountainous Area, %	59	70	83	100	15	70	20
Plain Area, %	41	30	17	0	85	30	80
Population (1999)	137.6	992.7	22.5	2.0	134.6	47.1	18.7
Pop'n growth rate, (75-99)	2.8	2.0	2.2	2.3	2.4	1.9	1.4
Highest Elevation	8611	8598	8848	7553	957	5881	2524
Lowest Elevation	0	0	60	97	0	0	0
Coastline (km)	1046	7000	0	0	580	3060	1585
Literacy,% (1999)	45.0	56.5	40.4	54 ('94)	40.8	84.4	91.4
Per Capita GDP, PPP US$ (1999)	1834	2248	1237	1341	1483	1500 (Est. 2000)	3279
Agriculture in GDP (%)	25	25	41	38	30	42	21
Forest Cover (%)	4	23	29	60	16	44	32

Table 1. Socio-economic data of countries in South Asia

Annex I

River	Location	Basin	Region	Lat	Long	A(Km2)	Q (Mm^3)	S(rad)	Eaverage(m)	Edifference(m)	L(km)	Sy(t)
Beas	Belelive	Indus	Himalaya	31.93	76.21	6009	11.10			3500	190	8503118
Beas	Pong	Indus	Himalaya	31.57	75.50	12562				3600	350	48991800
Chenab	Alexandria	Indus	Himalaya	32.43	74.17	33000		0.286	2846	6935	610	55803000
Chenab	Chiniot	Indus	Himalaya	31.67	73.00	67542	17.64	0.202	2061	6975	780	54660679
Gilgit	Gilgit Town	Indus	Hindu-Kush	35.90	74.20	12100	8.83	0.458	4067	6097	216	14000000
Gilgit	Alambridge	Indus	Hindu-Kush	35.86	74.55	26148	21.50	0.493	4276	6111	257	64768596
Gomal	Gulkatch	Indus	Sulaiman	31.95	69.55	39886	1.14	0.081	2005	2142	261	949780
Haro	Khanpur	Indus	Siwalik	33.86	73.00	777	0.30					1651125
Haro	Sanjwal	Indus	Siwalik	33.71	72.51	1799	0.60					4117911
Haro	Gariala	Indus	Siwalik	33.71	72.43	3055	0.80	0.104	799	2118	127	4518345
Harrow	Hassanabdel	Indus	Siwalik	33.80	72.75	6216	1.01	0.013			48	1804581
Hunza	Dainyor B.	Indus	Himalaya	36.39	74.89	13152	12.10	0.468	4715	4803	133	55882848
Indus	Kachural	Indus	Himalaya	35.36	75.49	112700	30.30	0.259	4891	5763	952	87000000
Indus	Pratab B.	Indus	Himalaya	35.68	74.66	142700	55.50	0.301	4772	6914	1091	160000000
Indus	Darband	Indus	Himalaya	36.02	71.50	164724	73.39	0.250	1329	3087	59	147511133
Indus	Tarbela	Indus	Himalaya	34.10	72.83	165000	79.00	0.315	4565	7865	1451	188000000
Indus	Kalabagh	Indus	Himalaya	33.00	71.58	305000	110.00	0.291	3753	7966	1658	750300000
Indus	Kotri	Indus	Himalaya	25.37	68.30	958000	213.60			5950	13000	480916000
Jhelum	Domail	Indus	Himalaya	34.12	74.00	13675	14.09	0.237	2548	3852	205	14639000
Jhelum	Mangla	Indus	Himalaya	33.15	73.73	34136	30.10	0.271	2385	5778	436	63595515

Swat	Munda	Indus	Middle Mts	30.55	71.23	12458	3.53					4185938
Kabul	Warsakdam	Indus	Hindu-Kush	34.20	71.33	67340	15.91	0.295	2845	7089	664	42726267
Kabul	Nowshera	Indus	Hindu-Kush	34.00	72.00	90000	21.40	0.283	2606	7089	724	25920000
Kahan	Rohtas	Indus	Indus Pln.	32.98	73.67	1217	0.05				64	609586
Kanshi	GTRoad	Indus	Siwalik	33.32	73.38	1803	0.04				48	412722
Kishanganga	Muzaffargadh	Indus	Middle Mt.	30.07	71.25	6734	7.92				240	8432316
Kunhar	Ghari	Indus	Middle Mt.	34.98	71.40	2797	2.54	0.469	3775	6502	393	4058149
Kurram	Kurram	Indus	Sulaiman	33.85	70.18	6819	1.20	0.219	2508	3276	1167	22238658
Poonch	Kotli	Indus	Siwalik	33.22	73.85	3236	3.80	0.208	1492	4170	149	13545896
Poonch	Palic	Indus	Siwalik	33.32	73.77	3937	3.12	0.223	1589	4108	133	7228686
Rabi	Shahdara	Indus	Himalaya	31.65	74.38	8089	14.31					44031782
Shyok	Yugo	Indus	Himalaya	35.19	76.15	33700	9.80	0.262	5069	5098	656	34000000
Siran	Thapla	Indus	Middle Mt.	34.29	72.71	2849	0.17	0.007			97	1146643
Soan	Chirah	Indus	Siwalik	33.64	73.36	326	0.20			600	20	1605550
Soan	Dhokpathan	Indus	Siwalik	33.14	72.62	6472	1.40	0.045	555	1801	144	22315456
Soan	Mukhad Rd.	Indus	Siwalik	33.07	72.00	12432	0.99	0.035	507	1842	213	8520386
Sutlej	Bhakra	Indus	Himalaya	31.40	76.47	56980		0.232	4471	6421	766	45128160
Sutlej	Gobindsagar	Indus	Himalaya	31.40	76.47	57000	14.60				1296	44061000
Banas	Dantiwada	Banas	Aravalli	24.32	72.35	2862	0.60					3009107
Bhadar	Bhadar	Bhadar	Mandav	23.82	70.78	2435				100	60	3956875
Mahi	Kadana	Mahi	Aravalli	23.22	73.52	25520	10.80			500	297	16291968
Mahi	Mouth	Mahi	Aravalli	22.25	72.94	37600	11.80		830	800	533	22100000
Tawa	Tawa	Narmada	Vindhya/Sat.	22.18	77.90	5983	4.30				172	6800000
Narmada	Garudeshwar	Narmada	Vindhya/Sat.	21.98	73.49	87892	46.70			6900	918	69700000
Narmada	Mouth	Narmada	Vindhya/Sat.	21.59	72.83	89000				900	1300	125000000

Narmada	Mouth	Narmada	Vindhya/Sat.	21.59	72.83	98800	40.10		1210	900	1300	61400000
Girna&Panza	Girna	Tapti	Deccan	20.46	74.81	4729	4.50			900	135	4955992
Tapi	Savkheoa	Tapti	Satpura/Dec.	21.14	75.35	49136	9.70			300	351	24700000
Tapti	Ukai	Tapti	Satpura/Dec.	21.28	73.65	62225				700	567	70936500
Tapti	Mouth	Tapti	Satpura/Dec.	21.07	72.73	66900	19.70		780	730	724	102000000
Kuttiyadi	Peruvannam'hi	Kuttiyadi	W. Ghat	11.38	75.43	109				1000	15	280784
Malampuzha	Malampuzha	Bharatha	W. Ghat	10.83	76.69	148				600	54	526288
Manali	Peechi	Periyar	W.Ghat	10.52	76.40	107				600	25	14338
Bharathpuzh	Mangalam	Bharatha	W. Ghat	10.51	76.54	49				500	10	75852
Aliyar	Aliyar	Bharatha	W. Ghat	10.46	76.98	195				1800	20	231465
Kailmani'har	Manimutharu	Tambraparni	W. Ghat	8.64	76.67	162				800	12	275724
Vaigai	Vaigai	Vaigai	Cardamom	10.05	77.56	2253				2300	81	1254921
Kundah	Upperbhawani	Cauvery	Deccan	11.22	76.52	34				1000	22	2584
Bhawani	Lowerbhavani	Cauvery	Deccan	11.83	77.00	4200				2300	108	1764000
Cauvery	Mettur	Cauvery	Deccan	11.92	77.88	42200		0.034	786	1361	324	14896600
Cauvery	Musiri	Cauvery	Deccan	10.97	78.43	66243	11.50			2400	270	1500000
Cauvery	Mouth	Cauvery	Deccan	11.43	79.82	87900	84.60			2500	432	32310000
Pannalarui	Krishnagiri	Ponnaiyar	Deccan	12.32	78.11	5430		0.020	830	795	165	1308630
Ponniar	Sathnur	Penniar	Deccan	12.18	78.83	10826				700	216	1537292
Gundukamm	Cumbumtank	Gundalakam	Deccan	17.75	79.19	993				550	80	1375305
Palar	Palar	Palar	Deccan	12.98	78.38	1687		0.015	846	393	95	33740
Pennar	Somasila	Pennar	Deccan	14.50	79.40	48660	5.20				477	6900000
Aliaru	Pocharam	Krishna	Deccan	18.11	78.19	673				200	16	94220
Bhima	Ghod	Krishna	Deccan	18.65	74.46	3629				1400	135	2286000
Bhima	Takali	Krishna	Deccan	16.05	76.84	33196	11.20					14075104

Bhima	Yedgir	Krishna	Deccan	16.73	77.11	69863	20.50	900	513	46039717
Dindi	Dindi	Krishna	Deccan	16.54	78.60	3920		400	108	94080
Issa	Himayatsagar	Krishna	Deccan	17.25	78.57	1308		400	70	817500
Koyna	Shivajisagar	Krishna	Deccan	17.42	73.77	891	3.30	500	54	961389
Krishna	Karad	Krishna	Deccan	17.32	74.25	5462	4.50		90	1690000
Krishna	Bagalkot	Krishna	Deccan	16.46	75.74	8610	3.40	300	108	2810000
Krishna	Huvanpur	Krishna	Deccan	16.39	76.64	11400	1.80		135	9170000
Krishna	Bawapuram	Krishna	Deccan	16.18	77.92	67180	6.90			6380000
Krishna	Srisailam	Krishna	Deccan	16.03	78.26	206041	69.80	900	621	116825247
Krishna	Morvakonda	Krishna	Deccan	16.04	78.35	210500	41.90	900	648	67720000
Krishna	Mouth	Krishna	Deccan	15.75	80.84	250000	35.00	2000	1026	64000000
Muneru	Shanigram L	Krishna	Deccan	17.68	80.00	321			54	51039
Wyra&Pangi	Wyra	Krishna	Deccan	17.18	80.26	710		300	20	285420
Nira	Sarati	Krishna	Deccan	18.00	74.80	7200	18.50	300	108	1029600
Sina	Wadakbal	Krishna	Deccan	17.46	75.26	12092	1.10			6480000
Tunga	Shimoga	Krishna	Deccan	13.93	75.52	2831	5.50	300	108	370000
Tungbhadra	Tungbhadra	Krishna	Deccan	15.04	75.85	14582	8.10	300	297	1450000
Tungbhadra	Tungbhadra	Krishna	Deccan	15.00	75.83	28180	12.60	600	270	25559260
Varada	Morol	Krishna	Deccan	14.82	75.37	4901	2.50		81	661635
Krishna	Vijaywada	Krishna	Deccan	16.50	80.65	251360	32.40	2000	837	4110000
Godavari	Ramtek	Godavari	Deccan	21.24	79.20	212				286412
Godavari	Dhlle	Godavari	Deccan	19.21	76.38	31000	4.00	300	324	10000000
Godavari	Gagra	Godavari	Deccan	19.07	76.65	34000	4.00	300	378	12000000
Godavari	Nanded	Godavari	Deccan	19.18	77.35	54000	8.00	300	459	25000000
Godavari	Basar	Godavari	Deccan	18.86	77.92	87000	11.00	300	513	16000000

Godavari	Sriramsagar	Godavari	Deccan	19.07	78.88	91751			800	756	79272864
Godavari	Mancherial	Godavari	Deccan	18.79	79.58	103000	80.00		800	864	133000000
Godavari	Perur	Godavari	Deccan	18.50	80.46	260000	80.00		800	972	133000000
Godavari	Rajhamundry	Godavari	Deccan	17.02	81.87	310000	92.00		1000	1107	170000000
Godavari	Mouth	Godavari	Deccan	16.54	82.38	310000	83.70	413	1000	1188	170000000
Indravati	Nowrangpur	Godavari	Deccan	19.21	82.62	5000	3.00		400	54	3000000
Indravati	Jagdalpur	Godavari	Deccan	19.07	82.08	7000	5.00		400	108	4000000
Indravati	P. Gudem	Godavari	Deccan	19.00	80.34	42000	23.00	490	400	297	21000000
Kaddam	Kaddam	Godavari	Deccan	19.12	78.41	2656			300	20	3404992
Lakhamvara	Lakhamvaram	Godavari	Deccan	18.15	80.08	268			400	40	399588
Manair	Ramappa L.	Godavari	Deccan	18.25	78.53	184			300	40	66608
Manjeera	Saigaon	Godavari	Deccan	17.86	77.02	10000	1.00			270	3000000
Manjeera	Raipalli	Godavari	Deccan	17.80	78.08	16000	2.00		700	378	6000000
Manjira	Manjira	Godavari	Deccan	18.07	78.00	16770			500	405	2381340
Kinnersani	Kinnersani	Godavari	Deccan	17.65	80.73	1338					113730
Kanigiri	Kanigiri	Penner	Deccan	14.70	79.41	163					88998
Musi	Musi	Krishna	Deccan	17.20	79.65	2057			800	162	483395
Tandava	Tandava	BOB	Deccan	17.85	83.11	451					366212
Hindri	Gajuladinne	Krishna	Deccan	15.45	77.53	1274					1699516
Tammileru	Tammileru	Krishna	Deccan	17.05	81.00	611					688597
Araniar	Araniar	Penner	Deccan	14.30	79.40	448			600	324	580160
Kadam	Swarna	Godavari	Deccan	19.37	78.35	290					251720
Mehadrigad	Mehadrigadda	BOB	Deccan	18.37	83.90	352			600	135	774400
Konam	Konam	BOB	Deccan	18.53	83.50	171			600	108	267957
Pampa	Pampa	BOB	Deccan	17.40	82.61	355					220100

Munyeru	Lower Saileru	Munyeru	Deccan	15.15	78.94	467				27	60243
Manjira	Nizamsagar	Godavari	Deccan	18.05	78.00	21694	4.10		400	405	14860390
Penganga	P. G. Bridge	Godavari	Deccan	19.82	78.64	19000	5.00		100	405	14000000
Pranahita	Tekra	Godavari	Deccan	19.75	79.98	100000	43.00	443	400	1242	65000000
Purna	Purna	Godavari	Deccan	19.04	77.04	15000	3.00		600	378	10000000
Sabari	Konta	Godavari	Deccan	17.71	81.44	20000	14.00	580	1800	891	6000000
Sidhapana	Magleaon	Godavari	Deccan	19.18	76.23	4000	1.00		500	297	2000000
Sileru	Machkud	Godavari	Deccan	18.14	82.12	1956	1.20			81	600000
Wainganga	Pauni	Godavari	Deccan	20.75	79.70	36000	15.00		200	216	21000000
Wardha	Bamini	Godavari	Deccan	19.79	79.54	46000	14.00		300	351	51000000
Wainganga	Asthi	Godavari	Deccan	19.71	79.85	51000	25.00		500	432	22000000
Hamp	A'Kore	Mahanadi	Deccan	21.82	81.73	2210	0.30		200	189	497515
Hasdeo	Bamnidih	Mahanadi	Deccan	21.89	82.75	9730	5.39		400	333	4850016
Ib	Sundargarh	Mahanadi	Deccan	22.07	84.13	5870	3.02		400	216	2760015
Jonk	Rampur	Mahanadi	Deccan	21.57	82.65	2920	1.52		200	216	680010
Mahanadi	Rajim	Mahanadi	Deccan	20.95	81.64	8760	2.95		500	135	3499620
Mahanadi	Tikarapara	Mahanadi	Deccan	20.53	84.93	41000	57.07			594	29889820
Mahanadi	Basantpur	Mahanadi	Deccan	21.71	83.15	57780	22.27			324	18799879
Mahanadi	Hirakud	Mahanadi	Deccan	21.53	83.92	83395	40.60		500	405	77307165
Mahanadi	Tikarapara	Mahanadi	Deccan	20.53	84.93	88320	54.50			324	30700000
Mahanadi	Naraj	Mahanadi	Deccan	21.75	82.48	132034	90.20	330	200	857	67865476
Mand	Kurubhata	Mahanadi	Deccan	22.04	83.15	4625	2.04				2540004
Ong	Salebhata	Mahanadi	Deccan	20.96	83.65	4650	2.25		300	205	1889993
Pairi	Baronda	Mahanadi	Deccan	20.73	82.00	3225	1.17			54	3029984
Seonath	Simga	Mahanadi	Deccan	21.71	81.75	16010	5.71			385	1854278

Seonath	Jondhra	Mahanadi	Deccan	21.79	82.27	29645	9.16			100	162	4329949
Tel	Kantamal	Mahanadi	Deccan	20.61	83.77	19600	9.36			1100	240	6790028
Brahmani	Samal	Brahmani	Deccan	20.75	86.70	28200	16.30					20400000
Mayurakshi	Mayurakshi	Hugli	Maikal	24.11	87.30	1860	8.20			300	43	4464000
Damodar	Panchet Hill	Hugli	Maikal	23.68	86.75	10878	4.00			300	189	8919960
Damodar	Mouth	Hugli	Maikal	22.28	88.04	20000	10.00			500	459	28000000
Barakae	Maithon	Hugli	Maikal	23.80	86.78	6294	2.30			300	135	9000420
Arun	Tribeni	Ganga	Himal/Tibet	26.93	87.15	29532	20.12	0.208	4561	8489	537	48440000
Bagmati	Chovar	Ganga	Middle Mts	27.67	85.30	585	0.49				34	760000
Betwa	Matatila	Ganga	Vindhya	25.08	78.33	20720	6.00			400	243	17404800
Betwa	Sahijna	Ganga	Vindhya	25.89	80.00	49940	17.80			470	405	10537340
Betwa	Gandhisagar	Ganga	Vindhya	24.65	75.68	21875	4.70			400	243	29400000
Chambal	Gandhisagar	Ganga	Vindhya	24.65	75.68	22533	4.70			400	200	11000000
Chambal	Udi	Ganga	Vindhya	26.72	78.93	139785	31.40			766	702	18032265
Gandak	Conflunce	Ganga	Himalaya	25.78	85.17	64300	52.20		1400	4800	594	24000000
Ghagra	Conflunce	Ganga	Himalaya	25.82	84.58	127000	94.40		1200	4800	1404	125000000
Gomti	Conflunce	Ganga	Ganga P.	25.56	83.00	30400	7400.00		150	100	486	6000000
Kaligandaki	Setibeni	Ganga	Himalaya	28.00	83.60	6630	8.42	0.374	3659	7221	199	32000000
Kankai	Mainachuli	Ganga	Middle Mts.	26.68	87.88	1148	1.78	0.250	1329	3087	59	5800000
Karnali	Asaraghat	Ganga	Himalaya	28.95	81.43	19260	15.93	0.342	4090	7175	354	17000000
Karnali	Chisapani	Ganga	Himalaya	28.65	81.30	42890	44.15	0.353	3350	7632	470	105000000
Ken	Chilla	Ganga	Vindhya	25.78	80.44	288224	11.30				360	63121056
Kosi	Chatara	Ganga	Himal/Tibet	26.87	87.17	54000	49.35	0.264	3874	8602	550	133000000
Bhilanganga	Tehri	Ganga	Himalaya	30.20	78.53	7511		0.386	3551	6182	221	13962949
Kosi	Baltara	Ganga	Himal/Tibet	25.40	87.20	67000				4800	594	80000000

Kulekhani	Kulekhani	Ganga	Middle Mts	27.58	85.17	126	0.12	0.189	1882	1091	23	20000
Lotharkhola	Lothar	Ganga	Middle Mts	27.60	85.72	169	0.30	0.369	3550	7144	140	1400000
Narayani	Narayanghat	Ganga	Himalaya	27.70	84.43	31100	50.14	0.379	2972	7615	337	176000000
Phewa	Phewa	Ganga	Middle Mts	28.28	83.97	113	87.00	0.632	2994	5607	3700	769912
Gandak		Ganga	Himalaya	26.36	84.78	45312						195974400
Ramganga	Ramganga	Ganga	Himalaya	30.13	79.01	3134	3.60			2700	162	10060140
Ramganga	Conflunce	Ganga	Himalaya	27.84	79.49	32400	15.20		1100		648	10000000
Rapti	Bagasoti	Ganga	Himalaya	27.90	82.85	3380	2.95	0.267	1557	3104	128	17000000
Seti	Phoolbari	Ganga	Himalaya	28.23	71.83	582	1.65				43	3300000
Seti	Banga	Ganga	Himalaya	28.98	81.15	7460	9.52	0.384	2486	6085	200	19000000
Son	Conflunce	Ganga	Maikal	25.52	84.76	71200	31.80		325		189	50000000
Sunkosi	Kampughat	Ganga	Himalaya	26.87	86.82	17600	20.75	0.342	3026	8506	305	75900000
Tamor	Mulghat	Ganga	Himalaya	26.93	87.33	5640	10.19	0.351	2932	8220		41400000
Tons	Ichari	Ganga	Middle Mts	30.54	77.81	4913		0.368	2652	5414	152	913818
Tons	Ichari	Ganga	Middle Mts	30.54	77.81	4913	5.30					7924000
Trishuli	Betrawati	Ganga	Himalaya	27.97	85.18	4110	5.83	0.425	4349	6449	175	3400000
Yamuna	Tajewala	Ganga	Himalaya	30.29	77.43	9572	10.50			3700	189	18081508
Yamuna	Delhi	Ganga	Himalaya	28.67	77.23	28988	13.90			3700	351	26089200
Yamuna	Okhla	Ganga	Himalaya	28.47	77.40	30013	14.20			3700	405	28752454
Yamuna	Etawah	Ganga	Himalaya	26.77	79.02	81997	16.90			3800	675	8445691
Yamuna	Pratappur (Allahbad)	Ganga	Himalaya	25.45	81.83	345848	96.10			3800	945	64327728
Yamuna	Confluence	Ganga	Himalaya	25.45	81.83	366000	93.00		1200	3800	1026	125000000
Ganga	Hardwar	Ganga	Himalaya	29.97	78.15	95500	23.90	0.378	3045	7076	311	14000000
Ganga	Kannauj	Ganga	Himalaya	27.03	80.00	240000	39.50		1800	4800	702	15000000

Ganga	Allahabad	Ganga	Himalaya	25.50	81.72	358000	152.00		1500	4800	999	228000000
Ganga	Ghazipur	Ganga	Himalaya	25.34	83.35	399000				4800	1242	340000000
Ganga	Farakka	Ganga	Himalaya	27.83	87.91	648000	459.00		1200			729000000
Ganga	Calcutta	Ganga	Himalaya	23.79	98.45	750000	493.00		920	4800	1701	328000000
Ganga	Delta, B. D.	Ganga	Himalaya	23.79	98.45	1060000	445.00					1450000000
Ganga	Brahma Con’ce	Ganga	Himalaya	23.75	89.69	950000	460.00			6950	1782	520000000
Burhi Dihing		Brahmaputra	Naga Hills	27.25	94.92	5180				4900	162	3626000
LhasaHe		Brahmaputra	Tibet	29.40	90.55	6225				1000	864	249000
NyangHe		Brahmaputra	Tibet	29.27	88.21	6215						932250
Brahmaputra	Ganga Confl	Brahmaputra	Tibet	23.85	89.75	580000	630.00			4900	1600	540000000
Ganga/B’utra		GB	Himalaya	23.13	90.54	1648000	957.00	0.135	1406	5000	2430	1100864000
Irrawadi	Delta	Irrawadi	Hen’n/Ara’n	15.85	85.06	419000	416.00	0.148	745		2092	259780000
Burhi Gan’k	Rosera	Ganga	Himalaya	25.75	86.05	12500					500	28000000
Shakkar	Gadarwara	Narmada	Vindhya/Sat	22.56	78.50	2270	1.14				81	1781950

APPENDIX VII

Gap-Filling Studies – Pakistan

Abstracts of Papers presented at the 32nd International Geological Congress, Florence (based on gap-filling studies)

Contents

Recent Changes in the Coastal Evolution of the Indus River Delta and Impacts from Human Activities

Inam Asif [1], Amjad Shahid [1], Danish Mohammed [1], Tabrez Ali Rashid [1], Tabrez Syed Mohsin [1]
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Abstract

The Indus River is one of the major river systems of the world and the principal contributor in the creation of the Indus Fan - second largest sediment body in the ocean basins, totalling ~5 x 106 km3. Seasonal and annual river flows in the Indus River system are highly variable. The largest flow of the Indus occurs between June and late September, that relates to the summer monsoon season, at which point the snow melt (from the mountains) increases the discharge of water along with the eroded sediments. The waters are used primarily for irrigation of agricultural crops; dams have been constructed to provide flood control and hydroelectricity.

The construction of the barrages and the link and irrigation canals has, over the years, led to a systematic abstraction of water from the Indus. The overall impacts of man-made changes in the Indus River system are best observed downstream Kotri Barrage where prior to the Kotri barrage there were no days without water discharge. The present situation is much more alarming due to below average rain fall in the Indus River catchment area as there are only two months (August-September) in a year when Indus flows downstream Kotri Barrage. As a consequence, the river south of Kotri shows increased braiding and sand bar development. Sediment passing down the system tends to be deposited in the section below Kotri, rather than maintaining the growth of the delta. This has increased the risks of high flooding, and clear channels to the delta must be maintained through releases of flushes of water.

Consequently, there has been intrusion of sea water upstream of the delta - at places extending up to 75 km in the coastal areas of Thatta, Hyderabad and Badin districts. The twin menace of almost total absence of fresh water in the river downstream of Kotri and heavy sea water intrusion from the delta has destroyed large areas of prime agricultural land, including submersion of some villages in the coastal belt of these districts - causing desertification and displacement of several hundred thousand local residents who had been living there for many generations. An extreme level of wave energy and little or no sediment contribution from the Indus River is transforming the Indus delta into a true wave dominated delta and development of sandy beaches and sand dunes along the former deltaic coastline is underway.

Distribution of Clay Minerals and Trace Elements in the Indus River System

Tabrez Ali [1], Inam Asif [1], Danish Mohammed [1], Rehman Shafiq [2], Haq Rehan [3], Siddique Azher [4]
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2 - Environmental Sciences, University of Peshawar, Peshawar
3 - Geological Survey of Pakistan, Geoscience Laboratory, Shazad Town, Islamabad
4 - Chemistry Department, Karachi University, Karachi

Abstract

Geological environment influenced the Indus River system since Miocene time, recently constructed dams forced to change the course of the river and diverting the river water for irrigation purpose have resulted in the drastic reduction of sediment and water discharge of River Indus into the Arabian Sea. The Indus River system draining the Himalayan mountains has been the dominant supplier of sediments to the Indus Fan. The Indus River is about 2900 km long. The river travels a distance of about 1200 km in the plains before it join the Arabian Sea. Terrigenous materials eroded from High Mountain ultimately deposited in the deltaic region and finally reached into the Arabian Sea.

Generally, quartz, albite and muscovite are the common minerals with the exception of clinochlore, anorthite sodian in the coarser river sediments. Illite, chlorite and montmorillonite are the common clay minerals.

Concentration of heavy metals in the river sand and fine-grained deltaic sediments are are dominated by Mn (ranging from 47.43-370.90 ppm), Fe ranges from 2599.26-5137.44 ppm, Cu ranges from5-26.32 ppm, Zn ranges from14.51-46.38 ppm, Cr ranges from 10.7-30.70 ppm, Ni ranges from 11.26-123.56 ppm and Pb ranges from 4.2-13.52.

Natural and Man Made Stresses on the Stability of Indus Deltaic Eco Region

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Abstract:

The seawater intrusion has resulted in tidal intrusion in the prime agricultural land in the Indus Deltaic region. Extensive use of fresh water for irrigation in recent years has caused a decline in the down stream discharge of the Indus River. Construction of barrages, dams, and link canals has further reduced the freshwater flow downstream Kotri Barrage from 146 MAF/year to less than 10 MAF/year in the Northeast monsoon period practically zero discharges. As a consequence, the river below Kotri shows increased braiding and sand bar development. Sediment passing down the system tends to be deposited in the section south of Kotri, rather than maintaining the growth of the delta. As a result the Indus Delta that used to occupy an area of about 6,180 km^2 consisting of creeks, mudflats and mangrove forest is now reduced to 1,192 km^2 since the construction of dams and barrages on the Indus River.

The analysis of historical tidal data shows that Pakistan coastal sea level has risen in the same way as the global sea level due to global climate change. Besides eustatic sea level rise, the dominance of local factor like subsidence of land may be a catastrophe for low-lying areas. There are no direct measurements available on subsidence rates in the Indus deltaic creek system. However, as observed in other deltas (e.g. Ganges delta) the lack of sediment flux in the Indus delta must have increased the subsidence rate. Indus Delta could experience a relative sea level rise of up to 8-10 mm/yr as per the projected rate of global component of sea-level rise of up to 6 mm/yr in the next century. If the present trends continue the Indus Delta will ultimately establish a transgressive beach dominated by aeolian dunes, due to lack of sediment inputs and high energy waves (Haq, 1999). Ground investigation and the interpretation of satellite imageries indicate increased erosion of Barrier islands southeast of Karachi. Assessment of past and present findings indicates an alarming increased in the erosion rates of these Islands since the 1980's resulting in destabilisation of sediments in older Indus Delta. To mitigate the impacts of rising ground water and associated problem of water logging and salinity, a network of drainage canals was constructed down in the Indus Basin to drain saline ground water into the Arabian Sea. The drainage system has been less effective due to low gradient/flat topography and it has in fact resulted in the seawater intrusion into the link canals up to about 80 km upstream.

The man made changes coupled with natural physical forcing in the Indus delta and adjoining area will conspicuously change the geomorphic and hydrodynamic setting of the delta, that may result in the associated changes in the prevailing physical processes, which in turn will have a negative influence on coastal resources, communities, infrastructures, industries, ecosystems and habitats and socio-economy of the area.

APPENDIX VIII

Gap – Filling Studies – Sri Lanka

Contents

Physical Processes and Water Quality of Batticaloa Lagoon.

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Crow Island, Colombo 15, Sri Lanka

1 Introduction

The Oceanography Division along with Environmental Division of the National Aquatic Resources Research and Development Agency (NARA) and Eastern University conducted an extensive field investigation in Batticaloa Lagoon to identify the gaps to be filled for the successful completion of the Asia-Pacific Network for Global Change Research (APN) project titled "An assessment of nutrient, sediment and carbon fluxes to the coastal zone in South Asia and their relation ship to human activities". The study, submitted here, exclusively reports on the "Field investigation of the physical processes and water quality of Batticaloa Lagoon" conducted by the Oceanography Division of NARA. It primarily focuses on the measurement of bathymetry, water level variation, salinity and temperature distribution in Batticaloa Lagoon and evaluates the flushing mechanism, residence time and water exchange of the lagoon.

2. Study area

The eastern province, well known for its beaches, is undulated with Vaharai, Valachchenai and Batticaloa Lagoon. The Batticaloa Lagoon, largest among the three in the Eastern Province, lies on the central part of the eastern province, while the other two lagoons are found north it. The All the three lagoons are the type of *coastal plain estuaries* (in accordance with Pritchad (1952) classification), formed either due to land submergence or due to sea level rise. The Valachchenai Lagoon is a typical example of earlier river, which was flooded during the Holocene sea level rise, while the Batticaloa Lagoon shows characteristic features of *bar built estuary*, an indication of high rate of siltation.

The Batticaloa Lagoon is 57 km long and reaches its maximum width at the northern head (Fig.1). The wider northern and narrow southern lagoon opens into the sea by an even narrower channel at Palameenmadu. Vinobaba (1996) reported that the lagoon has a maximum depth of about 27 m. In entity, the lagoon, third largest in Sri Lanka spreads over an area of area of 115 km^2 (Jayasingham, 2000). In addition to the northern mouth at at Palameenmadu, the lagoon opens at southern end in Kallar. The southern mouth is seasonally closed, northern mouth is almost kept open throughout the year, though its width varies seasonally. The lagoon, located on the northeast monsoonal regime, receives about 1500 mm of precipitation annually. It receives freshwater from about 19 tanks, five major lakes, eleven rivers and streams and numerous irrigational channels (Shanmugapriyan, 2001). The eastern bank of the lagoon is extensively inhabited, while the western borders encompass extensive irrigated paddy field. The study here is restricted to the northern part of the lagoon (Fig. 2), which supports extensive shellfish fishery. Seasonal fish mortality is reported on this part of the lagoon, indicating poor flushing and water exchange.

3 Measurements

Hydrographic surveys for salinity and temperature distribution in Batticaloa Lagoon were conducted during the period from October 8 to 10, 2003. The period coincides with Second Inter Monsoon (SIM), which is almost the end of the continued dry period. The SIM is followed by the Northeast Monsoon, which brings more than 75% of the total annual rainfall to the study area.

Fig.1 Batticaloa Lagoon

In total, nine locations (see Fig. 2) were occupied for water-sampling. The salinity and temperature were measured at the nine locations using Aanderaa Digital Salinometer (Fig. 3a). The surface and bottom salinity were measured at surface and bottom on 09.10.2003, while middle water was sampled on 10.10.2003. The surface and bottom measurements were made at least 20 cm below the surface and above the bottom respectively. An Environmental Monitoring System (EMS), capable of recording temperature and salinity at 10 minutes interval were installed at Locations I and II (see Fig. 2) from October 08-11, 2003. Both Digital Salinometer and EMS are of Aanderaa type, the specification the instrument is given on Table. 1. Further more, horizontal variation of conductivity, temperature and depth CTD) recorder of SBE 19plus SEACAT profiler is used to record the horizontal distribution above mentioned parameters. However, the data is being processed, thus not included on this report

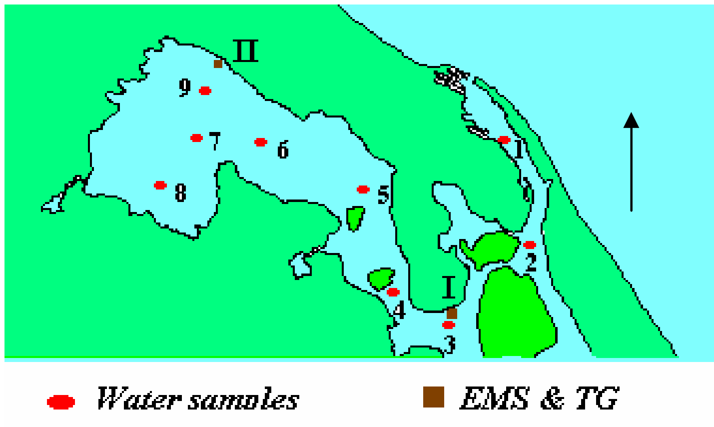

Fig.2. Sampling locations

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Table. 1. Salinity-Temperature sensor (Aanderaa 3010) specifications

Parameter	**Range**	**Accuracy**	**Resolution**
Salinity	0 - 40(60) PSU	$\pm$0.2 PSU	0.04 PSU
Temperature	-7.5 -+41^{o}C	$\pm$0.1 ^{o}C	0.05 ^{o}C

A Micro Tide Gauge (Fig. 3b) manufactured by Coastal Leasing was installed at Location I, along with the EMS. Thus, simultaneous salinity, temperature and sea level variations were recorded at Location I. The specification of the tide gauge is given on Table. 2. The instrument possessed an additional capability of measuring temperature.

Fig.3a Salinity-temperature sensor (Aanderaa) in recording mode equipped with data

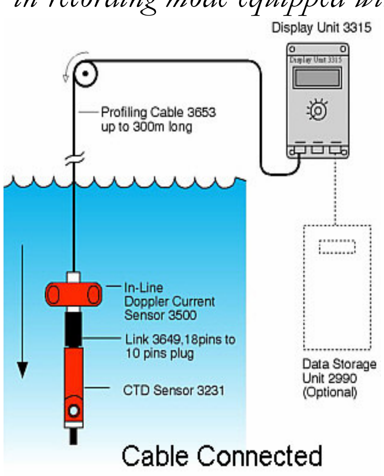

Fig. 3b Recording tide gauge (MicroTide, Coastal Leasing)

An extensive bathymetric survey was conducted during the survey period (October 9-10, 2003) using a Raytheon Echo Sounder (Model: DE-719 CM). The positioning of the sounding was obtained using a hand held Global Positioning System. In total twelve12 bathymetric lines were run on zigzag pattern, in addition to the bathymetric line run along the middle of the lagoon.

Table. 2. Tide gauge sensor specifications (MicroTide- Coastal Leasing).

Micro Tide Gauge	Range	Accuracy	Resolution
Pressure	0-18 psia or 0-25 psia	0.01%	0.01 psia
Temperature	-8 to 40^{o}C	$\pm$0.1 ^{o}C	0.1 ^{o}C

4 Results

The data from bathymetric survey and hydrographic sampling for physical parameters of the Batticaloa Lagoon are summarized here. The observations and results are to be used d to identify the major mechanism of flushing and water exchange of the lagoon.

Bathymetry:.

The (northern sector of the) Batticaloa Lagoon opens into the sea at Palameenmadu by a narrow channel. The mouth is about 260 m wide. In combination, the surface area of the channel and the lagoon amounts to about 55 km^2. The channel is 8.8 km long and 600 - 800 m wide. The lagoon is 12.5 km long and its width varies from 2.5 to 5.5 km. The maximum depth of channel and lagoon are 4.8 and 2.5 m respectively. The channel is about 4.5 m deep at the middle and reaches about 3 m closer to the banks. The depth, where the channel open into the lagoon, is about 3 m at the middle and reduces to one meter closer to the banks. In general, the average depth of the lagoon reduces from mouth to head of the lagoon. The depth is about 2 m at the middle of the lagoon, while closer to the head it reduces to about 1.75 m. The cross sectional depth variation at the middle and head of the lagoon is small. The detail bathymetric contour map is being prepared.

Salinity:

The salinity measurements from the water sampling locations indicate that the lagoon salinity is well below the sea salinity. The observations conducted on 09.10.2003 and 12.02.2003 are given on Table 3a and 3b respectively. The measurements represents the period just prior and after the northeast monsoon (rainy period). The mean salinity of the channel (Loc 1 a-2) is about 28.06 and 26.92 during the first (dry season) and second survey (wet season) respectively. It clearly indicates that invariant to the amount of the freshwater supply, the salinity at Loc. 1-2 do not vary very significantly. This is a typical phenomenon of tidal mixing. Inside the lagoon proper (Loc. 5-9), the salinity varies from 12 to 1 psu in between the two surveys. The vertical salinity profiles of CTD indicated, the channel is stratified at least during the neap tide.

Table .3a Salinity on 09-10-2003

Loc	Sur	Mid*	Bot
1	28.65	-	28.84
2	26.56	-	28.19
3	21.03	20.54	22.35
4	17.56	18.69	18.47
5	12.13	14.36	12.97
6	12.45	14.35	12.95
7	12.78	13.05	12.93
8	12.55	12.83	12.77
9	12.88	13.62	12.88

Table .3b Salinity on 12-02-2004

Sur	Bot
28.63	29.38
24.4	25.29
3.00	3.34
3.20	3.22
3.03	3.06
1.15	1.16
1.14	1.15
0.5	0.50
0.88	0.88

Sur- Surface, Mid-Middle, Bot-Bottom
*Measured on 10-10-2003

In Table 3a, the middle water salinity is measured one day after the surface and bottom measurements. The measurements are undertaken such way that they would be in opposite phase of tidal cycle. The second day measurements (i.e the middle water salinity), is slightly higher than the first day measurements. An indication enhanced mixing, generally could be attributed to tidal mixing. However, it is proved under the section "Tide" that the channel is efficient enough to completely eliminate the tide before reaching the lagoon proper. Furthermore, it is proved that a continuous net inflow of sea water gradually raises water level of the lagoon during the three days survey period. The Loc 7-9, located almost on a cross section at the head, indicates a horizontal salinity variation. The salinity at the middle section (Loc 7) is slightly lower than the salinity value closer to the west (Loc. 8) and east bank (Loc. 9).

The Fig. 4 compares the salinity recorded at ten-minute interval on Loc. I and II. The salinity at Loc. I and II on the commencement of measurement is about 20 psu and 11.5 psu respectively. At Loc. I salinity increases at a rate of 1 psu per day, though Loc. 2 too the salinity shows similar pattern, the total raise in salinity during the entire period is less than 0.2 psu.

Temperature:
The temperatures at the water sampling locations during the first and second surveys are given on Table 4a and 4b. The mean surface and bottom temperature during the first survey is 32.6 and 32.2^{o}C respectively, while during the second survey it is reduced to 28.5 and 28.7^{o}C respectively. The temperature difference between the dry and wet season

is 4.1°C . The other notable feature is that the mean surface temperature is slightly higher (0.4°C) than the mean bottom temperature during the dry season, while the order is reversed and magnitude is lesser (0.2°C) during the wet season.

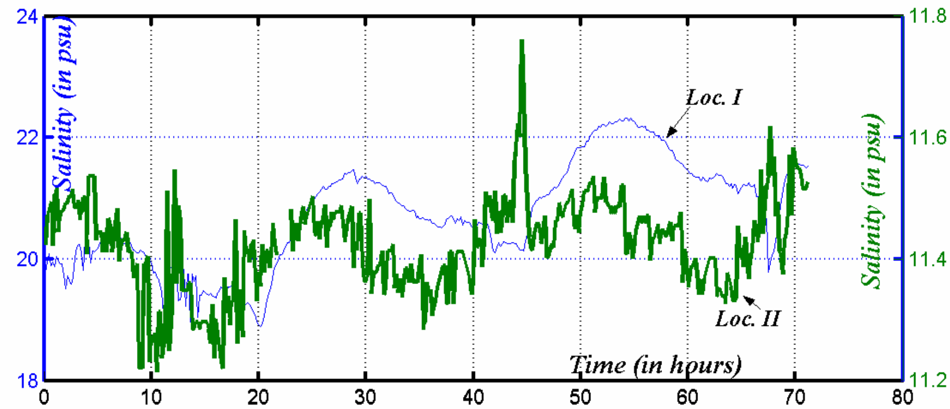

Fig.4 . Comparison of salinity at Loc. I and II. (First and last measurements represent 12.15hrs on 08-10-2003 and 16.05hrs on 11-10-2003 respectively.)

The Fig. 5 compares the temperature recorded at ten-minute interval on Loc. I and II. The night and day temperature fluctuates in between 28 and 35°C. The average diurnal temperature variation (due to the solar radiation) amounts to 6°C, typical for tropical waters. The temperature fluctuation at Loc. I is slightly higher that at II, most properly due to variation on the deployment depth of the temperature sensor.

Loc	Sur	Mid*	Bot
1	30.59	-	30.62
2	32.14	-	31.97
3	32.01	32.62	32.08
4	33.02	32.09	32.57
5	32.98	33.47	32.70
6	32.36	32.63	31.88
7	33.95	31.87	33.53
8	32.80	31.63	31.90
9	33.93	31.77	32.56

Table .4a Temperature (in °C) on 09-10-2003

Sur	Bot
28.79	29.05
28.17	29.22
28.75	28.74
28.31	28.41
28.32	28.35
28.45	28.37
28.46	28.42
28.66	28.61
28.82	28.83

Table .4b Temperature (in °C) on 12-02-2004

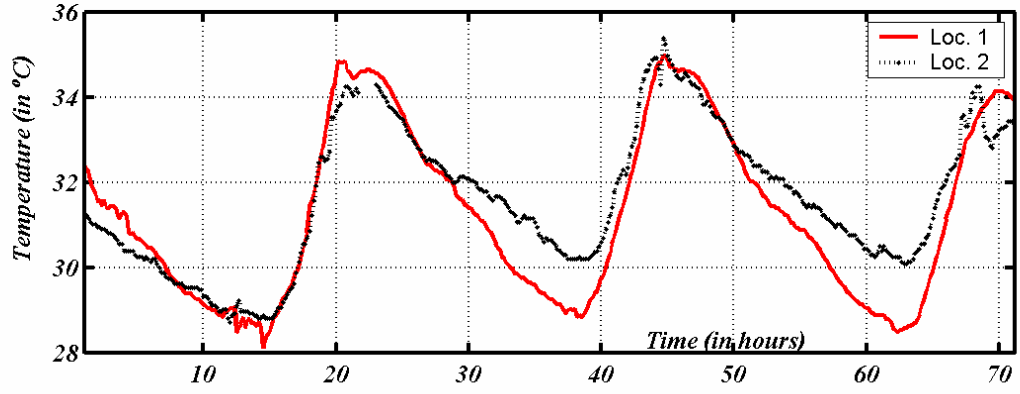

Fig.5 . Comparison of Temperature at Loc. I and II. (First and last measurements represent 12.15hrs on 08-10-2003 and 16.05hrs on 11-10-2003 respectively.)

Tide:

The water level variation recorded at 10 min interval is compared with the salinity fluctuation at the Loc. I on Fig. 6. The mean diurnal water level variation is about 6 cm. It shows a long-term tendency for rising water level. The water level has increased by about 1.5 cm within the three days period. The diurnal water level fluctuation of 6 cm corresponds to diurnal air pressure variation. Thus, it indicates that the astronomic tide is unable to reach even the Loc. I., which is almost the end of the channel and the beginning of the lagoon proper.

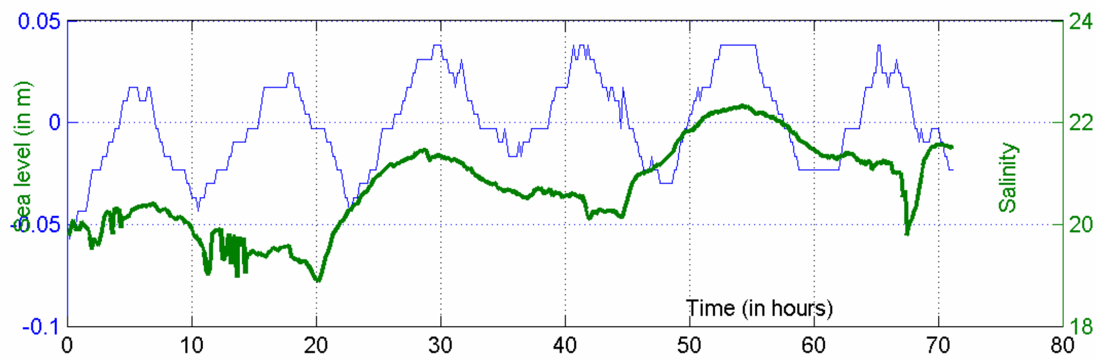

Fig.6 Comparison of sea level and salinity variation at Loc. I. (First and last measurements represent 12.15hrs on 08-10-2003 and 16.05hrs on 11-10-2003 respectively.)

5. Discussion and Conclusion

The Batticaloa lagoon is reportedly served as the main seaport for the trade in 19th century. Vinobaba (1996) and Selvadurai (1997) indicated that the average depth of the lagoon is 27 m, however our bathymetric survey on the northern lagoon shown that the depth may not exceed 5 m. The siltation rate could be significantly high on this type of coastal plain estuaries, however it seems that the earlier values are bit exaggerated. The hydrography measurement of the two surveys, which falls into the extremely varying season, indicates that the lagoon may remain as normal estuary throughout the year. The tidal influence is negligible (may be 1-2 cm) even at the starting point of lagoon proper. However, there is an increase in mean sea level at Loc. I by 1.5 cm during the survey. It indicates a net inflow of water, most properly induced by the high water level of the open sea.

The constant salinity invariant to the seasons at the channel indicates that the channel water is well exchanged with the open sea by the tide. The channel has shown a tendency for stratification, which is a precondition for efficient flushing. The shallow goon is vertically homogenous, most properly due to the convectional mixing. The tide being filtered out by the channel, the gravitational circulation could be the only mechanism to exchange the lagoon water with the open sea. However, except during the Northeast Monsoon (November to February), the freshwater discharge could be very minimal. Thus, the diffusive exchange could be the only mechanism, which could operate during the dry season. It indicates the lagoon may be flushed during the west season only. This means that water quality would be continuously diminished till the arrival of the Northeast Monsoon.

6. Future work

The results of the preliminary studies are provoking, thus a monthly survey was commenced by the NARA from January 2004. The study is to be extended for a period of at least one year, during which DO, BOD, Chlorophyll, zooplankton, salinity, temperature, etc. to be monitored on the hydrography stations, while EMS are installed at Locations I and II (Fig. 2).

7. References

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Three-dimensional Hydrodynamic Modelling of Sri Lankan Estuaries and Lagoons using the Estuary Lake Computer Model (ELCOM)

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Introduction

The hydrodynamic processes in lagoons and estuaries are complex. The fluid flow can vary from weakly to highly nonlinear, due to complex bathymetry and a wide range of temporal variation of the forcing functions. Therefore, a large number of spatial and temporal observations are essential in order to understand the hydrodynamics of these systems. Hydrodynamic models can be used to interpolate the temporal and spatial gaps in the field data, since they allow great resolution in time and space. Thus, there is a general step from analytical to numerical modelling where the numerical solution is used basically when there are no longer analytical solutions available or when looking for higher resolutions in time and space.

Hydrodynamic numerical models are not only used to describe the present physical environment in coastal water bodies, but also to predict changes in hydrodynamics resulting from future changes in bathymetry, freshwater inputs and climate. The models are used as an aid in developing management strategies to increase water exchange by deepening of inlets or re-opening of sandbars. At best, models may also lead to an advance in the conceptual understanding of the various processes involved in the dynamics.

This report summarises the training on three-dimensional estuarine modelling undertaken at Centre for Water Research, University of Western Australia, Perth, Australia during 10 November to 7 December 2003, by E.M.S. Wijeratne of National Aquatic Resources Research and Development Agency. The primary objective of the training programme was learning of three-dimensional hydrodynamic modelling in Estuaries. CWR has provided training of Estuary Lake Computer Model (ELCOM). During training, ELCOM was applied in to several Sri Lanka Lagoons (Putalam, Negombo and Jaffna Lagoons). This report summarises the numerical modelling in estuaries using ELCOM and application to Sri Lanka Lagoons.

Numerical modelling in estuaries using ELCOM

The numerical models for estuaries and lagoons are based on finite difference representations of hydrodynamic equations. They vary from fully explicit to fully implicit. However, the model performance is a key factor in addressing long-term transport of properties. The computational efficiency in explicit models is much lower compared to that of implicit models. On the other hand, an implicit model formulation is more complicated compared to an explicit one. Thus, semi-implicit (partly implicit and partly explicit) numerical approaches are commonly used to solve the equations (e.g. Alternating - Direct Implicit). Estuary Lake Computer Model (ELCOM) solves the unsteady Reynolds-averaged Navier - Stokes equations using a semi-implicit method similar to the momentum solution in the TRIM (Casulli and Cheng, 1992) code with the addition of quadratic Euler - Lagrange discretization, scalar (eg., temperature) transport using a conservative flux-limited approach, and elimination of vertical diffusion terms in the governing equations. In general ELCOM is a three-dimensional hydrodynamics model for lakes and reservoirs, and is used to predict the variation of water temperature and salinity in space and time. In this training programme, the ELCOM was applied into Sri Lanka Lagoons with tidal forcing including other meteorological and hydrological forcing.

Preparation for ELCOM

ELCOM source code is written in Fortran 90 (with F95 extensions) and it can be compiled in varies operating systems; Digital on Unix, Lahey (LF95) v6.0 on Linux, Lahey (LF95) v5.6 on Win32 and Absoft Pro Fortran on Mac OSX. Unix system was used to run the model during my training at CWR, however currently (in NARA) I am using Linux system for ELCOM implementation.

Following directory structure was used for installation of source code files, data files, configuration files and out put files.

<table>
<tr><td rowspan="6">ELCOM</td><td rowspan="2">SOURCE</td><td>PRE</td><td>Pre-processor source code files</td></tr>
<tr><td>ELCOM</td><td>ELCOM source code files</td></tr>
<tr><td>BIN</td><td colspan="2">Executable files; elcom.exe, pre_elcom.exe and db2nc.exe</td></tr>
<tr><td>BATHYMETRY</td><td colspan="2">Bathymetry file, boundary condition bc.dat file and the run_pre.dat file that is a text file that contains the names and location of user-supplied input files and pre-processor output files.</td></tr>
<tr><td>ELCOMRUNS
Within the directory contains run_elcom.dat and run_db2nc.dat files</td><td>INFILES</td><td>Input files for a simulation (ie. sparsedata.unf, usedata.unf, temporal boundary condition files, and datablock.db that is configuration data used to set up the users output)</td></tr>
</table>

	The run_elcom.dat configuration file controls execution of optional modules and models within ELCOM, allowing the user to set the parameters that govern the physical and numerical simulation. The run_db2nc file specifies the path directory for spf and nc files	TXTFILES	Out put txt file from ELCOM
		UNFILES	Out put unf file from ELCOM
		NCFILES	NetCdf format file after converting unf files from "UNFILES" directory

Application of ELCOM to Sri Lanka Lagoons

Several Sri Lanka Lagoons (Puttalam, Negombo and Jaffna) were used for ELCOM training demonstration.

Negombo Lagoon

Negombo Lagoon (Fig. 1) is located on the west coast of Sri Lanka. The lagoon covers a total area of 35 km2. Its length is about 10 km and the average width is 3.5 km. The mean depth of the lagoon is about 1.2 m. The lagoon is connected to the ocean by two parallel narrow channels. The channel located to the west is the main channel and is 2 km long and 150 m wide with an average depth of 2 m. The other one is more narrow (20 m) and shallow (1m). Two rivers namely Attanagalu Oya (Dadugama Oya) and Ja-Ela discharge into the southern part of the lagoon. The river discharge vary from 20 to 225 m3s-1 and also the major contribution comes from Attanagalu Oya exceeds 70% (Rajapaksha, 1997).

Puttalam Lagoon

Puttalam Lagoon is a large, shallow lagoon situated on the west coast of Sri Lanka (Fig 2). The lagoon is separated from the ocean by a 45 km long, permanent sand bar, which opens up in its northern end. The lagoon consists of several well defined basins and the width varies from 3 to 13 km. The surface area inside the Kalpitiya Narrows is 225 km^2, with a mean depth inside the narrows of 1.7 m at MSL. Puttalam Lagoon, which is situated rather far north in the dry season, receives rain during both seasons. The winds are moderate averaging 4-6 ms^{-1} during both seasons. During SWM, the maximum mean winds may reach 7-8 ms^{-1}(Wijeratne, 2003). The freshwater supply is dominated by two rivers, Kala Oya and Mee Oya. In addition there is a small seasonal supply through the Dutch Canal, which enters in the southern end. In the 70'ies mean river discharge was

$20 m^3 s^{-1}$ and $8 m^3 s^{-1}$, respectively (Amarasinghe et al., 1999). The long-term mean rainfall at Vanathu Villu and Puttalam Weather Stations is 1200 mm/year. The annual pan evaporation is about 1800 mm with values of 5.5 mm/day during the South West Monsoon (May to September) compared 3.5 mm/day during the North East Monsoon (November to February; Arulananthan, 2003).

Jaffna Lagoon

Jaffna Lagoon is the largest lagoon in Sri Lanka and is shown in Fig. 3. It is located in the northern part of the country. The surface area of this lagoon is about 410 km^2. There is no river discharge into Jaffna Lagoon. Sachthanathan and Perera (1970) conducted depth soundings using hand held line and it is the only bathymetry data available at present, other than the official navigational charts. The seasonal variation of salinity in the lagoon are influenced by the monsoon rains, and the salinity is low (28 psu) during NEM and high (37 psu) during SWM (Sachithananthan , 1969).

Model forcing data

In order to implement model on a lagoon, the bathymetry as well as initial and forcing boundary condition must be specified. Bathymetric data metrics were prepared according ELCOM requirements. For Puttalam Lagoon, 450 m grid mesh bathymetry data was digitised from a bathymetry map from Prerera and Sirieardana (1982) and NHO (1993). Recent bathymetric chart of Negombo Lagoon (NHO, 2002) was used to extract 50 m grid mesh data. Rough depth data was extracted from Jaffna Lagoon using Sachithananthan and Perera (1970) depth map.

Other necessary data such as open boundary condition, meteorological and hydrological data were obtained from measurements conducted during 1996 –1998 by NARA under coastal ecological programme. Table 1 and 2 shows the measurements used for the ELCOM model forcing. Measurement includes sea level, salinity, temperature, river discharge and meteorological data from weather mast data. The weather mast data includes solar radiation, net radiation, relative humidity, sun duration, air pressure, air temperature, win speed, wind direction, water temperature and salinity.

Table 1: Field data (during 1996) used in Puttalam Lagoon for ELCOM model application. Instruments locations are shown in Fig.1

Tide Gauges for sea levels and temperature				
Stn	*Period I*	*Period II*	*Period III*	*Period IV*
P-1	1 Feb -1 March	1 March – 6 May	6 May - 11 June	-
P-2	-	8 March – 6 May	11 May - 11 June	-
P-3	1 Feb - 1 March	-	-	-
P-4	-	8 March – 6 May	-	-
P-5	1 Feb - 1 March	-	11 May - 11 June	-

RCM for current measurements				
P-1	-	1 March – 12 April	9 May – 22 June	-
EMS Unit for salinity and temperature				
P-1	-	9 March – 25 April	-	-
P-4	-	-	20 May - 10 June	-
P-5	-	-	-	22 June–24 July

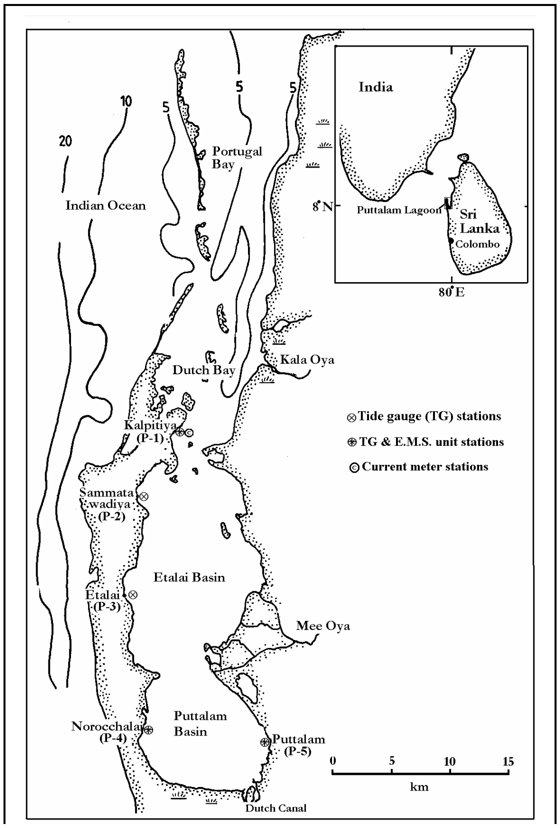

Fig.1: Puttalam Lagoon

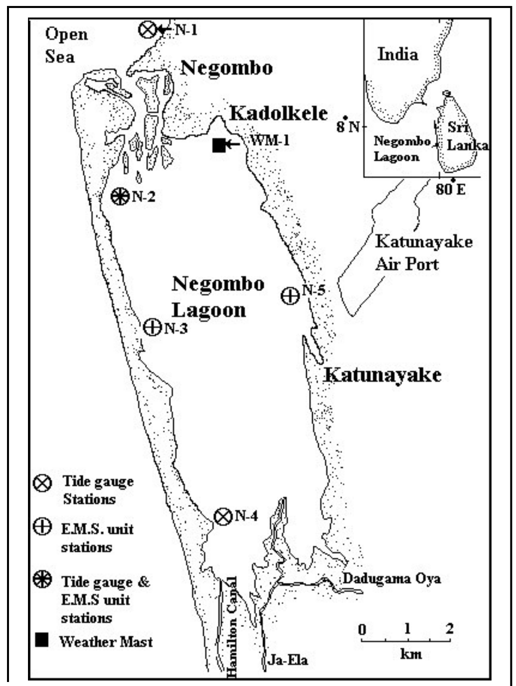

Fig.2: Negombo Lagoon

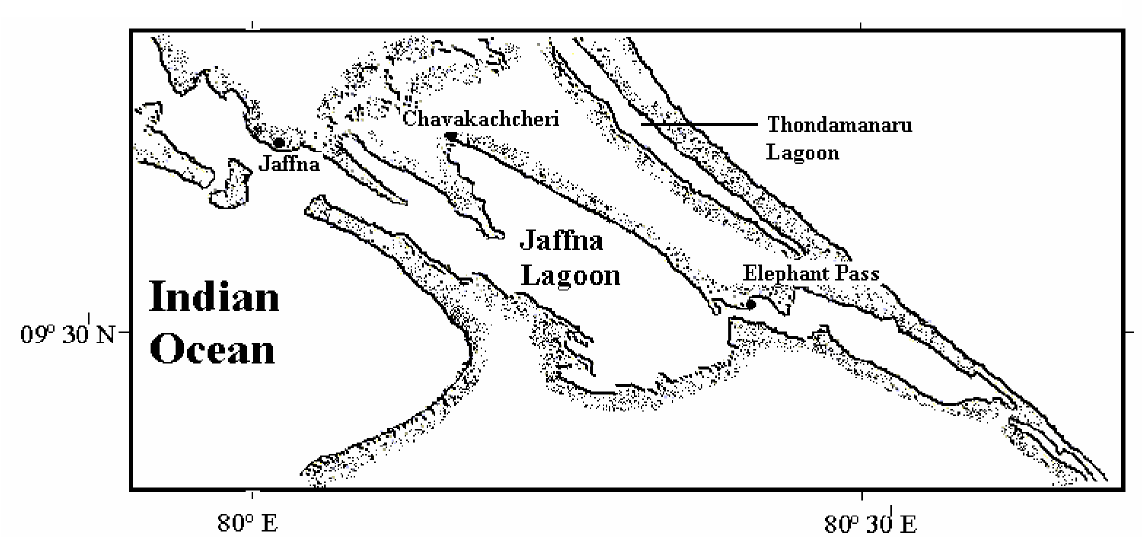

Table 2: Field data (during 1997-98) used in Negombo Lagoon for ELCOM model application. Instruments locations are shown in Fig.2

Station	N-1	N-2	N-3	N-4	N-5
Micro Tide	18 Dec. 96 to 27 Feb. 97	18 Dec. 96 to 03 Feb. 97		1 Jan. to 3 March 97	
EMS unit		4 March to 9 April 97, 2 May to 20 May 97, 28 May - 19 Sep. 97	18 Oct.- 4 Dec. 96 18 Dec. 96 - 16 Feb. 97		3 July - 19 Sep. 97
Weather Mast at WM-1 during 1997		15 Jan.- 22 Feb, 4 March –11 April, 7 May - 14 June, 3 July - 6 Aug. and 15 Aug.- 19 Sep.			

Model Simulations

ELCOM model runs were made with different forcing and boundary conditions. Observed sea levels, salinity and temperature measurements form open sea were used to specified open boundary condition. Brief results from ELCOM simulations in Puttalam, Negombo and Jaffna Lagoons are given in below section.

Model simulations for Negombo Lagoon

ELCOM model results of temperature and salinity vertical profiles at entrance channel are shown in Fig 4a and 4b.

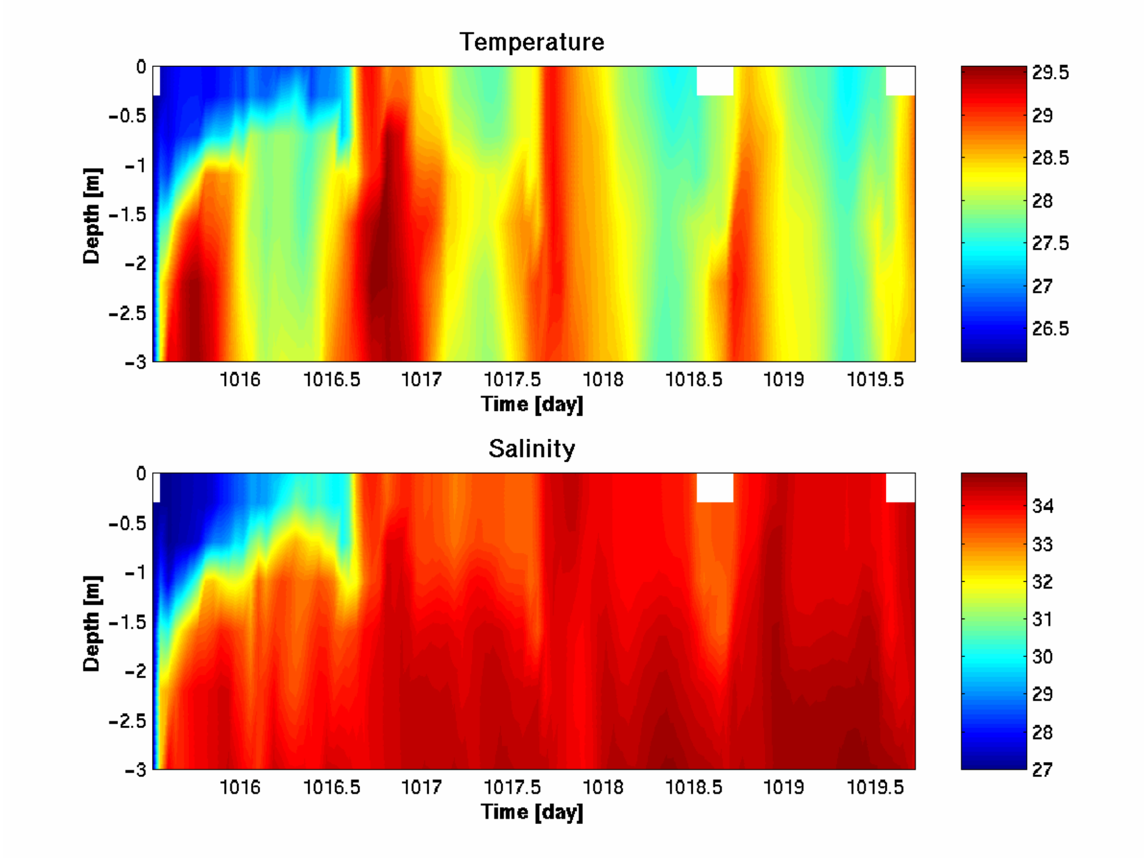

Fig. 4a-b: Modelled time series temperature (a) and salinity (b) profiles at Negombo Lagoon entrance (tidal forcing with river flow).

A model result of surface salinity variability with constant river discharge of 20 m3s-1 is show in Fig 5a. Corresponding bottom salinity is show in Fig 5b.

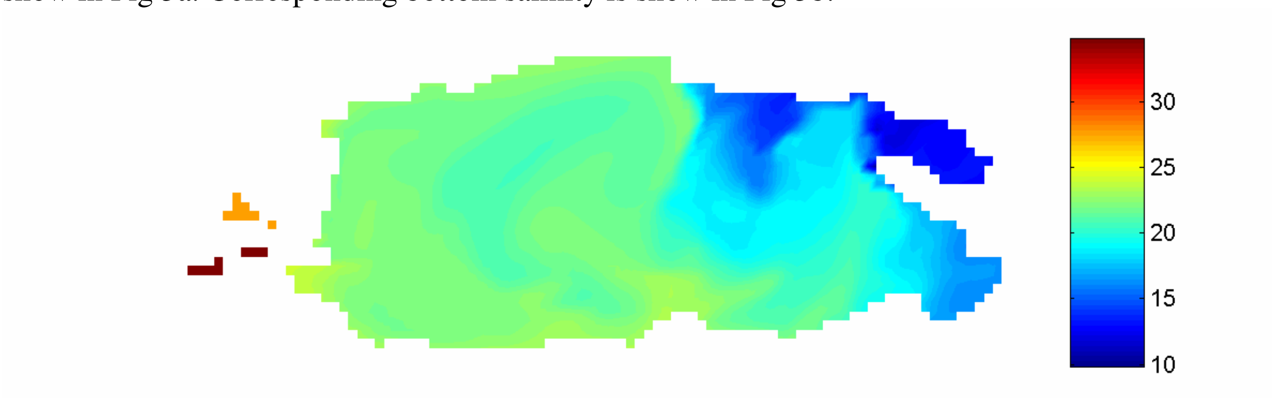

Fig 5a: Modelled surface salinity in Negombo Lagoon

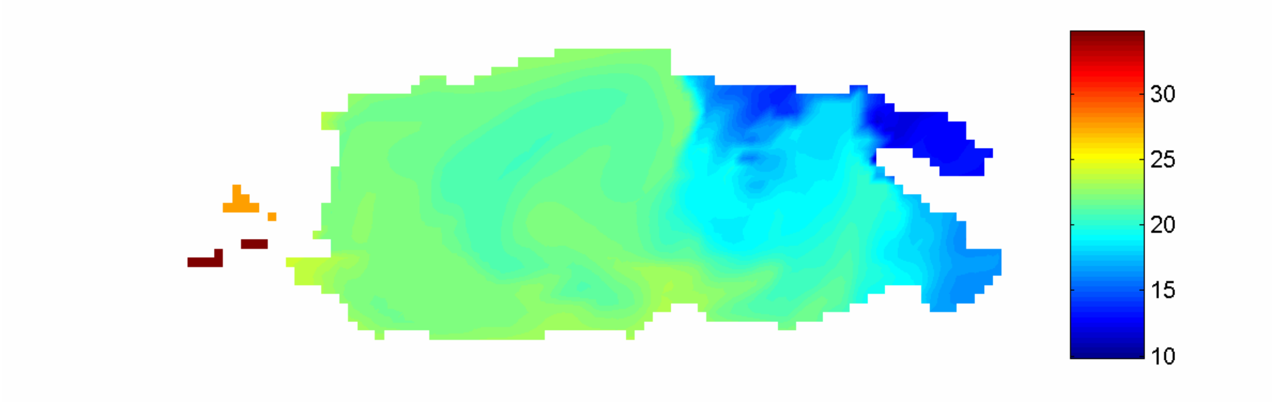

Fig 5b: Modelled bottom salinity in Negombo Lagoon

Example figure of model simulated wind driven circulation is shown in Fig. 5c.

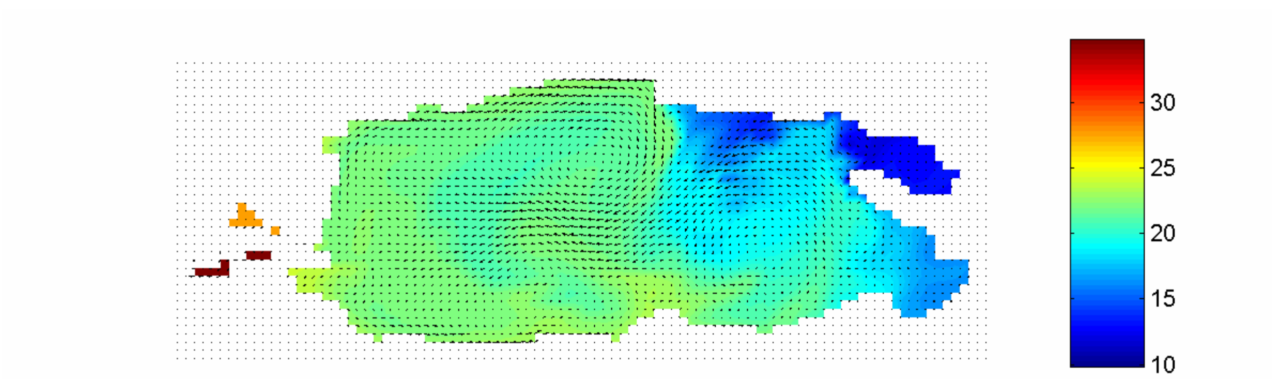

Fig 5c: Modelled wind driven circulation in Negombo Lagoon

Model simulations for Puttalam Lagoon

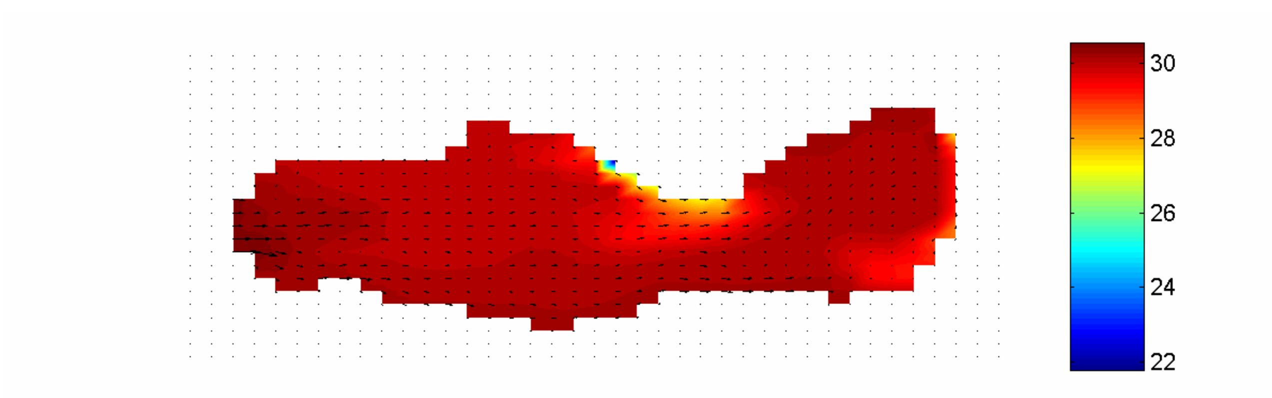

Fig 6a: Modelled surface salinity and tidal current during high tide in Puttalam Lagoon

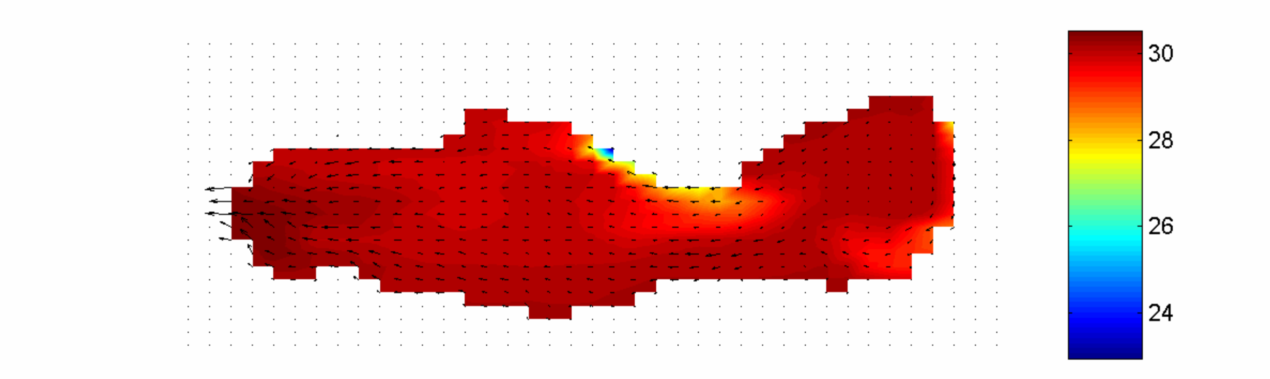

Fig 6b: Modelled surface salinity and tidal current during low tide in Puttalam Lagoon

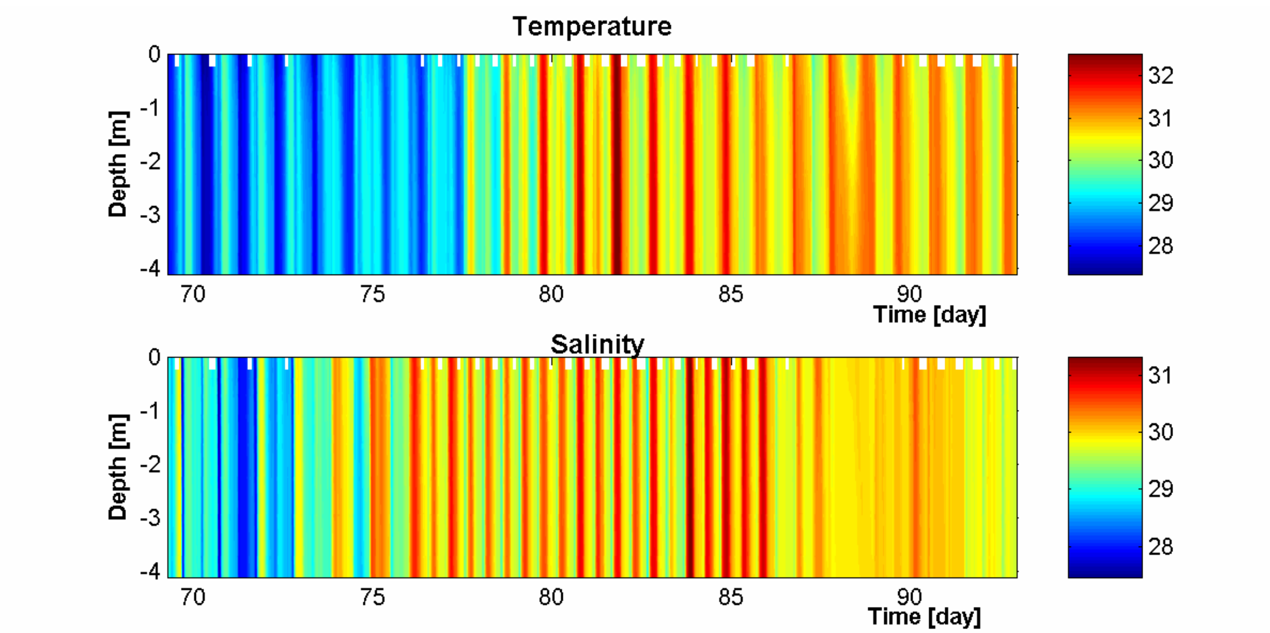

Fig 6c: Time series modelled salinity and temperature profiles at Kalpitiya Narrows in Puttalam Lagoon

Model results for Jaffna Lagoon

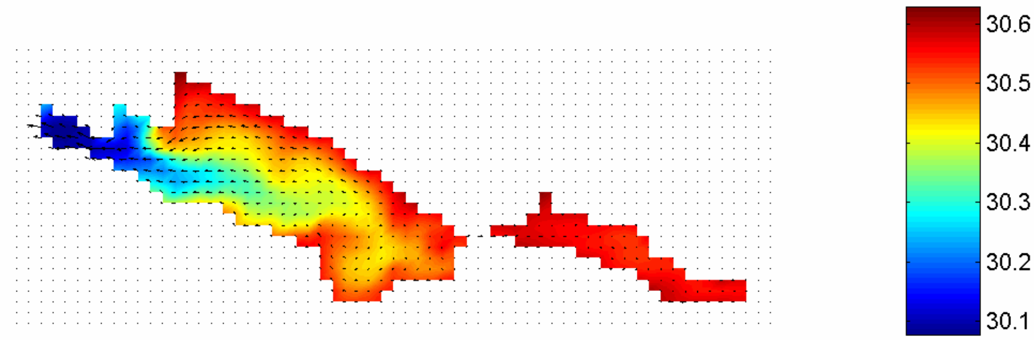

Fig 7a: Modelled surface salinity and tidal current during low tide in Jaffna Lagoon

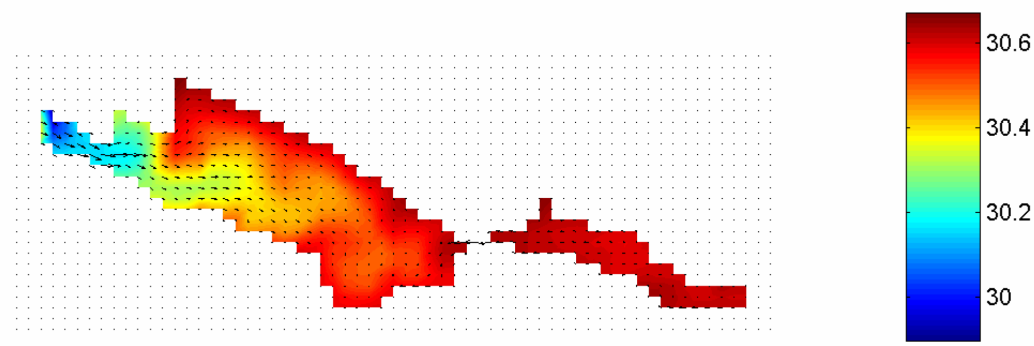

Fig 6b: Modelled surface salinity and tidal current during low tide in Jaffna Lagoon

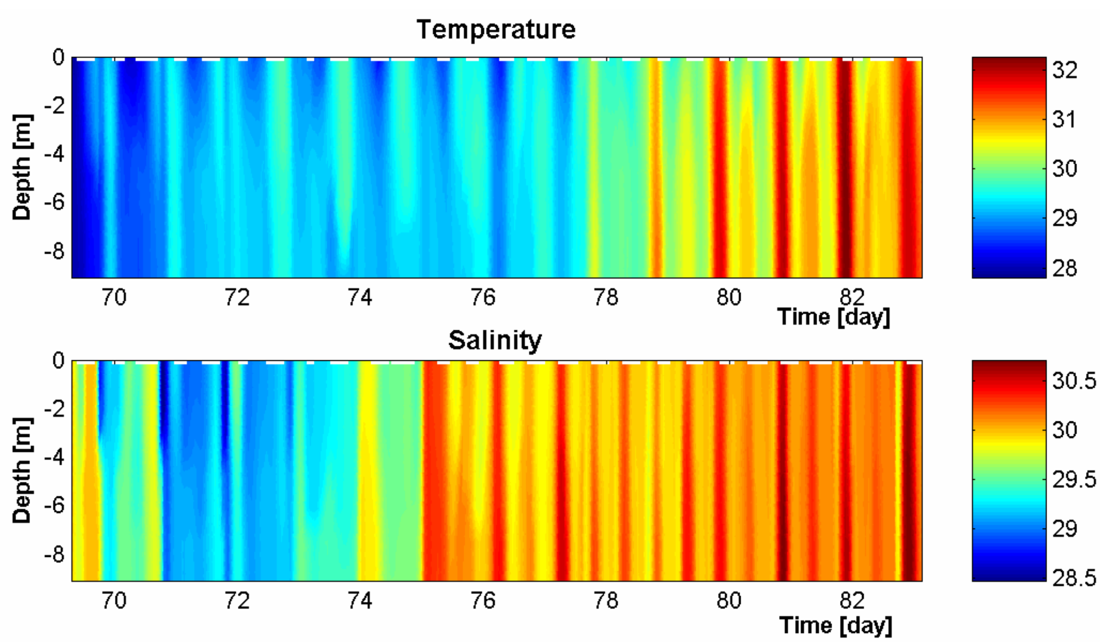

Fig 7c: Time series modelled salinity and temperature profiles Near Mouth in Jaffna Lagoon

Future Activities

- ELCOM application to Sri Lanka Estuaries and Lagoons
- Training will be provided on ELCOM to researchers who are working in Estuaries and Lagoon Processors
- Training workshop on ELCOM model application will be conducted on September 2004

APPENDIX IX

International Workshop on Marine Pollution and Eco-toxicology

February, 2004, Goa, India[1]

Extended Abstracts of Papers relevant to the Project presented at the Workshop and List of Participants

Contents

• [1] Workshop held to felicitate Dr Simon de Sousa on the occasion of his retirement on the 28th February.

Integrated Coastal and Marine Area Management (ICMAM) Plan for Goa

An Overview

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Introduction

Management of the Coastal Zone is one of the most complicated and difficult tasks. Several land and sea-based activities, like disposal of wastes from municipalities and industrial units, operation of ports and harbours, activities related to tourism and fishing industries, etc., are performed in this zone. These activities that are inter-related and inter-dependent, if planned in isolation, can have adverse impact on the ecology of the coastal zone. Severe degradation of the coastal water quality, loss of critical habitats like mangroves, coral reefs, loss of land due to soil erosion, are some of the examples of such impacts. Hence, management of the coastal zone in a coordinated manner by integrating several activities and planning and managing these activities according to their suitability for the type of coastal area, will help in sustaining the natural resources and protection and conservation of critical habitats, which in turn will help in the long-term economic growth of a country. Taking into consideration the above, and with a view to promote sustainable development of coastal resources of Goa and achieve balance between the environment and development, the Department of Ocean Development in collaboration with the National Institute of Oceanography, Goa, launched an extensive programme to prepare the framework for the Integrated Coastal and Marine Area Management (ICMAM) for Goa. The objective of the ICMAM Plan is to promote sustainable development of coastal resources, ensure protection and preservation of coastal areas and facilitate sustenance of economic growth in the coastal areas through integrated management of all activities.

The state of Goa occupies a narrow strip of land, about 105 km from north to south and 65 km from east to west. Mining and tourism are the main activities contributing to the economic development of the state. About 65,000 ha of land in Goa is covered by activities related to mining industry. Over 99% of the mineral ore produced in Goa consists of iron ore, the rest being manganese and bauxite. Mining and ore processing generate large quantities of rejects/wastes impacting the environment to varying degrees. During the last decade (1990-2000) iron ore production in Goa touched 156 million tones and waste generation 360 million tones. About 30-35 million tones of wastes are being added up annually, thus causing an acute problem of surface area for disposal of waste. This huge quantity of waste, aided by the undulating topography and the incidence of heavy rainfall (around 3000 mm annually) contribute to heavy runoff from dumps and siltation of low lying areas which include agriculture fields, nallahs, riverbeds and creeks, and cause high turbidity of stream water during monsoon.

The Study Area

With its unique scenic beauty together with rich cultural and aesthetic heritage, Goa has emerged as a major center both for domestic and international tourism. The industry has registered phenomenal growth from 2 lakhs tourists in 1955 to 12.44 lakhs in 1999 comprising of both domestic and international. Simultaneously, state's earnings from tourism sector in terms of foreign exchange earnings showed a steady rise of about 25% annually. Like any other industry, tourism also has its own inherent adverse impacts on the host country's ecology. These include:

- Social changes
- Generation of solid and liquid wastes
- Pollution of air and water including groundwater
- Exploitation of groundwater and its associated impacts on the neighbouring population's need for groundwater
- Impacts on forests including deforestation, loss of biodiversity, introduction of exotic species, etc.
- Impact on social life including introduction of exotic pathogens, destruction of traditional cultures, resources, drug trafficking, etc.

Preparation of ICMAM Plan for Goa involved the following aspects:

i. Identification of key issues and problems
ii. Analysis of key issues and problems to understand the nature and extent of the problem
iii. Development of Integrated Management solutions to solve each problem or to address each issue.

The Department of Ocean Development (ICMAM-PD) has identified the following key issues/problems:

- Mining of iron ore, transport and disposal of mine rejects, and its impacts
- Tourism development and its impact
- Socio-economic issues associated with mining, tourism and resource exploitation
- Impacts of hydrodynamic activities on coastal ecosystem

Data

The analysis of the first three issues was based mostly on the use of secondary data, while the last issue was based on the collection and analysis of hydrodynamic data of estuarine and coastal waters, on the following aspects:

Hydrodynamics

- **Bathymetry**. Bathymetric surveys were conducted in the estuaries (Chapora, Mandovi, Zuari and Cumbarjua Canal). Cross-sectional transects were run every 200m, and at each transect soundings were recorded at 10m intervals

- **Tide.** Simultaneous tide measurements were made during 3 phases – 2 dry seasons (April-May) and 1 monsoon season, by deploying tide poles and electronic (self recording tide gauges - *Valeport and* those made by *NIO*) at 13 locations covering the Mandovi and Zuari estuaries and the coastal waters. At each location tide elevations were recorded over a period of 1 month during each phase. Simultaneously, tide measurements were also made using a back-up tide pole and tide elevations recorded at 15 minutes interval.

- **Wave.** Measurement of waves was made by installing a directional wave rider buoy at a depth of 20m at a coastal location off Mormugao. The measurements were made during the 1st and 3rd phases (dry seasons) over a period of one month each.

- **Currents.** Measurements of currents were made simultaneously at all the 13 locations where the tides were measured, over a period of 15 days during phase-I and phase-II, while during the phase-III the measurements were made over a period of one month. Self-recording RCM-9 current meters were deployed on anchor-moorings at each location.

- **Beach profiles.** Ten base stations were established covering the entire Goa coast. Beach levels were measured with reference to a local bench mark at every 5m interval along the transect from backshore dune upto 1m depth. Zeiss Automatic level and graduated staff were used to record the beach levels. These levels were reduced to respective local bench mark. Nearshore profiles were also recorded upto a water depth of 8m, using Ceeducer.

- **Littoral environment observations.** Long shore current velocity and direction, surf zone width, wind speed and direction, breaking wave height, wave period and direction are the parameters measured during this study.

- **Sediments.** Surface sediment samples from the inter-tidal region close to the shore were collected at each station. The sediments were subjected to sieve analysis to study the grain size distribution. Similarly, seabed sediment samples were collected at 3 locations along each transect and subjected to Laser particle analyzer for clay particles analysis. Water samples from surface, mid-depth and bottom were collected at each location with water depth of 3, 6 and 10m to study the suspended sediment concentrations.

- **Longshore sediment transport rates.** Longshore sediment transport rates were estimated using Walton's equation (Walton and Bruno, 1989).

Water Quality

- Water quality measurements were made simultaneously at 24 stations covering the estuarine and coastal waters of Goa, using Coastal Research Vessels *Sagar Paschimi/Sagar Shukti* or fishing trawlers. At each location water samples were collected from surface (1m) and mid-depth (where the water depth >5m) at 3-hourly intervals over a period of 36 hours (Phase-I) and 24 hours (Phase-II & Phase-III). The water samples were analyzed for salinity, pH, dissolved oxygen, BOD, suspended sediment, nitrate, nitrite, ammonia, phosphate, total-N, total-P, total petroleum hydrocarbon, iron and manganese.

- **Sediment Quality.** Surface sediment samples were also collected at each location once during each phase and analyzed for total petroleum hydrocarbons, iron, manganese, cadmium, lead and mercury. Standard methods of analysis were followed for the above analysis of water and sediment.

Biological measurements

The following biological measurements were made at all the 24 locations where water quality measurements were made:

- **Chlorophyll *a* and phaeopigments.** 3-hourly measurements for 36 hours (phase-I) and for 24 hours (phase-II & phase-III) were made at surface and mid-depth.

- **Primary productivity.** Two samples each from each station were collected during daytime and incubated *in situ* for the PP measurements.

- **Phytoplankton and Zooplankton.** One sample each during low tide and high tide were collected for qualitative and quantitative measurements.

- **Benthos.** Sediment samples were collected at each station once during each sampling session, for measurements of benthic fauna (qualitative and quantitative).

Microbiology

- **E.Coli & Faecal coliforms.** Water samples from each station were collected at 3-hourly intervals and analysed for the presence of the E. Coli & Faecal coliforms. Similarly, sediment samples from each station were collected once during each sampling session and analyzed for the above parameters.

Important findings:

The distribution of salinity in relation to tidal height in Mandovi estuary during the monsoon and dry seasons is shown in Fig.1. It is clear from the Fig. 1(a) that the salinity in the estuary increases with the progress of tide. Highest salinity was observed during the high tide while during the low tide almost the entire estuary was freshwater dominated. During the dry season, however, the tidal influence on salinity is minimum as seen in Fig. 1(b) as the entire estuary showed high salinity.

The effect of tides on the dissolved oxygen distribution in the estuary is shown in Fig. 2(a&b) that during the ebb tide low salinity water brings in river water rich in dissolved oxygen content, while the high salinity seawater entering the estuary during the flood tide has lower concentration of dissolved oxygen leading to decreased levels of oxygen in the estuary.

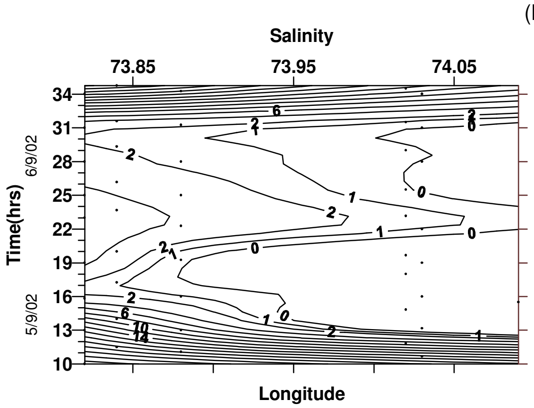
The influence of tide on the distribution of nutrients in the estuary is shown in Figs. 3&4. Fig. 3(a) shows that during monsoon, the nitrate concentrations increase towards the upstream region indicating that the river water entering the estuary is rich in nitrate-N. This high nitrate is probably derived from the fertilizers used in the agricultural lands lying in the river basin. Apart from this other sources for the high nitrate during this season may be the land runoff from human settlements that carries nitrate derived from sewage and other wastes. It may be pointed out here that there is no sewarage and sewage system in Goa except for the cities of Panaji and Margao, and most of the villages use open type latrines or individual septic tanks with soak pits. During monsoon season, it is quite probable that the contents of these soak pits diffuse into the rainwater and is carried to the estuary via streams. During the dry season, however, the nitrate content of the estuary is reduced, as the riverwater entering the estuary itself has low nitrate content as seen in Fig. 3(b). The source of nitrate in the estuary during this season appears to be the seawater entering the estuary during the flood tide. The phosphate on the other hand shows a different distribution as seen in Fig. 4(a). The seawater appears to be the source of phosphate content in the estuary irrespective of the season. The phosphate concentration is high at the mouth of the estuary and gradually decreases towards upstream. Fig. 4(b) shows a plot of nitrate against salinity during the monsoon and dry season. It is clear from the above figure that during monsoon the nitrate shows inverse relationship with salinity indicating the river water to be the source, while during the dry season the nitrate shows direct relationship with salinity indicating that during this season the nitrate is derived from the sea.

Fig. 5(a) shows the distribution of Primary Productivity in Mandovi estuary during the dry season. Highest productivity was observed at the upstream region of the estuary, while it decreased gradually towards the downstream. A comparison with Figs. 3(b) and 4(a) indicates that this high productivity cannot be explained in relation to nutrients (nitrate and phosphate) as both these nutrients are low at this end of the estuary during the dry season, however, a comparison with the Fig. 5(b) indicates that probably the high iron content of the water in the upstream region is responsible for the high primary productivity in this region. Heavy mining activities carried out in the upstream region of the estuary results in high concentrations of iron in the water column. Another important observation made in this study is the occurrence of highest PP at station #MN (Sarmanas) during both flood and ebb tides. Although intense mining activities are being carried out at this location this is not reflected through the distribution of iron. The concentrations of nitrate and phosphate also do not show any elevated levels at this location, so the question is what is it that leads to the high productivity at this location (?).

Conclusions

From the above discussion it can be concluded that the tides play an important role in the chemistry of the Mandovi and estuary.

(MONSOON)



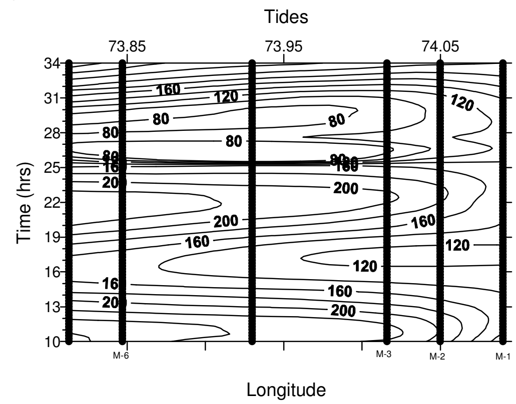
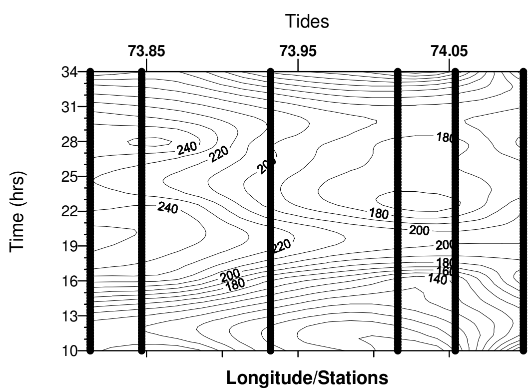


Fig. 1(a)

(DRY SEASON)



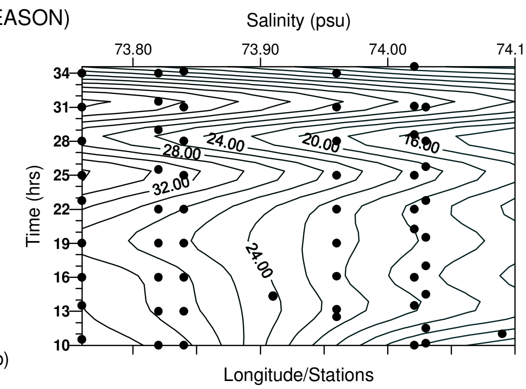


Fig. 1(b)

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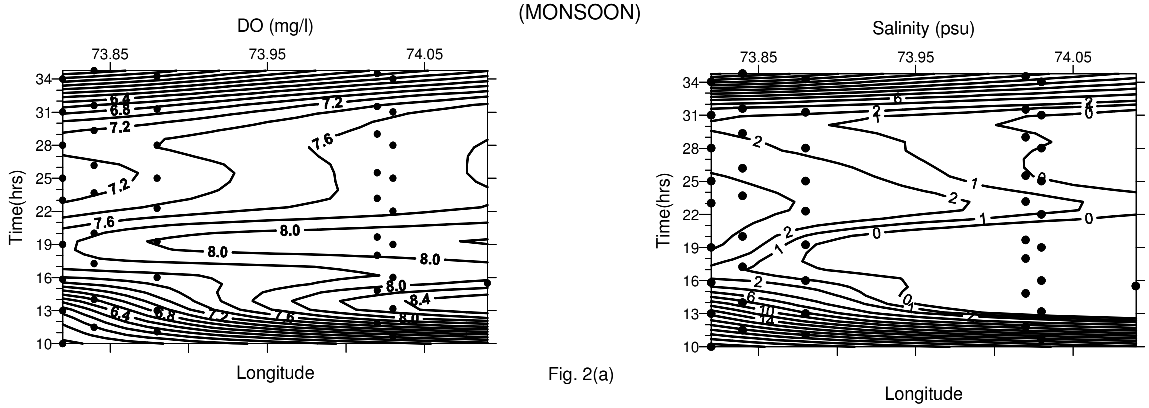

Fig. 2(a)

(DRY SEASON)

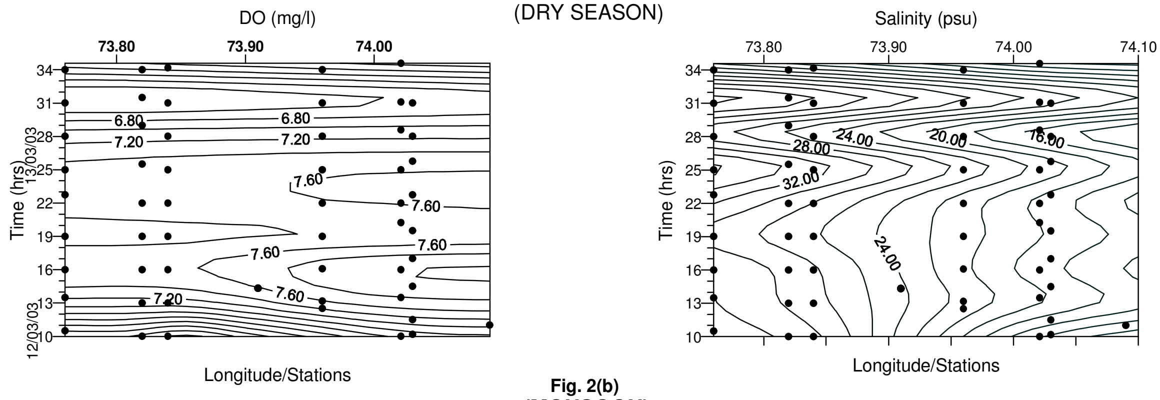

Fig. 2(b)

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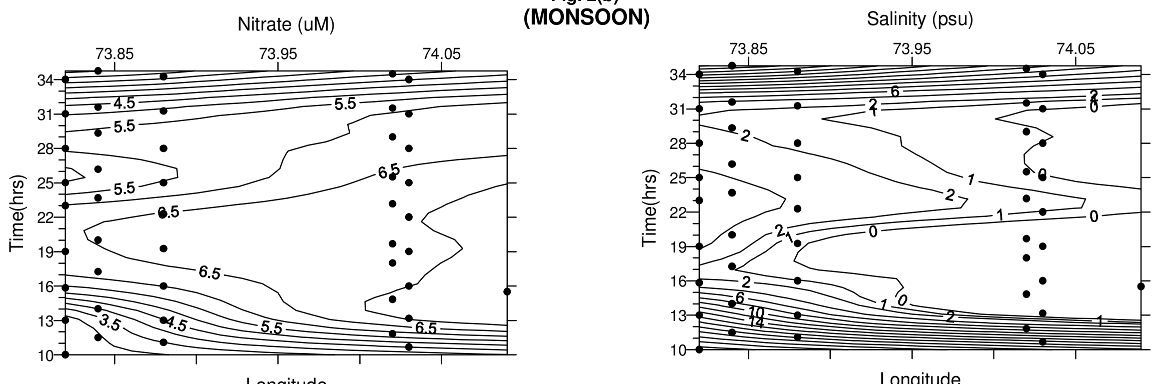


Fig. 3(a)

(DRY SEASON)

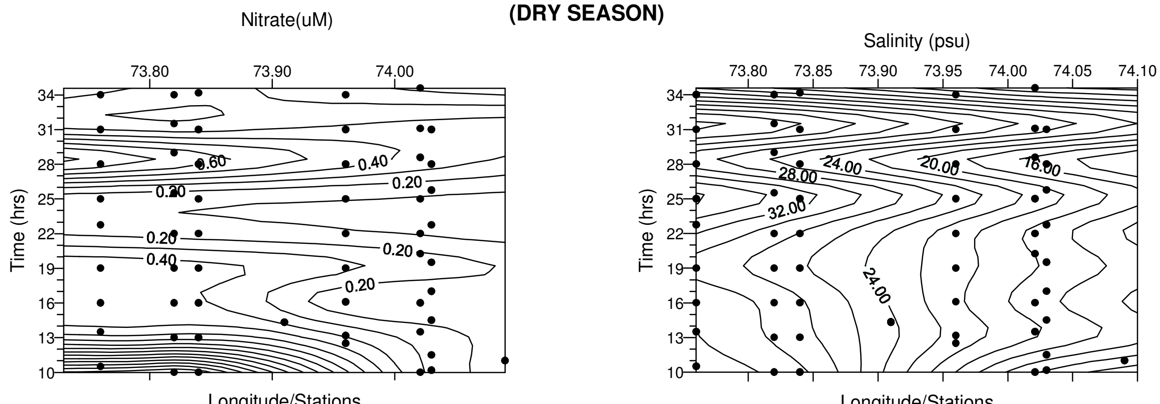


Fig. 3(b)

(MONSOON)

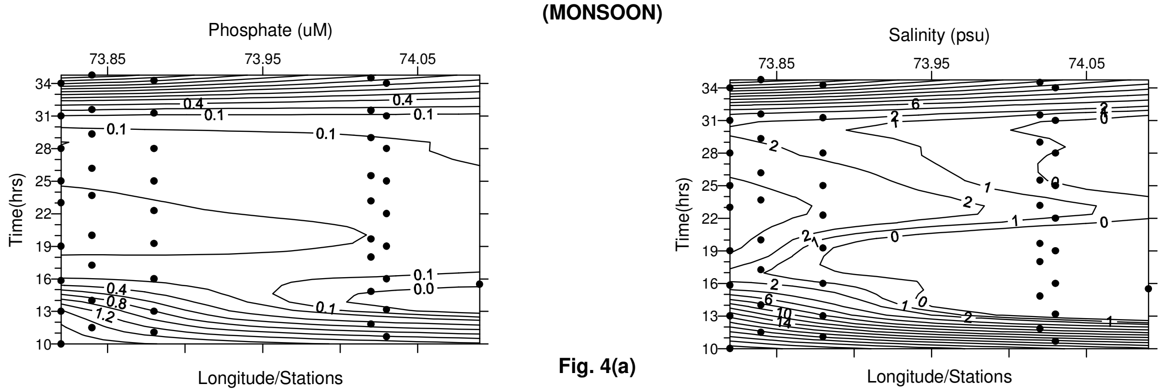
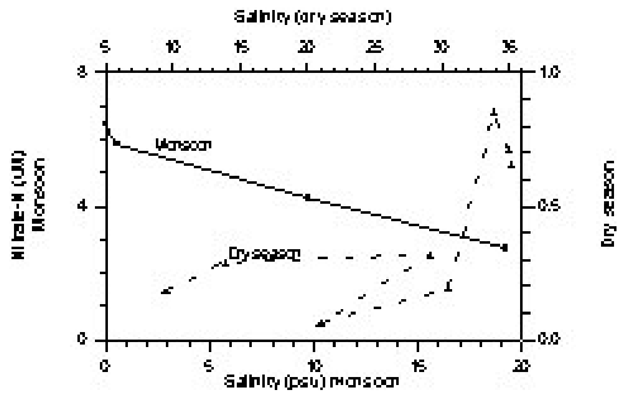


Fig. 4(a)



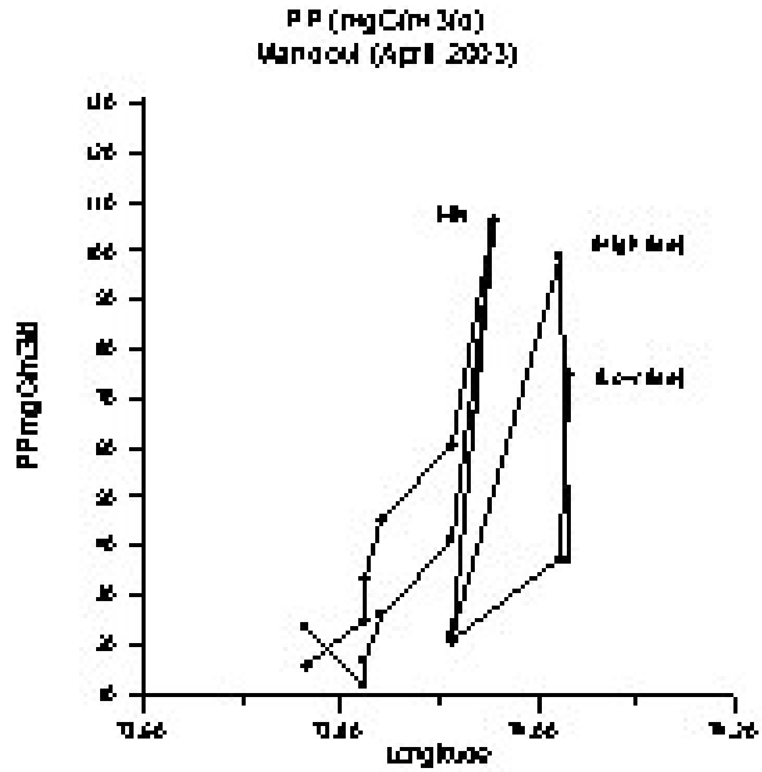
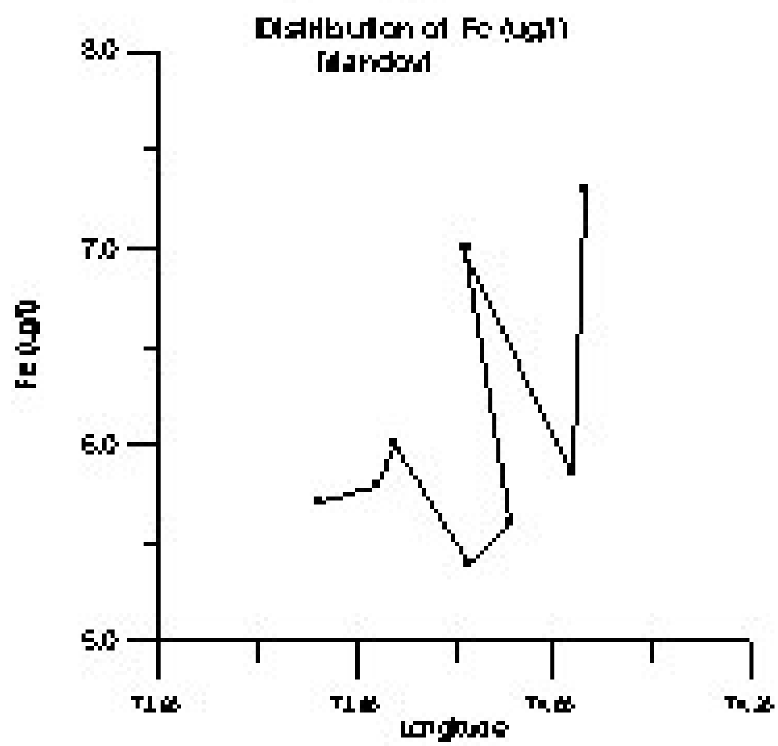


Fig. 5(a)



Marine Water Quality Assessment For Mumbai West Coast

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1. Extended Abstract

In recent past, Mumbai city has not been able to keep pace with required infrastructural facilities due to unprecedented population growth. Sewage disposal is one of the major issues, which needed immediate attention because huge quantity of sewage with only preliminary treatment disposed into the nearby coastal areas and had deteriorated the water quality of the near coastal region. World Bank assisted Bombay Sewage Disposal Project undertaken by the MCBM envisaged sewage discharges through marine outfalls at Worli & Bandra and after treatment by aerated lagoons for other areas before disposal in Malad and Thane creeks (Table 1). After Commissioning of BSDP, studies were undertaken on water quality status along the west coast of Mumbai before and after commissioning of Worli outfall (Figure 1)

Table 1 : Sewerage Areas and Disposal Method

Areas	Disposal Method
Colaba – 1.2 Km; Worli, Bandra- 3.5 Km	Outfall
Versova, Ghatkopar and Bhandup	Aerated Lagoon
Malad	Long Outfall

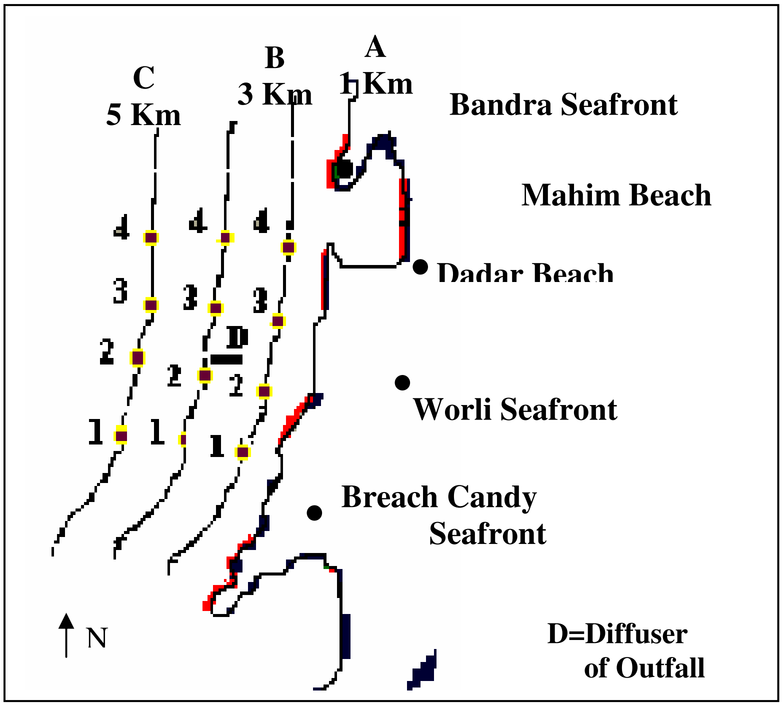
A Baseline and post commissioning water quality database for selected parameters (Table 2) was generated for the near shore as well as 5 km seaward distance of the west coast to assess the efficacy of the Worli outfall and delineate the area affected around diffuser location of the outfall due to sewage disposal. This paper presents the observations of the coastal studies for the impact zone of 3.4 km long Worli outfall.

Table 2 : Parameters Selected

Physico-chemical	Temperature, pH, Dissolved Oxygen (DO), Bio-chemical Oxygen Demand (BOD), Ammonical Nitrogen, Phosphate, Anionic detergent (selected samples), Pesticides (selected samples), Heavy Metals (coastal waters)
Microbiology	Total Coliform, Fecal Coliform, Fecal Streptococci
Biological	Phytoplankton, Zooplankton (coastal waters)

Sediments	Benthos, Nutrients, Heavy Metals, Detergents

Fig 1. Study area



Conclusion

Status of Beaches and Seafronts

- Improvement in DO
- Water quality deterioration with respect to BOD, Ammonical Nitrogen and Microbial parameters.
- Non–point discharges along the west coast contribute significant pollutants.

Coastal Water Quality

- Low DO observed close to diffuser during post commissioning as compared to pre-commissioning phase. Depletion of DO near diffuser observed as the tide recedes.

- Higher BOD observed after implementation of outfall at all the sampling locations. Maximum BOD observed at diffuser was 5-7 mg/l during slack period of tide.
- Adverse Impact of the sewage discharges noticed at 1, 3 and 5 km distance with respect to ammonical nitrogen concentrations
- The modeling exercise indicated possibility of fish toxicity due to higher concentration for ammonical nitrogen
- Microbial water quality at 3 and 5 km deteriorated due to wastewater discharge from Worli outfall and SW II & III standards for microbial parameters are not satisfied.
- No significant change in the heavy metal, nutrient and detergent concentrations has occurred after the commissioning of the outfall.

Studies on the complexation of humic substances with metals and their effects on the bioavailability and toxicity of metals in the Mangrove environment of Sundarban, India.

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Extended Abstract:

Heavy metals flux to the NE coast of Bay of Bengal from Hooghly River, the first detaic offshoot of the river Ganges seems to be considerably increased due to the growing industrialization and urbanization along the bank of the river. Sundarban mangrove forest is situated at the estuarine phase of the Hooghly river which exhibit large property gradients in the mixing zone of the river and can be regarded as acting as filters of river transported trace metals.

The land ocean boundary condition of Sundarban, NE coast of Bay of Bengal is highly irregular and criss-crossed by several creeks and waterways. There are about 54 islands covered with thick mangrove forests. High litter production from the forest sub-ecosystem along with *in situ* high biological occurrence in the aquatic sub-ecosystem results in the high production of the humic substances which are resistant to biological degradation both in water and in the sediment. The humic substances constitute the predominant form of organic matter present in the seawater and soil. These humic substances may form complexes with the toxic metals, lowering the toxicity of metals and also on biota. Studies on complexation of humic substances with trace metals and their effects on bio-availability and toxicity to biota in Sundarban mangrove system are very important in understanding the fate of those toxic metals in the environment. No information is available on the complexation study of humic substances with trace metals in this estuarine system. The present work is intend to fill this gap and to present a comprehensive picture about the nature of complexation of humic substances with trace metals, their effects on bio-availability and toxicity to biota and finally the toxic trace metals.

Humic acids (HA) and fulvic acids (FA) were extracted and elemental and chemical characteristics of humic and fulvic acids were also performed. pK_A values for HA and FA and formation constants of the complexes with metals like Fe(III), Cu(II), Zn(II) and Co(II) were determined by potentiometric titration. Spectral characteristics of humic and fulvic aacids were determined using infra-red, UV –VIS and fluorescence spectroscopy. A non electro-chemical approach, synchronous fluorescence spectroscopy was also explored for the determination of the stability constant. The adsorption of Cu(II), Zn(II) and Co(II) onto the different sediments were studied at different temperature and

salinities at pH 4.5. Using the principle of adsorption isotherm, values of partition coefficient (K_d) for different metals at different salinities were determined.
Adsorption of metals on different phases, FeO_x phase and organic phase (HA &FA) in the sediment were also critically examined. Linearised Langmuir isotherm equation was applied to determine the adsorption coefficient (K). The kinetic study for the adsorption of metals on the sediment showed the first order nature from where values of adsorption (K_1) and desorption coefficients were determined.

Trace metal concentrations (Fe, Co, Cu, Zn) in the tissue of *Macoma Birmanica* occurring in the Sundarban mangrove environment were studied and their accumulation in the bivalve was found in the same order as they are found to occur in the sediment. But the enrichment of Zn was considerably higher in comparison to the other metals indicating that Zn was more loosely bound at the binding sites of HA and FA occurring in the sediment. A detailed biochemical study in relation to the Zn accumulation in *M. birmanica* was performed. Monthly variations of concentration of glycogen content per individual and seasonal variations of concentration of Zn in *M. birmanica* was found species specific and it could be used as bio-indicator for Zn contamination.

Methane dynamics in the Hooghly estuary, Northeast coast of the Bay of Bengal, India.

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Extended Abstract

Methane is a greenhouse gas and contributes to the global warming or global climatic change. There has been sustained interest in the trend of atmospheric pollutant like methane with a global warming potential of 21. Natural sources of methane include wetlands, forest fires and methane hydrate reserves in the sea floor. Estuaries are coastal wetlands being associated with mangrove and salt marsh ecosystems also act as a significant source for atmospheric methane. Methane concentrations, exchanges at the sediment-water interface and emissions to the atmosphere were studied covering three seasons during 2000-2001 along an estuarine gradient in the Hooghly estuary which is fed by one of the world's largest rivers, the Ganges with a flow rate of 15646 $m^3 s^{-1}$ (1.6 % of the world's combined river flow). Seasonal variations of CH_4 concentrations in surface water collected from the salinity gradient zone of the Hooghly estuary are given in tables 1, 2 & 3.

Methane concentrations in the surface water varied between 29.31 and 59.25 nM with an average 41.85 ± 10.8 nM during premonsoon, between 13.65 and 23.62 nM with an average of 19.15 ± 4.56 nm during monsoon and between 18.44 and 52.42 nM with an average 37.8 ± 12.19 nM during postmonsoon. Partial pressure of atmospheric methane varied from 1.49 – 2.50, 1.71 – 2.3 and 1.62 – 2.40 µatm with median concentrations of 1.89 ± 0.33, 1.90 ±0.32 and 1.87 ± 0.25 347 µatm during premonsoon, monsoon and postmonsoon, respectively. The overall variations of dissolved methane reflected by the saturation value and high supersatuation with respect to atmospheric equilibria were recorded. The lowest mean saturation was calculated for the monsoon (950 ± 345 %), which was increased to 1767 ± 403 % in premonsoon. Higher degree of saturation and 8.24% increase in methane concentration in surface water was found in premonsoon than that of postmonsoon. Increasing trend of saturation of methane was found with the increase of salinity (Fig. 1). This could be attributed to the lower concentration of CH_4 in the water during monsoon. Moreover during monsoon this estuary receives a considerable amount surface runoff rich in organic load and particulate matter might have consumed or oxidized water column methane. The highest concentration of CH_4 in surface water as well as saturation was observed during Postmonsoon and this may be attributed to the phytoplankton abundance during post. The concentration of methane in bottom water (sediment water interface) and pore water (3-4 ft below the subsurface) were also analyzed (Table 4). The average concentration of methane in bottom water was found to be 56.1±4.5, 43.6 ± 6.8 and 53.95±5.7 during premonsoon, monsoon and postmonsoon, respectively. The methane concentrations in the pore water of anoxic

sediment layer of mangrove forest were observed to be 1.3±0.8, 0.78±0.53 and 1.88±1.69 μM during premonsoon, monsoon and postmonsoon, respectively.

Table 1: Concentration of methane in the atmosphere and surface water of the Hooghly estuary at different salinity and its emission rate during premonsoon.

Salinity (psu)	**Water temp. (^oC)**	**Gas transfer velocity (cm h^{-1})**	**Solubility (nM)**	**Partial press. of CH_4 in the air (μatm)**	**CH_4 conc. in water nM**	**Flux of CH_4 ($nMm^{-2}h^{-1}$)**
0.54	31.2	0.65	2.83	2.50	59.25	371.13
1.69	30.0	5.39	2.45	2.12	54.39	2801.23
8.37	30.0	1.15	2.61	2.36	30.40	320.95
8.95	31.2	1.04	1.78	1.66	53.54	541.5
9.12	31.3	0.72	2.24	2.09	45.21	309.19
13.66	30.5	5.92	2.01	1.90	30.41	1680.98
17.22	31.5	6.22	1.60	1.57	34.18	2027.4
18.8	29.5	11.14	1.79	1.71	34.63	3658.38
19.7	29.5	11.87	1.78	1.71	29.31	3267.65
22.48	31.9	11.74	1.46	1.49	46.88	5333.72
22.65	32.8	15.15	1.63	1.69	42.45	6193.46

Table 2: Concentration of methane in the atmosphere and surface water of the Hooghly estuary at different salinity and its emission rate during monsoon.

Salinity (psu)	**Water temp. (^oC)**	**Gas transfer velocity (cm h^{-1})**	**Solubility (nM)**	**Partial pressure of CH_4 in the air (μatm)**	**CH_4 conc. in water nM**	**Flux of CH_4 ($nMm^{-2}h^{-1}$)**
0.11	31.5	0.26	1.99	1.71	22.10	53.73
5.1	31.0	0.49	1.73	1.57	23.62	107.86
9.62	31.2	0.41	2.46	2.29	17.25	61.64
13.36	30.6	0.60	2.16	2.05	13.65	69.30

Table 3: Concentration of methane in the atmosphere and surface water of the Hooghly estuary at different salinity and its emission rate during postmonsoon.

Salinity (psu)	Water temp. (°C)	Gas transfer velocity (cm h^{-1})	Solubility (nM)	Partial pressure of CH_4 in the air (µatm)	CH_4 conc. in water nM	Flux of CH_4 (nMm^{-2}h^{-1})
1.0	22.5	2.88	2.60	1.94	45.33	1230.5
1.2	23.0	0.18	2.14	1.61	23.25	39.93
2.5	22.8	0.62	2.60	1.96	18.44	99.1
4.8	23.0	0.64	2.30	1.77	49.23	300.76
7.0	24.2	1.25	2.21	1.79	32.19	375.52
10.0	22.6	0.59	2.10	1.59	42.21	239.4
11.0	24.2	2.61	2.30	1.89	39.39	968.09
15.5	23.0	0.30	2.91	2.40	52.42	151.75

The same trend of seasonal variation in methane concentration was observed for surface, bottom and pore water indicating the common set of environmental factors controlling their variability. In order to explain the seasonal variation of CH_4 concentration in surface water, its flux through the sediment water interface (F_{SW}) and to the atmosphere was calculated. * The estuarine sediment was found to be silty (7.34% sand, 62.23% silt and 30.34% clay) and the porosity was calculated to be, $\varphi = 0.65$. Considering the diffusion coefficient (D_S) of 5.09×10^{-6} cm^2 s^{-1} (Rothfuss et al., 1996), diffusive flux was calculated (Table 4). The diffusive flux of CH_4 through the sediment water interface was observed maximum (52.1 nM m^{-2} d^{-1}) and minimum (21.3 nM m^{-2} d^{-1}) during postmonsoon and monsoon. Calculated median flux to the atmosphere was found maximum during premonsoon with a rate of 57.8 µM m^{-2} d^{-1} and minimum during monsoon with a rate of 1.75 µM m^{-2} d^{-1}. Considerably higher values of methane evasion rate were observed by de Angelis and Scranton 1993 for Hudson river, New York (381.3 µM m^{-2} d^{-1}), by Pulliam, 1993 for Ogeeche River, Georgia (106.3-6025.0 µM m^{-2} d^{-1}) and by Hamiolton et al., 1995 for Amazon river, Brazil (37.5 mM m^{-2} d^{-1}). In spite of the higher CH_4 flux at the sediment water interface, its rate of emission was found low (9.0 µM m^{-2} d^{-1}) during postmonsoon.

The oxidation methane by methanotrophic bacteria during postmonsoon could account for substantial loss from waters and hence low emission. Lower wind velocity and temperature could also be partly responsible for the low methane flux during postmonsoon. The diffusive flux of CH_4 showed maximum value of 57.8 µM m^{-2} d^{-1}

during premonsoon, nevertheless the concentration of CH_4 was increased between the period of postmonsoon and premonsoon. This could be attributed to rapidly decreasing methane oxidation activity. Further significant decrease of CH_4 concentration and its air-sea flux during monsoon could be due to the considerable fresh water discharge and increased CH_4 oxidation activity in the water column. Dissolved oxygen concentration was near saturation in the water column owing to the tidal mixing and wind driven diffusion. Its concentration was significantly above the range of the estimated half saturation constant for methane oxidation (K = 0.5-0.8 mg O_2 l^{-1}, Lidstorm and Somers, 1984), or the reported optimum range of 0.1-1.0 mg O_2 l^{-1} (Rudd and Hamilton, 1975) for microbial methane oxidation in the water column, indicating dissolved oxygen was not the major limiting factor for methane oxidation activity.

Utsumi et al., 1998 also observed that methane oxidation activity was not dependent on water temperature, dissolved methane, dissolved oxygen and dissolved inorganic nitrogen in lake Kasumigaura, Japan. With the turbulent tidal mixing of water, methanotrophs in the sediment could be transported to the oxic water by re-suspension of the sediment and retain their activities in the planktonic state and the activity was directly seasonal with high specific rates during monsoon. Methane efflux exponentially increased in relation to salinity (r^2 = 0.36), (Fig. 2) indicating that increased CH_4 flux at the sea end could be due to enhanced diffusion across the air-water interface, controlled by increased wind velocity towards sea end. The concentration of dissolved CH_4 and its flux to the atmosphere were found to be related to the different processes occurring in the estuary such as methane supply from sediment, oxidation in the water column and wind driven diffusion to the atmosphere.

Table 4: Seasonal variations of methane flux in relation to its concentration in surface, bottom, and porewaters.

Concentration	**Premonsoon**	**Monsoon**	**Postmonsoon**
Pore water CH_4 conc. (nM)	1297.8 ± 844.1	788.6 ± 530.6	1877.8 ±1689.1
Bottom water CH_4 conc. (nM)	56.1 ± 4.52	43.6 ± 6.8	53.95 ± 5.68
Surface water CH_4 conc. (nM)	41.58 ± 10.8	19.15 ± 4.56	37.8 ± 12.2
Saturation (%)	1579.4 ± 478.6	950.4 ± 345.0	14060 ± 559
Oxygen saturation (%)	103 ± 5.1	85.1 ± 3.6	97.1 ± 4.24
F_{SW} (nM m^{-2} d^{-1})	21.8	21.3	52.1
F_{wa} (µM m^{-2} d^{-1})	34.8	55.0	9.0

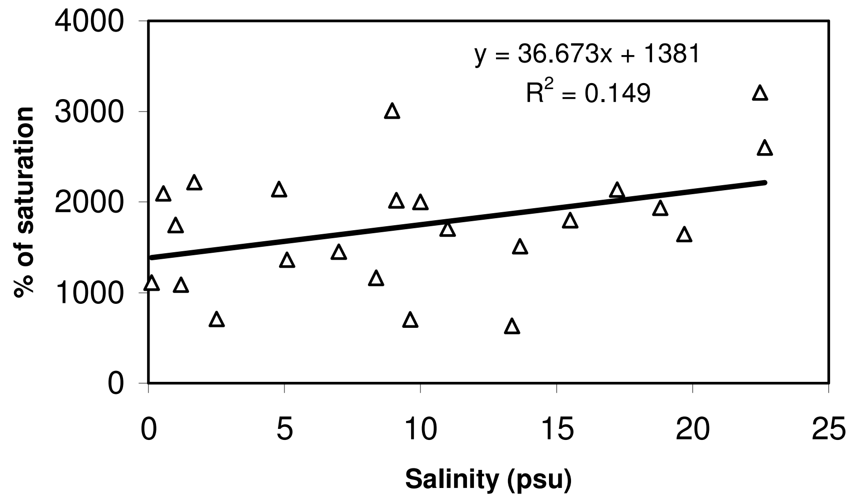

Figure 1: Graphical presentation of methane saturation at different salinity in the Hooghly estuary.

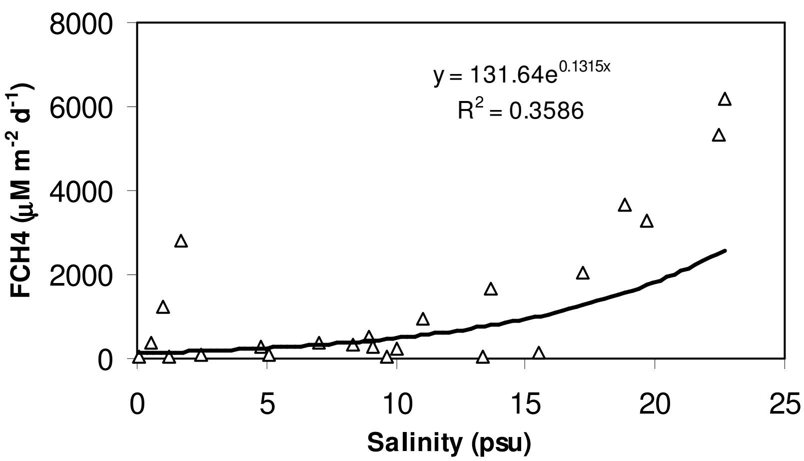

Figure 2: Regression curve between salinity and methane flux for the Hooghly estuary.

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The integration of tools and data bases for oceanographic applications in a GIS Environment

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Extended Abstract

The Oceanographic information system (OIS) is the ArcInfo based Geographic information system application. Its goal was to provide an integrated set of tools for oceanographic, acoustic, geophysical, and bathymetry data assessment and product generation for users and their customers.

The most significant among these interfaces are the GIS based Map-query and Contour visualization interfaces. The GIS based interfaces are very user-friendly and are oriented towards bridging the gap between user's knowledge and the technical knowledge required to operate the software system. The system also provides users with other analysis tools like query based reports and graphs.

It can be used as a powerful tool to synthesize all the data, for comprehensive interpretation and forecasting of marine environmental ecosystems for the study region. This system has been applied to the Karnataka Coastal Environment, India and it is very useful for the clients and policy makers.

This paper highlights the subsystems of OIS. The OIS is divided into two main modules. 1. GIS module and 2. non-GIS module.

GIS module:

The GIS module is a major part of this paper and is carried out in the following manner:

1. Map digitization.
2. Creation of the SDE database.
3. Visualization interface (ArcIMS website) to deploy the maps and data over the network.

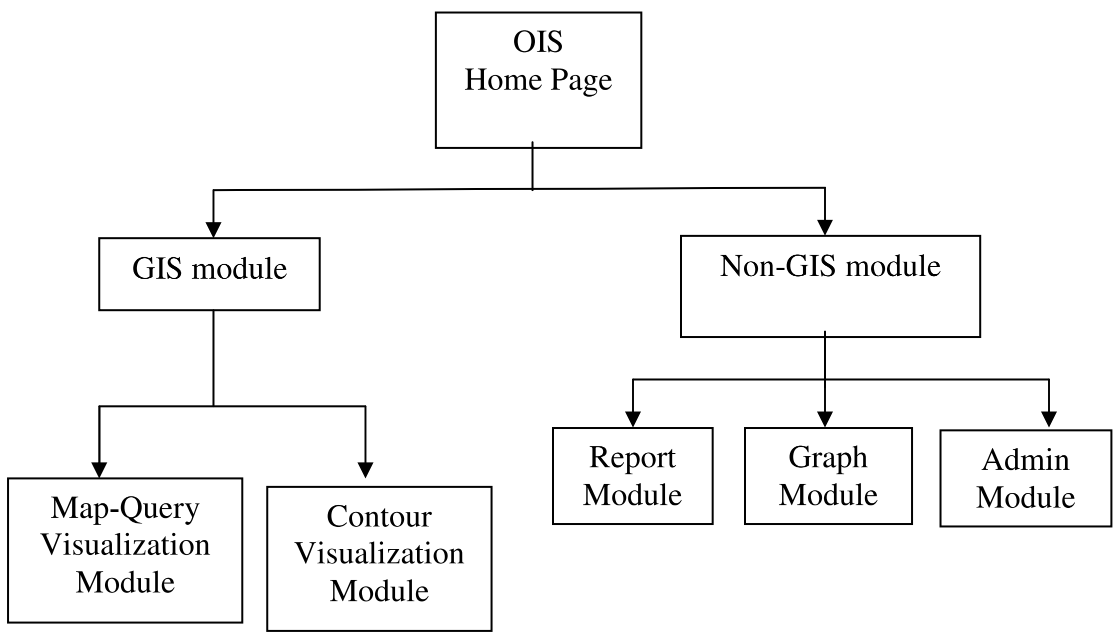
Non-GIS module:

The non-GIS module shall consist of 3 sub modules:

1. The report module: This module shall provide the users with additional reporting services to complement the services provided by the GIS module. The reporting interface shall generate reports for multiple parameters both period-wise and depth-wise.

2. The graph module: The graphing application shall support dual axis analysis (2 parameters), in addition it shall also provide the user with a choice of graphs like line, bar, and area charts along with 2-D or 3-D view.

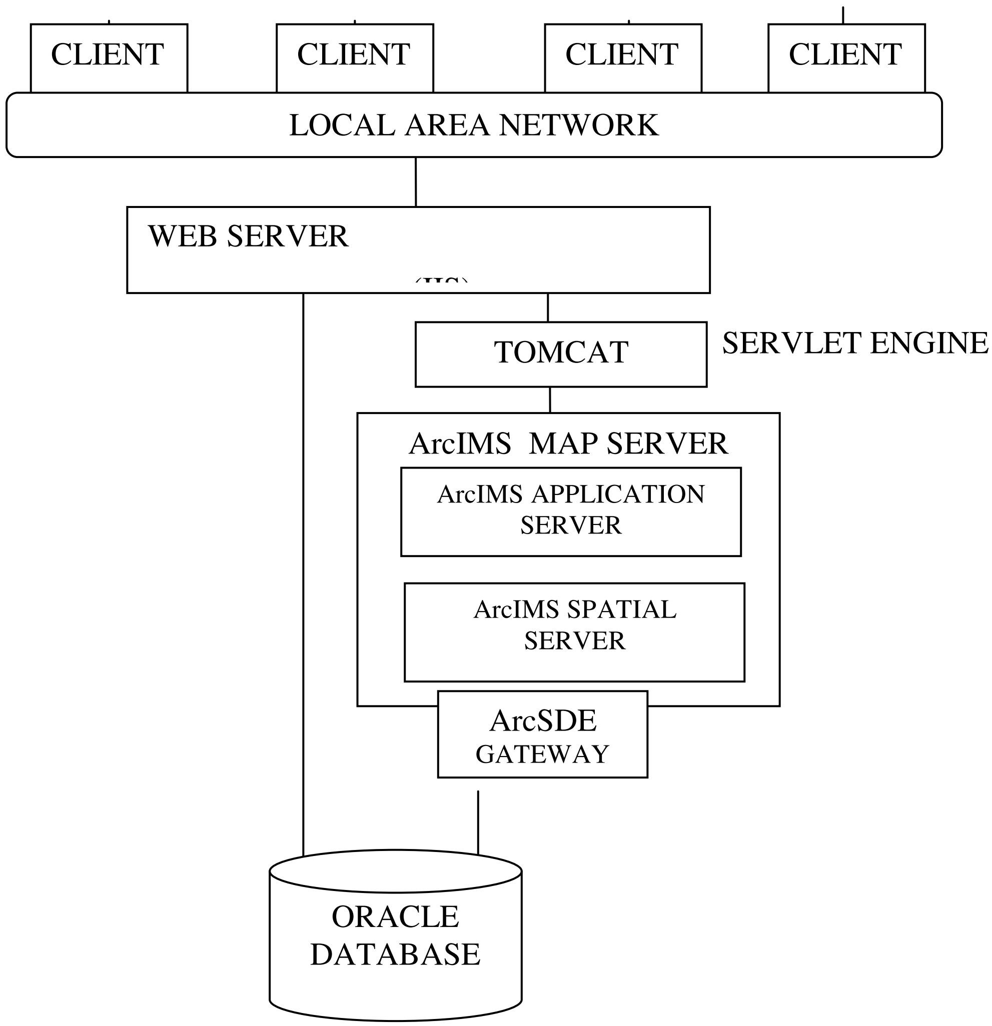
3. The Administrator module: This module shall allow the administrator to manage the database once it is created. This module shall provide the administrator with a one-time solution to the tedious task of compiling data by the admin user to add and modify the oceanographic database in a structured manner. This module shall also provide the administrators with individual login accounts, thereby maintaining database security. The administrators shall also be granted rights to create a new user and change passwords.



System Architecture

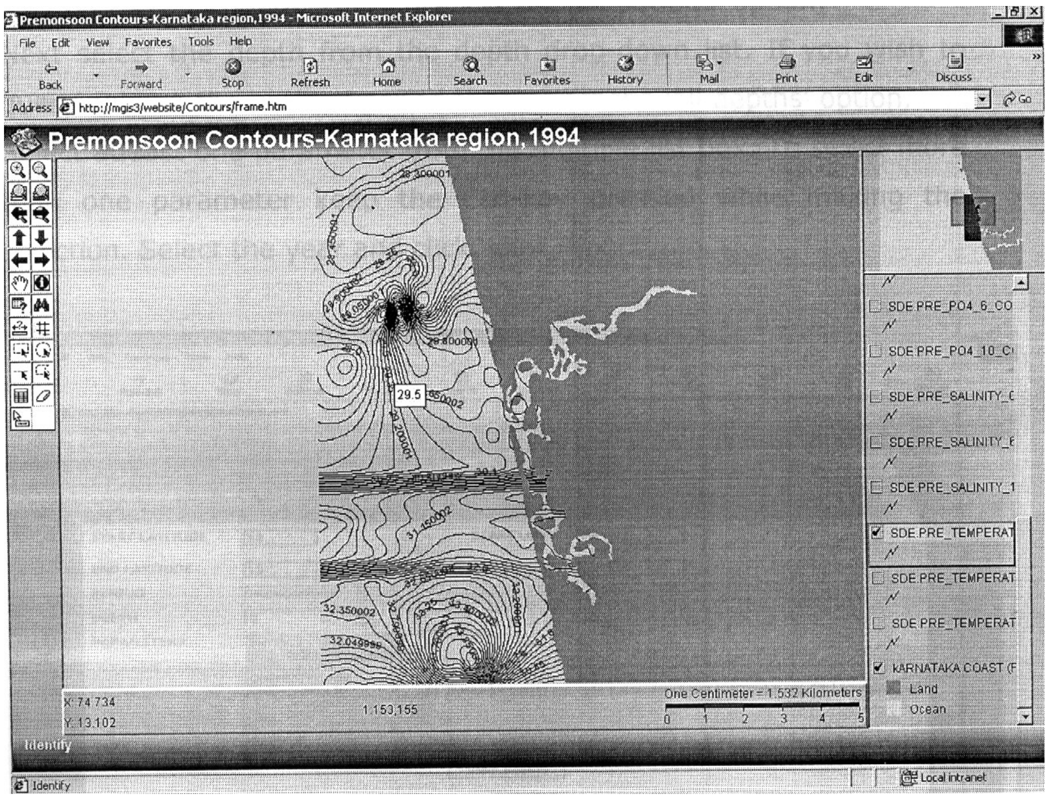
The OIS follows two separate architectures for the implementation of the GIS and non GIS subsystems. The architecture is designed for deployment on the Internet Information Server (IIS), running on Windows NT or Windows 2000. All requests from the client are based on a HTTP Request-Response mechanism. All client requests are routed through the web server (IIS) to the layers behind it.

The non-GIS subsystem follows the traditional 2-tier client-server architecture. The client tier consists of the web browser, whereas the web server (IIS) and the DBMS make up the server side. The connection between the web server and database is established using the standard ODBC application programming interface. The GIS module follows a more complex multi-tier architecture. The overall architecture of the system is depicted in the figure below.



The Oceanographic Information System, for Karnataka region is developed and it serves as a central reference, for any oceanographic information relating to the Karnataka region. The creation of the Oceanographic Information System using GIS, shall also organize the data collected for the region, into a systematic repository of information, which can then be efficiently used, to gain knowledge and improve the understanding of the coastal environment about the study region. The GIS contour visualization interface allows the users to visualize the distribution of each parameter off the coast of Karnataka which is shown in the figure given below.

This system can be utilized for other coastal /offshore areas of the seas around the world. This however requires the digitization of the maps of the respective areas. This system is also useful for displaying the time



Model For Estimating Index of Environmental Degradation of Water Quality of Coastal Sea.

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Extended Abstract

Water quality parameters need to be assessed to search for environmental degradation of coastal sea. Degradations can easily be assessed on the basis of changing states of aquatic lives. Diatoms or microscopic algae plays an important role to specify the state of degradation of coastal aquatic environment. Diatoms preserved in sediments and their distributions are linked with water quality of coastal sea. Diatoms have also been extensively used to identify changes in pH, salinity, nutrients and climatic changes.

In this investigation attempts have been made to look into the environmental impacts of some parameters of water and sediments on different phytoplanktonic algaes. The changes in the attributes of these parameters are due to contribution from agriculture field, fertilizer factory, use of pesticides, domestic source of sewage, bathing of animals & industrial effluents.

Here, we have worked upon 4 diatoms i.e. Cosinodiscus, Hemidiscus, Nitzscia & Asterionela. These diatoms are the indicators which help us to know the ecological system of that area. To understand the state of coastal sea environment (near Sagar island 21^{o} 39' N, 85^{o} 03' E) we have analysed 22 measured variables of coastal water at 8 stations situated near the eastern part of Sagar Island. The measured parameters are 1) velocity of Water 2) Water temperature 3) Turbidity 4) Total Suspended Solid 5) pH 6) DO 7) Total dissolved solid 8) Salinity 9) Chlorinity 10) Chlorophyll 11) Nitrate 12) Nitrite 13) Phosphate 14) Silicate 15) DDT 16) BHC 17) Lindane 18) Endosulphane 19) Total Coli 20) Vibrio 21) Pseudomonas 22) Streptococcus. Measurement on concentration number of diatoms were also taken at these 8 stations.

These data were used to construct a correlation matrix to understand the nature of interaction among them. Further analyses with developed model were carried out to find dominant factor indices .And it was found that there are six dominant factors. Each of these factors comprise of dominant influence of some of the 22 variables. Factor indices and corresponding dominance of variables are as follows

Factor 1 ,	dominance of Turbidity, TDS, Salinity, Chlorinity ;
Factor 2	Nitrate, Nitrite, Phospate, Silicate ;
Factor 3	BHC ;

Factor 4	Ph, DO, Lindane ;
Factor 5	Total Coli, Vibrio ;
Factor 6	TSS, Endosulphane

The factor indices are used to find the role of pollutants affecting aquatic life. Cosinodiscus is inflenced by factor 1; Hemidiscus by factor 5; Nitzscia has positive correlation with factor 1 & 3(i.e. required in greater amount) Asterionela by factor 5.

Moreover Factor-1 is influnced by seasonal variation,phytoplankton growth & domestic source;
Factor-2 from agricultural,field;
Factor-3 from pesticide;
Factor-4 from domestic wastes,Calcutta sewage, less turbid zone,pesticide;
Factor-5 from bathing of animal, sewage ;
Factor-6 from pesticides, bacteria (bathing of animal) and sewage.

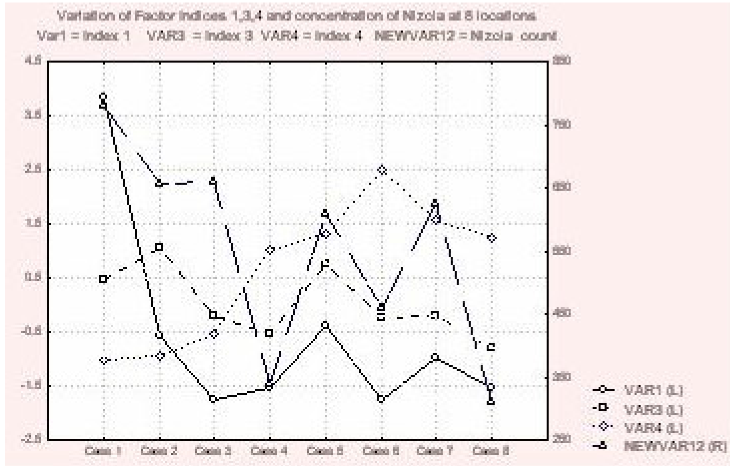
These impact of dissolved & suspended inorganic & organic matter in water is used to understand the changes in the growth of planktonic diatoms.

The mathematical model has been prepared to estimate critical levels of contaminants in coastal water conducive to survival or abnormal growth of the phytoplanktonic diatoms which are marked as indicator species. Deficiency of diatom concentration lead to hazardous impact due to insufficiency of food supply for the aquatic life. Again excess growth of these diatoms may lead to augmenting bloom of algae which has disastrous impact on the whole ecosystem.

1. Discussion of Result

1. Factor index 1 has positive correlation 0.65 with growth of Nitzscia.
2. Factor index 2 has negative (-0.52) with Asterionela.
3. Nitzscia has a very high degree of positive correlation (0.72) with factor index 3.
4. Factor index 4 has negative correlation -0.62 with Nitzscia.
5. Factor index 5 has positive correlation 0.87 and 0.52 with Hemidiscus and Asterionela respectively.

In the figures 1 and 2 variation of Indexes with concentration counts of diatoms at 8 locations have been shown to understand location specific variation of coastal sea environment.



1. Figure – 1. Variation of Indexes 1, 3, 4 and concentration of Nizcia at 8 Locations.

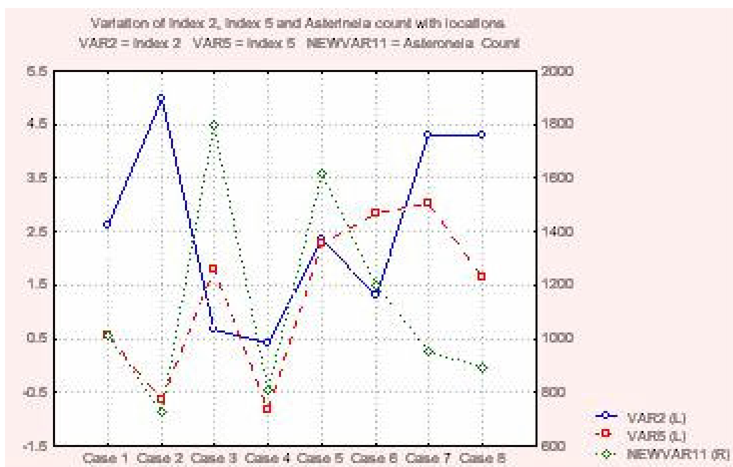


Figure – 2 Variation of Indices 2, 5 and concentration of Asterionela at Locations.

It is now apparent that domestic waste, sewage and pesticide have significant influence on Nizcia growth. Sewage has strong negative impact on Nizcia growth. So locations with small Nizcia count has dominant distributions of water contaminants from sewage. This can be marked as an indicator to take appropriate precautions.

Contribution of agriculture and fertilizer factory have negative impact on Asterionela growth. Animal bathing and sewage has positive bathing have positive impacts on Asterionela growth.

Conclusion

In this investigation we have got some idea about the role of water quality parameters on the phytoplanktonic diatoms specifically in the context of their survival and growth. The diatom growth has also found out to be dependent on some indices constructed through mathematical model. These indices have some direct bearing on the pollution load due to various activities and as a result of which precautionary measures can easily be adopted. Methodologies adopted here for analyzing data will be of much use for integrated coastal zone management.

BOD-DO Modeling for water quality analysis around a waste water outfall off Kochi, southwest coast of India

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Extended Abstract

Release of large quantities of domestic and industrial wastewater into the Kochi backwaters has become an issue of intense concern as the water quality of backwater ecosystem is deteriorating day by day. Most of the urban wastewaters from the surrounding areas are released directly into the backwaters, while the industrial wastewaters are released in the upstream regions of the rivers that discharge into the backwaters. Eventually, during ebb tide and southwest monsoon season when the currents are favourable, part of the wastewater gets flushed out of the system and reaches the coastal Arabian Sea off Kochi. However, Majority of organic particulate matter in the wastewater settles down in the backwaters itself as the currents inside the backwaters are very sluggish. This causes serious environmental problems such as fish mortality, foul smell and deterioration of the water quality in the backwater system. In order to overcome this, it is proposed to seek an alternative option for suitable waste water management by discharging the treated wastewater into the offshore region in the Arabian Sea (Fig.1).

Numerical modeling is an effective tool in this regard that can be used to reduce environmental pollution through proper wastewater management (Thomann and Mueller, 1987). Using numerical modeling, the water quality parameters can be simulated which would be useful in estimating the waste assimilative capacity of coastal waters. Water quality modeling would reveal the net effect of the BOD (Biochemical Oxygen Demand) load on the environment. Indrani Gupta et al, (2003) have studied the water quality of the Thane Creek in Maharashtra using BOD-DO simulations and similar studies have been conducted to model the water quality of rivers such as Ganga and Yamuna (Bhargava, 1983). In the present study, water quality module of MIKE21 modeling package has been used to simulate BOD and DO as indicators of waste assimilation level of the coastal waters off Kochi. The assimilative capacity of the waters of a specific area around the outfall is determined by estimating the area influenced by the presence of higher BOD.

BOD and DO data collected during February 1999 and current measurement taken during March, 1999 were used as initial and boundary conditions to the model as well as for calibration and validation of the model. Model runs were carried out for two scenarios by

keeping the outfall at 5m and 10m depth respectively with a continuous discharge of the effluent at the rate of 10 m^3s^{-1} having BOD 50 mg/. This would lead to a BOD load of 43200 kg day^{-1} . The estimated BOD load for Kochi based on the urban and industrial wastewater discharged into the Kochi backwaters is about 5200kg/ day which is about 12% of the BOD load assumed in the model. Higher value of BOD load is assumed in the model to overcome the uncertainties associated with the BOD load measurements.

The simulation results show that higher BOD levels are noticeable in an area of 2-5 sq. km around the outfall for case 1 after 24 hours and 48 hours of discharge(Figs 2a&b). Beyond this area ambient BOD level is noticed. The maximum resultant BOD around the outfall was found to be 6.5 mg/l which is about 4.0 mg/l higher than the average BOD observed in the region. It is probable that the flora and fauna in the vicinity of the outfall will be effected by higher BOD and subsequent lower dissolved oxygen. The assimilative capacity in terms of BOD around this outfall would be ~43200 kg day^{-1}. The model results indicate that the offshore waters could be used as an alternative site for sewage discharge, without damaging much of the offshore waters. This would improve the water quality of the backwaters and save the Kochi backwaters from deterioration.

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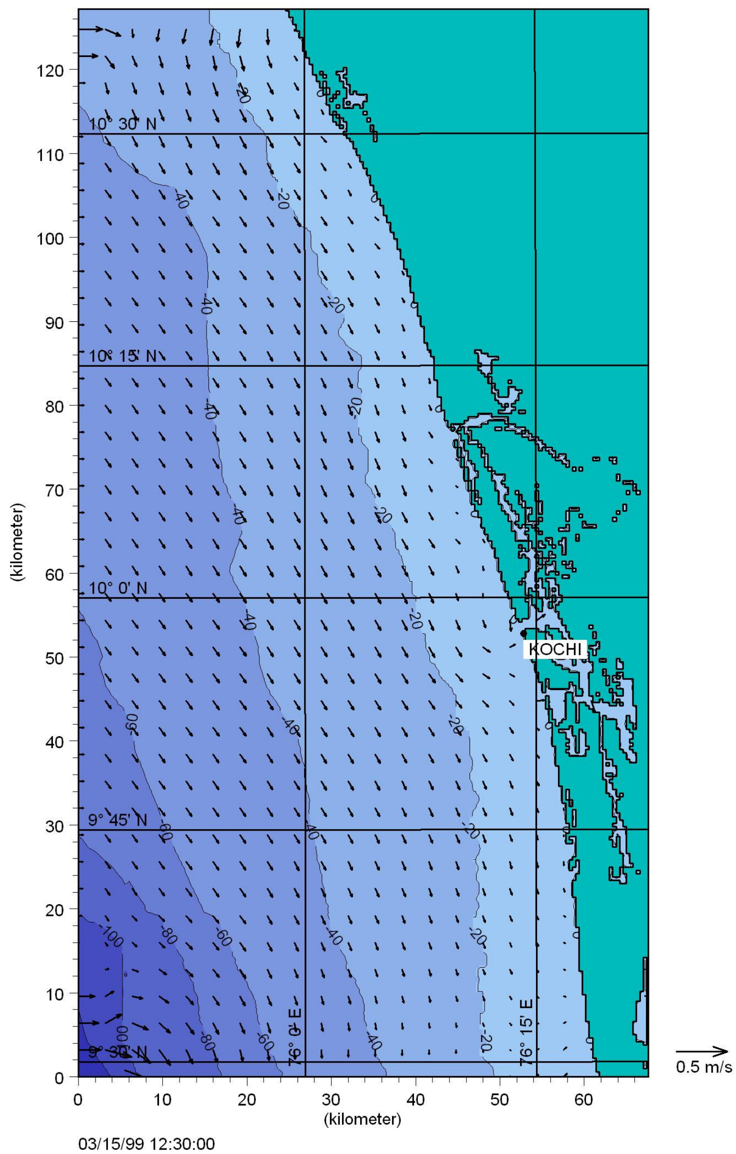

Fig.1 Study area with bathymetry and simulated currents during ebb phase of the tide (depth contours are in metres)

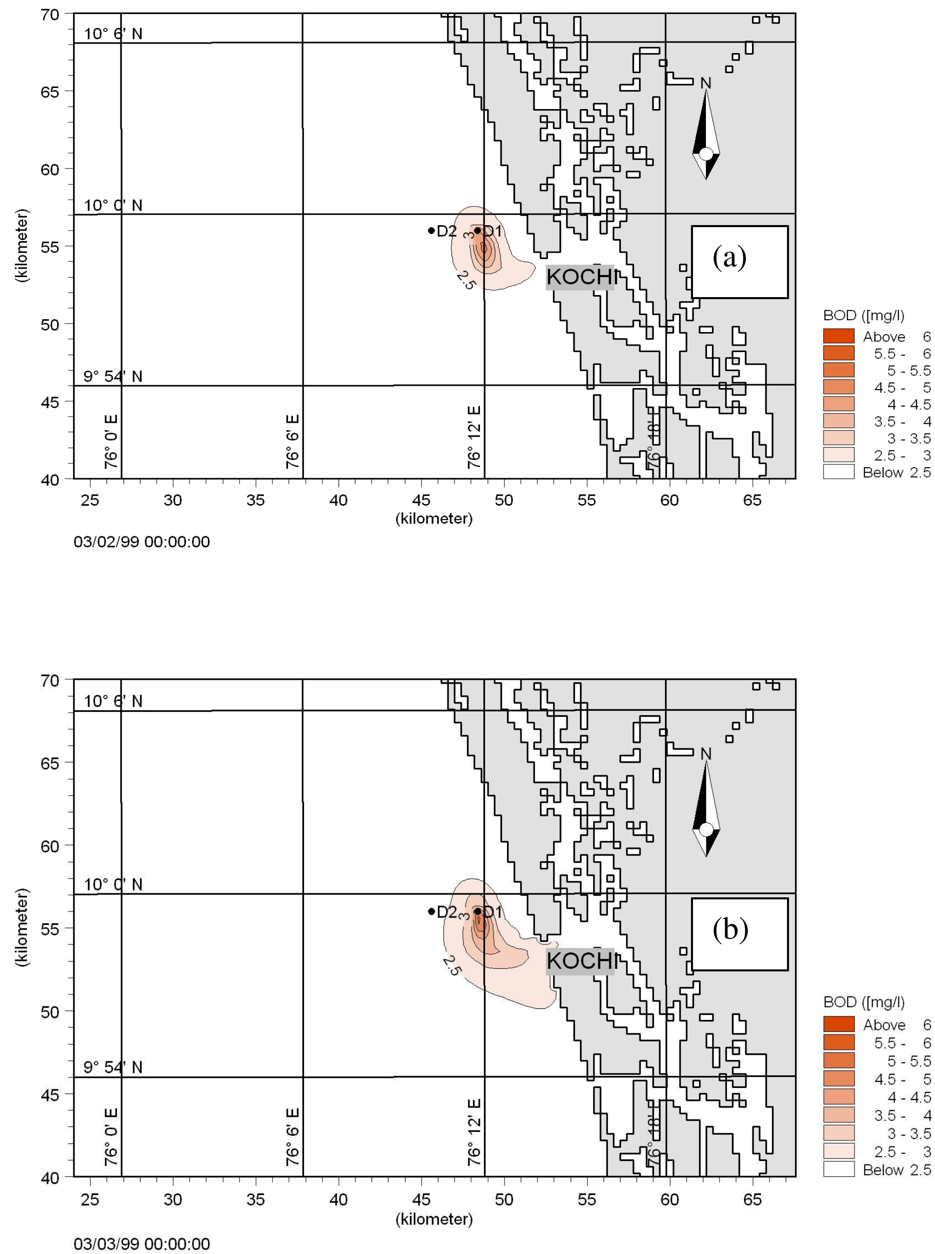

Fig. 2. Distribution of BOD around the outfall (a) after 24 hours of discharge and (b) after 48 hours of discharge (outfall depth =5m).

Application of Remote Sensing Technique for formulation of Integrated Coastal Zone Management (ICZM) Plan of West Bengal, India

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Introduction

The Coastal Zone, an unique geo-bio-ecological domain, is the most dynamic of all the known environment. It is also unique in terms of productivity. The transitional strip of land and sea that straddles the coastline contains some of the most productive and valuable habitats of the biosphere including estuaries, lagoons, coastal wetlands, mangroves, seagrass, fringing coral reefs, etc. It is a place of natural dynamism where huge amount of energy is being continuously released throughout the year; at the same time it nurtures a great abundance of life. Despite its fragility, the coastal zone is amazingly resilient. The ecosystem as a whole is a dynamic and regenerative forces, if "left alone", natural mechanism operate to maintain equilibrium between all living and the natural environment (Beatly et al., 1994).

At the same time, it is a high priority zone to industry, to defence, to commerce, to town planners and so on. Some 60% of the world's population live in coastal areas. It has been estimated that 75% of the world's population will be living within 60 km of the sea by the year 2020. World Development report points to the fact that two thirds of cities with populations over 2.5 million are situated near estuaries. Due to this intense activities**,** the coast undergoes great environmental modification and deterioration through landfill, dredging, deforestation and pollution caused by urban, industrial and agricultural development. There are limits, however, to the extent the coastal ecosystem can withstand external assaults to its integrity. That is why, proper assessment of coastal resources as well as dynamics working in this region need to be studied in detail. Unless properly managed, such modifications may lead to disaster.

Realising the importance and fragility of coastal zone, Government of India has decided to monitor the activities in and along the coastal stretches of our country and has declared certain specific coastal stretches as Coastal Regulation Zone in February, 1991. This includes the coastal stretches of seas, bays, estuaries, creeks, rivers and back waters which are influenced by the tidal action (in the landward side) up to 500 m from the High Tidal Line (HTL) and the land between the HTL and Low Tide Line (LTL). The notification has been made under Environmental Protection Act, 1986 and includes the Regulating Activities in this zone.

* To whom all correspondences should be made

Background

After the CRZ notification came into force, a baseline information on the landuse / landcover features in Coastal Regulation Zone (CRZ) of the state of West Bengal was generated in order to assess the sustainability as well as vulnerability of the coastal resources before formulation of any policy matter like Coastal Zone Management Plan (CZMP). For this purpose, preparation of land use/land cover maps, with special emphasis on built-up area, tidal wetlands, sand mining areas, brick kiln areas on 1:25,000 scale was carried out following Survey of India (SOI) topographic sheets. Considering the efficacy and cost effectiveness of Remote Sensing, it was decided to utilise this technology. A three-tier classification system adopted at the national level was accepted for carrying out this work.

CRZ maps were prepared through visual interpretation technique of SPOT I HRV 2 MLA multi-spectral FCC (bands 123) data of 1988-1989 (in transparent sheets on 1:4,00,000 scale) using PROCOM II instrument. IRS 1B LISS II FCC (bands 234) data of 1992-93 in transparent sheets on 1:5,00,000 scale were also been consulted during interpretation for the areas where SPOT data was not available. The minimum mapping unit (MMU; 3 mm X 3 mm) at 1:25,000 scale is 0.5625 ha (1.38 acre). However, considering the average plot areas in rural areas, this particular scale appears to be quite small so as to reflect the plot level details of the land use – land cover units.

At the same time, these maps carry the Latitude-Longitude details rather than the local level administrative units and their boundaries. Thus, the database created through such effort, although very useful at the State Level, seems to be of little help for carrying out any work at the local level. Not to talk of the villagers, even the policy makers and administrators at the district level get confused with the exact location of any particular project since they are more accustomed with the village boundaries and the cadastral level plots bearing specific settlement survey number rather than world geographic co-ordinate system. As a result, it has become always a problem to react for allowing or prohibiting any particular developmental project in this region following the guidelines of CRZ notifications, as amended from time to time. Incidentally, these maps are being used consistently mostly for this purpose only. At the same time, objective analysis points to the need for any such map showing certain additional features which can be easily understood at the local level.

Integrated Coastal Zone Management (ICZM)

Integrated Coastal Zone Management (ICZM), is used to describe a "continuous and dynamic process that unites government and the community, science and management, sectoral and public interests in preparing and implementing an integrated plan for the protection and development of coastal systems and resources" (GESAMP, 1996). The goal of ICZM has been declared as "to improve the quality of life of human communities who depend on coastal resources while maintaining the biological diversity and productivity of coastal ecosystems" (GESAMP, 1996). ICZM comprises of management of natural resources, conservation of biodiversity, maximization of socio-economic benefits and protection of life and property from natural hazards (such as cyclonic seastorms). It is generally understood that there is no standard universally accepted blueprint to organise, plan and implement an ICZM program. The plan must be tailored to fit into the institutional and organizational environments of the countries or regions or at the local level, including political and administrative structures, economic conditions, cultural patterns and social traditions. Simultaneously, from the traditional planning process, a strong departure is envisaged in case of ICZM. The keyword here would be 'Participation' rather than 'Planning', locus of decision making would be 'Decentralised' rather than "Centralised' and the relationship with the clients, i.e. the people at large would be 'Enabling, Empowering' rather than 'Controlling, Inducing'. Thus, the role of local people as well ground level planners are of immense importance for carrying out ICZM. As a result, the tools to be used for such process should be devised in easily understandable manner so that the local people can utilise it with the backdrop of their real life existence. No systematic effort in this regard has ever been taken up. The present work seems to bridge this gap by developing maps showing HTL, land use patterns, CRZ boundaries etc. in relation to the smallest possible administrative boundaries of our country i.e. land holding plots. Considering the efficacy and cost effectiveness of Remote Sensing, it was decided to utilise this technology. With the advent of high resolution data, IRS 1D LISS III data fused with PAN data has been utilised for this purpose.

Study Area

The 220 km. long coastal stretch (between 87^0 26'E to 89^0 08'E) of West Bengal extends from Subarnarekha estuary on west to Harinbhanga river in the east. The Coastal Regulation Zone of West Bengal is the Lower Ganga Delta plain. This stretch of coastal Quaternaries exhibits varied geomorphological signatures (sand dunes, beach ridges, flood plains, tidal shoals etc.) evolved out of dynamic and varied interactions of river and marine agencies.

Methodology

There are two major steps for carrying out this work – i) analysis of remote sensing data and ii) GIS data base creation.

2.

3. Analysis of Remote Sensing data

Base maps showing various prominent and permanent features like roads, man-made canals, embankments, even creeks (particularly in case of mangrove region) etc, identifiable in images were prepared on 1:50,000 scale for the entire area from SOI topographic sheets. These base maps were scanned and geo-referenced so that correlation between images and ground can be established. IRS 1D LISS III and PAN data (February'03) were obtained from NDC, NRSA, Hyderabad. The data used are mostly acquired during low tide condition since during low tide condition, most of the coastal wetlands are exposed and there by easy to identify.

IRS 1D PAN data are first georeferenced with the help of the already georeferenced scanned base maps. Subsequently IRS LISS III image were registered with the help of these PAN data. As a result, both these data become compatible with each other. Both the data were projected to polyconic projection with E006 ellipsoid and D076 datum and with respect to a fixed point of longitude of central meridian and latitude of projection origin. These data were then fused with each other to produce a merged product with higher resolution of 5.8 m.

On screen visual interpretation of these merged geo-referenced image on 1:12,500 scale was carried out to produce the land-use/land-cover map of entire CRZ area and shore line maps along the coast. MMU at this scale is 0.1406 ha. For this purpose, HTL is delineated first. In coastal area of west Bengal especially in Midnapore coast, an earthen embankment was constructed in pre-independence period all along the coast to protect the cropland from tidal inundation. This embankment is easily identifiable in RS images and has been identified as HTL since today also in highest of high tide water reaches up to this extent. But in other part of the coast where such anthropogenic structures are absent, demarcation of HTL has been done by considering preliminary image interpretation factors like sudden change of color, tone, texture and along with the geographic association of the land cover. After delineation of this HTL, a buffer of 500 m is drawn which serves the purpose of CRZ boundary. Individual land use/land cover map units within the CRZ are demarcated through the same technique of on screen digitisation based on the method of visual interpretation technique. The entire CRZ area was then clipped out from the original image so as to isolate the area of interest (AOI). The raster data thus created was transformed into vector format through Raster to Vector (RTV) transformation and stored in the ARC-Info environment for further integration of other secondary data in GIS environment.

4. GIS data base creation

Individual village boundaries, based on revenue survey, were demarcated during pre-independence period on the then police station (PS) maps on 1:63,360 scale maps (1 inch = 1 mile). It has been observed that more than one police stations have now evolved out of the individual police station. To bring the village-wise information, these old PS maps are digitised and stored in ARC-Info environment with the same parameters, as mentioned above. Primary Census Abstract (PCA) data are then attached with the individual polygons representing respective villages. Based on PCA, the outer boundaries of new PS have also been deciphered out of the old ones. This vector layer is then overlaid on the raster CRZ image so as to identify the individual villages, which are concerned from the management point of view of CRZ of West Bengal.

Once these villages are identified, the cadastral maps of these villages on 1:3960 scale have been collected from the district land revenue office and digitised to transfer the analog information in digital format. It is to be mentioned here that these cadastral level maps were created based on plane table survey and they do not have any georeferencing or projection system. In order to put them into GIS environment, these cadastral level maps are georeferenced with the help of GPS and with respect to prominent points (such as particular corner of any water body etc. Once this has been over, these cadastral maps are also projected in polyconic projection with the same parameters, as mentioned above.

The location of HTL as well as CRZ boundary with respect to individual land plots have then noted. Paper prints of individual CRZ maps, if required, can now be printed out for use of the local level policy makers. These outputs posses clearly an advantage over the initial maps which were created through analysis of SPOT data on 1:25.000 scale.

Results and Discussions

Results obtained so far, is very encouraging. So far the entire database of PS maps have been created. Due to considerable amount of distortions within the PS maps, it has been observed that PS maps should be registered individually with respect to reference points available within the individual map itself. After that only stitching of the adjacent maps should be carried out. With this technique, the output seems to be more accurate and the amount of distortions in individual maps can be made confined within the same map. But when it comes the question of cadastral maps, since these maps are devoid of any projection system, stitching and joining of these maps are leading to major distortions. As a result, it has been found that these maps should be kept in isolation and linked with the original database with a key link. This will result in viewing the individual cadastral maps at a time, whenever a specific map is asked for. Thus the spatial database of CRZ area has been made in such a manner, so that the village level policy makers and even the general people can be involved with preparation of ICZM along the West Bengal coast.

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Dona Paula, Goa, India 403 004

International Workshop on Marine Pollution and Eco-toxicology
February 2004

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Note: This list includes the participants from Institutions other than NIO, Goa.

APPENDIX X

BRAINSTORMING WORKSHOP - NEPAL

Contents

TECHNICAL BRAINSTORMING WORKSHOP ON RIVER SEDIMENTATION

NEEDS AND ISSUES

Jointly Organized by

Department of Hydrology and Meteorology (DHM), Babar Mahal, Kathmandu
Department of Water Induced Disaster Prevention (DWIDP), Jawalakhel, Lalitpur
Hydro Lab Pvt. Ltd. (HL), Lalitpur

24-25 January 2003

Opening

The workshop started with the welcome remarks by Adarsha P. Pokharel, Director General, DHM. In his address, he expressed the view that water resources development of Nepal cannot be materialized without proper management of sediment. He indicated the lack of proper documentation of disaster caused by sediment, although Nepal has been suffering severe damage because of such recurrent disasters. He added that although DHM is mandated to monitor sediment, it is lagging behind to do so due to several practical and technical difficulties.

Mr. N.P. Gautam Director General, DWIDP expressed that sediment and disaster are closely related to each other in Nepal. He further highlighted the importance of studies on sediment for proper understanding of the processes involved so that effective measures could be taken to mitigate sediment related disasters.

Highlights of the proceeding are attached as Annex I and the list of the participants is attached as Annex II.

Discussion

The workshop had major focus on the ongoing sediment related activities at DHM, NEA, and Hydrolab. Most of these presentations included the sediment monitoring activities and research on sediment control for water resources projects. Each presentation was followed by open discussion. The major discussion was focused on problems related to quantity and quality of data and research areas on sediment that required urgent actions.

One of the major problems identified at DHM was the limited training provided to sediment sampling technicians. This has resulted in the poor quality of sediment data obtained from the gauging sites. Participants realised that, unlike other hydrological and meteorological observations carried out by DHM, sediment sampling and monitoring is a much more difficult task requiring high level of expertise and complex procedures. Hence, less sophisticated equipment and simplified procedures have to be explored for a sustained sediment monitoring system. Such a system, developed as a part of a project supported by Asia Pacific Network (APN) in Nepal was one of the major areas discussed in the workshop.

Lack of coordination among sediment monitoring organizations including DHM was another problem discussed in the workshop.

The additional research area identified was the development of procedures to ascertain proportion of bed load to suspended load in Nepali rivers. Development of bed load estimation formula and verification of applicability of available bed load formula for Nepali rivers was considered essential particularly because of the highly diverse nature of the river characteristics.

The sediment data for over ten years collected in lower Marsyangdi for the Marsysngdi Hydropower Project was considered as a source of well documented information on sediment sampled using modern equipment and technology. Participants were advised to make the best use of these data while assessing sediment load for medium sized river valley projects in Nepal.

Recommendations

After the presentations by participants on various aspects of sediment followed by discussions, finalized recommendations of the workshop are presented below.

- Institutional development of sediment monitoring and research system can provide significant input in water resources development and disaster mitigation activities. Accordingly, sediment monitoring and research activities should get due importance.
- Reliable and accurate sediment data is very difficult to secure because of the complexities of standard sediment monitoring procedures. Appropriate but simple sediment monitoring methods and equipment should be adopted for regions lacking skilled human resources.
- Sediment data collection, monitoring and evaluation have been done and are being done by various government and non government organizations such as Nepal Electricity Authority, Department of Irrigation, Water and Energy Commission, Hydrolab, International Centre for Integrated Mountain Development and several donor funded projects in Nepal. Because of these uncoordinated activities, the effort put in the sediment data management in Nepal

has become ineffective and inefficient causing inadequate sediment data and data availability problem. Therefore, DHM needs to be strengthened as a leading and coordinating agency to carry out sediment monitoring and sediment management activities in Nepal.

- Detail plan of action for strengthening DHM needs to be prepared.
- An Interagency Technical Committee consisting of members representing from government and non-government organizations should be formed. The committee should also include organisations that use sediment data. Such a committee is necessary to avoid duplication of efforts, and to monitor ongoing activities. The committee should have access to planning and policy formulation bodies so that it could influence such organizations for developing proper schemes in relevant projects and departments.
- Sediment has remained as a neglected subject in planning and policy despite its high importance in any water resources development programs in Nepal. Therefore, policy-making bodies, such as the National Planning Commission, should review sediment related activities as a very important component in any water resources development and disaster mitigation projects.
- Sediment is a subject requiring short and long-term programs. DHM needs to explore and involve the skills and expertise of academic institutes such as Tribhuvan University, Kathmandu University, Institute of Engineering and other appropriate private research organizations such as HL. Involvement and collaboration of outside organizations is essential because of inadequate infrastructure, skill and expertise available at DHM at present.
- Next workshop should follow this workshop for strategic plan for sediment monitoring, management of sediment related activities and for prioritising research areas.

Annex I

Highlights of Proceeding

Dr. K.P. Sharma, Senior Divisional Hydrologist, presented a comparative study of sediment research carried out for different projects in Nepal. He pointed out some discrepant result of sediment load of the same river prepared by different consultants following their own procedures of sampling. He focused on the need of simplification in monitoring and analysing sediment samples for continuous and quality data. Some proposals for simplification of sediment monitoring system were pointed out for discussion. One of the issues identified was that sediment monitoring for small rivers was severely lacking. Estimates for small rivers, using the data available for relatively large rivers, were likely to differ significantly from the realities.

Mr. P.M. Singh, General Manager, Hydro Lab Pvt. Ltd, highlighted the importance of Sediment data in Hydro Power Plants for efficient planning, management and operation. He emphasized on the quality of sediment data in addition to some specific requirement for typical Hydro Power Plants. He highlighted the problems related to standardization for comparative studies.

Mr. G. R. Rajkarnikar, Senior Divisional Hydrologist, Water and Energy Commission (WECS), presented the present status and policies of sediment activities in Nepal. He pointed out the difficulties in compilation and accessing the information on sediment activities carried out by various agencies. He suggested forming a pressure group to include sediment monitoring and research activities in Integrated Water Plan, presently being formulated in Nepal.

Based on group discussion by the participants, formation of an Inter Agency Technical Committee containing technical experts from various sediment interested agencies was recommended. A higher-level committee for commitment to strengthen and activate the recommendations of the technical committee had also been emphasised.

G Kayastha, Sedimentlogist Nepal Electricity Authority (NEA) presented the scope of sedimentation in development context giving his experience in Marsyangdi Hydropower project. He described a few specific requirements of sediment information for various aspects of application in planning and management of water resources schemes. He found average bed load in Marsyangdi River to be approximately 15% of the average suspended load and observed the variation between 10% to 20%. Mr Kayastha presented the status of sediment information collected for the Marsyangdi Hydropower Project in Nepal. He suggested a method for estimating sediment loads on the basis of sediment rating curve developed for the Marsyangdi.

Mr. J. K. Bhusal, Senior Divisional Hydrologist, DHM, presented methodologies and approaches applicable for sediment management in Nepal. Such approaches wee presented in view of the drawbacks in the existing sediment monitoring system in Nepal. He proposed a pressure group, which could work on enhancing co-ordination and co-operation improve the quality of sediment information in Nepal. Roles of private organizations and academic institutes were also discussed for their potential inputs in different areas of research work.

A.P. Pokhrel, Director General, DHM summarized the following recommendations as an output of the workshop.

1) Policy makers pay special attention to bring up the sediment monitoring activity as one of the high priority areas in their plans and programs.
2) DHM take lead to expand sediment-monitoring activities in close co-operation and collaboration with various governmental, nongovernmental, academic institutes and private organizations.
3) Organizational adjustments within DHM to develop the organization as a focal point in sediment monitoring activities.
4) Initiation of the establishment of a pressure group “Interagency Technical Committee” to manage resources, identify specific requirements and to incorporate sediment related activities in the ongoing 'Integrated Water Plan' of Nepal.
5) A write up committee of K.P. Sharma; D.D. Bhattarai and P. M. Singh were formed to finalize the draft report of this workshop by the end of May 2003 under the co-ordination of K.P. Sharma.

List of Participants

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APPENDIX XI

National Seminar on

"Material Fluxes to the Coastal Zone: Synthesis of Sri Lankan Studies and Plans for the Future"

Contents

Workshop on "Material Fluxes to the Coastal Zone: Synthesis of Sri Lankan Studies and Plans for the Future"

13th September 2002
8.30 am – 3.30 pm, SLAAS Auditorium

PROGRAMME

Time (Hours)	
0830-0845	Registration

Session 1 : APN Project and associated research

0845-0900	Introduction and Overview of APN Project *Dr. Janaka Ratnasiri, Principal Investigator*
	Research Presentations
0900-0915	Changes of Mundel Wetland System *Prof KNJ Katupotha, University of Sri Jayawardenapura*
0915-0930	Silica retention in man-made lakes in Sri Lanka *Prof. Ivan Silva, Institute of Fundamental Studies*
0930-0945	GIS mapping of nutrient loading into rivers in the Mahaweli catchment area *Prof Swarna Piyasiri, University of Sri Jaya'pura (Presentation was not made)*
0945-1000	Flux dynamics of shallow tropical water bodies *Mr. Arulananthan, National Aquatic Resources, Research & Dev. Agency*
1000-1015	Fertilizer run-off from rain-fed paddy cultivation *Dr. Nalin Wikramanayake, Open University of Sri Lanka*
1015-1030	Discussion on presentations
1030-1045	Morning Tea

Session 2: Integration of Research and Environmental Management

1045-1100	Review of related research in Sri Lanka *Dr. Nalin Wikramanayake*
1100-1115	Presentation Integrated Resources Management Project – IRMP *Dr. Jayampathy Samarakoon*

1115-1130	Discussion
1130-1200	Panel Discussion - Including the human dimension in coastal environmental research

Session 3: Plans for the Future

1200-1245	Panel Discussion on “Action Plan and Recommendations for the North-east Coast”
1245-1345	Lunch

Session 3 : Plans for the Future (continued)

1345-1405	International Programs and Networking *Dr. Nalin Wikramanayake*
1405-1445	Working Groups on Future Projects and Environmental Monitoring
1445-1505	**Report of Working Groups and Discussion**
1505-1515	Summary
1515-1530	Afternoon Tea

National Seminar on Coastal Nutrient Flux Studies

13 September, 2002, SLAAS, Colombo

List of Participants

No.	NAME	ORGANISATION
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APPENDIX XII

Regional Workshop on Assessment of Material Fluxes to the Coastal Zone in South Asia and their Impacts 08 – 11 December 2002, Negombo, Sri Lanka

Contents

The Abstracts of the presentations made at the Workshop are given in Appendix III to this report.

The full papers of the presentations are given in the Proceedings of the Workshop, which has been published separately.

APN/START/LOICZ Regional Workshop on
Assessment of Material Fluxes to the Coastal Zone in South Asia and their Impacts

08 – 11 December 2002, Negombo, Sri Lanka

Workshop Programme

08th Sunday

Inauguration & Reception

1700 Welcome Address and Project Overview
Dr Janaka Ratnasiri, Principal Investigator

1720 Inaugural Address by the Chief Guest
Mr Thosapala Hewage, Secretary, Ministry of Environment and Natural Resources

1740 Address on behalf of SASCOM
Dr A P Mitra, Director, Centre for Global Change, National Physical Laboratory, India

1750 Address on behalf of APN
Dr C Sharma, APN/SASCOM Liaison Officer, Centre for Global Change, National Physical Laboratory, India

1800 LOICZ Address
Dr Chris Crossland, Executive Officer, LOICZ, The Netherlands

1820 Reception (Dinner)

09th Monday

0830 Registration

0900 Welcome and Introduction
Dr Nalin Wikramanayake, Country Leader – Sri Lanka

Session I: Technical presentations

0915 Keynote Address - Consideration of Future Changes in River Sediment Flux for Coastal Planning
Prof Steven L Goodbred, Jr., Stony Brook University, USA

Part 1: Technical papers on Deliveries to the Coastal Zone

0945 Fertilizer Runoff from Rain-fed Paddy Cultivation
Dr Nalin Wikramanayake, Open University, Sri Lanka

1000 Estimation of Nitrogen and Phosphorus Fluxes to Embilikala and Malala Lagoons in Southern Sri Lanka
Mr S C Piyankarage, International Water Management Institute, Sri Lanka

1015 Water, Nutrient and Sediment Flux study through the Lower Meghna River Estuary (Hatiya Channel)
Dr Nuruddin Mahmood, University of Chittagong, Bangladesh

1030 Material Flux through the Karnaphuli River-estuary
Mr Seydur R Chowdhury, University of Chittagong, Bangladesh

1045 Study of Nutrient, Sediment and Carbon Fluxes into the Indus Delta System
Dr S H Khan, National Institute of Oceanography, Pakistan

1100 Tea and Poster Session I

1120 A Study of Sediment Fluxes to Coastal Zone in South Asia and Their Relationship to Human Activities
Dr Keshav P Sharma, Department of Hydrology and Meteorology, Nepal

1135 Silica Fluxes in Three River Systems in Sri Lanka
Prof E I L Silva, Institute of Fundamental Studies, Sri Lanka

Part 2: Technical papers on Biogeochemistry

1150 Biogeochemical Budgets for Tapi Estuary
Dr Simon N de Sousa, National Institute of Oceanography, India

1205 Biogeochemistry of the Cauvery Estuary and Pichavaram Mangroves - SE Coast of India
Prof A L Ramanathan, Jawaharlal Nehru University, India

1220 An Assessment of Nutrient Budgets of Lunawa Lagoon, Sri Lanka
Dr Saman P Samarawickrama, University of Moratuwa, Sri Lanka

1235 Nutrient Characteristics in the Coastal and Coral Reef Environment of the Gulf of Mannar Biosphere Reserve, India
Dr L Kannan, Annamalai University, India

1250 Summary Discussion on Morning Papers and Future Research

1315 Lunch

Part 3: Technical Session on Material Concentrations in the Coastal Waters

1415 Heavy Metals Uptake by Marine Biota in Pondicherry Coastal Zone, Bay of Bengal – India
Dr Ragasakthi S S Sundarvel, Pondicherry University, India

1430 An Environmental Assessment of Metal Accumulation in the Karnafully Estuary, Bangladesh
Dr Shahadat Hossain, University of Chittagong, Bangladesh

1445 The Complex Estuarine Formation of Six Rivers (Cochin Backwater System on West Coast of India) - Sources and Distribution of Trace Metals and Nutrients
Dr Joseph S Paimpillil, National Institute of Oceanography, India

1500 Nutrient Level of Coastal Waters in and around Mumbai (Bombay)
Dr B G Kulkarni, The Institute of Science, India

Part 4: Technical Session on Coastal Impacts

1515 Impact of Reduced River Discharge on the Mangrove Ecosystem and Socio-economy of Indus Delta
Dr Shahid Amjad, National Institute of Oceanography, Pakistan

1530 The Anthropogenic Affects and Natural Hazards on the Stability of the Indus Delta and Creek System
Dr A Inam, National Institute of Oceanography, Pakistan

1545 Tea and Poster Session II

1600 Recent Trends in Environmental Degradation in the Coastal Areas Developed for Shrimp Culture
Ms A S L E Corea, National Aquatic Resources, Research & Development Agency, Sri Lanka

1615 Impacts of the Reclamation of Acid Sulphate Soil Sediments on Coastal Environment
Dr J M P K Jayasinghe, University of Wayamba, Sri Lanka

1630 Human Impacts on Wetland Ecosystems – A Case Study – The Mundel Lake and its Environs – Sri Lanka
Prof K N J Katupotha, University of Sri Jayawardenapura, Sri Lanka

1645 Human Activity Management in Coastal Zone of Sri Lanka
Eng L W Seneviratne, Irrigation Department, Sri Lanka

1700 Summary Discussion on Afternoon Papers and Future

10th Tuesday

Session II: Integration of Research and Management – Regional Issues

Part 1: Presentation of Country Papers

0830 *Introduction to Country Papers*
Dr Nalin Wikramanayake

0845 Bangladesh Country Paper
Dr Nuruddin Mahmood

0900 India Country Paper
Dr Simon N de Sousa

0915 Nepal Country Paper
Dr Keshav P Sharma

0930 Pakistan Country Paper
Dr Shahid Amjad

0945 Sri Lanka Country Paper
Dr Nalin Wikramanayake
1000 Summary discussion on Country Papers

1030 Tea

Part II: Presentations by Coastal Zone Management Programmes

1045 Coastal Resources Management Project
Mr Indra Ranasinghe, Coast Conservation Department, Sri Lanka

1105 Hambantota Intergrated Coastal Zone Management project
Mr.Hector Hemachandra(), Caost Conservation Department, Sri Lanka

1125 Integrated Resources Management Project
Dr Jayampathy Samarakoon, Central Environmental Authority, Sri Lanka

1145 Discussion session on integration of research and management and inclusion of human dimension

1215 Lunch

Part III – Presentations by other Regional Programmes

1315 UNEP Global Programme of Action

Mr Prashantha Dias Abeygunawardena, SACEP, Sri Lanka

1335 GIWA
Dr Jayampathy Samarakoon, Central Environmental Authority, Sri Lanka

1355 IUCN Regional Marine Programme
Mr Shamen Vidanage, IUCN Sri Lanka

1415 IOGOOS
Dr Nalin Wikramanayake, Open University, Sri Lanka

1435 Discussion on interaction between programmes

1500 Tea

Session III: Interactive Session 1

1515 Keynote Address – LOICZ Plans and Futures
Dr Chris Crossland, LOICZ

1530 Ranking of impacts and priority issues – Part 1

1615 Proposal development for EU funding – Preliminary discussion

Field Visit I: Negombo Lagoon and Muthurajawela Marsh

1645 Boat trip to lagoon mouth
Muthurajawela Visitor Centre

11th Wednesday

Session IV: Interactive Session 2

0830 Keynote Address – Modelling?
Prof Charitha Pattiaratchi, University of Western Australia, Australia

0900 Tutorial on Flux calculations, Budgets and Links to Management
Dr Laura David, University of Philippines, Philippines

0930 Group Work on Budget Calculations

1200 Lunch

1300 *Continue Budget Calculations*

1500 Tea

1515 Proposal development for EU Funding – Finalise

1615 Continue ranking and priority issues – Part II

1645 Wrap-up Discussion and Closing Announcements

APN/START/LOICZ Regional Workshop on Assessment of Material Fluxes to the Coastal Zone in South Asia and their Impacts
08 – 11 December 2002, Negombo, Sri Lanka

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Report on

APN/SASCOM/LOICZ Regional Workshop on Assessment of Material Fluxes to the Coastal Zone in South Asia and Their Impacts

8-11 December 2002, Negombo, Sri Lanka

by

Dr C. Sharma, APN Liaison Officer, SASCOM

The inaugural session of the `APN/SASCOM/LOICZ Regional Workshop on Assessment of Material Fluxes to the Coastal Zone in South Asia and Their Impacts', which took place at the `Browns Beach Hotel' in Negombo at 5 PM on 8th December 2002 was initiated with the lighting of lamp. Dr Janaka Ratnasiri, Principal Investigator of the project welcomed all the guests and delegates in the beginning of the inaugural session and provided the project overview. He also apprised about the efforts undertaken to strengthen the APN project team for achieving the objectives of the project. After the welcome address of Dr Ratnasiri, Dr C. Sharma, APN Liaison Officer for SASCOM welcomed the delegates on behalf of the APN and apprised the delegates about APN's history, background, objectives, framework and available opportunities.

Dr A.P. Mitra, Director, SAS-RRC provided the overview of the activities of START and SASCOM. He also informed the new programme being initiated by START like on Urbanization, Monsoon Asia, Young Scientists Conference etc. and opportunities available under START for capacity building like Young Scientists Scheme and Visiting Scientists Scheme.

Mr. Thosapala Hewage, Secretary, Ministry of Environment and Natural Resources, Sri Lanka, who was the chief guest of the inauguration function, next addressed the meeting. In his address, Mr. Hewage underlined the importance of coastal zones and related research for Sri Lanka. He told that Sri Lanka has already commissioned the `Inundation of Coastal Zone Program' under US Country Study Program. He also informed the audience that socio-economic modeling of ocean have been carried out in Sri Lanka and the gap areas have been identified on the basis of which a program has been formulated and presented during the Johannesburg meeting. Inaugural session was followed by the reception.

The second day's session was initiated by welcome and introductory remarks of the Dr Nalin Wikramanayake, Sri Lanka Country Leader of APN Project. This was followed by the keynote address of Prof. Steven L. Goodbred Jr. of Marine Science Research Centre of State University of New York, Stony Brook on global change issues related to coastal zones. During the rest of day, about 23 technical presentations were made by the project team members and other participants on the studies carried out by them in Bangladesh, India, Pakistan and Sri Lanka dealing with the deliveries to the coastal zones, bio-geochemistry, material concentrations in coastal waters and coastal impacts.

During the evening, participants worked with Dr Laura David of Marine Science Institute, University of Philippines on the LOICZ-CABARET model to quantify the nutrient fluxes based on their own data.

The third day's session was started with the presentation of country papers highlighting the regional issues. In the beginning, Dr Nalin emphasized the need to modify the country papers in a suitable form, which can be considered by LOICZ to bring out as its report on South Asia, which was accepted by the participants. Dr Ratnasiri suggested that modified papers could be resubmitted to him in next two months so that an integrated report on South Asian Coastal Zone can be formulated and that would also help in the preparation of report for submission to APN before the deadline.

In his country report on Bangladesh, Dr Nuruddin Mahmood outlined the logistic problems encountered by the Bangladesh team in dealing with large estuarine areas and the methodologies they have adopted. He informed that his team would be able to complete the identified task of the project by about July 2003. He distributed a printed copy of the Bangladesh Country Study to the participants.

Dr Simon N. de Sousa, who presented the Indian Country Report, informed that although the gap filling activities could bot be undertaken so far due to various problems, a large number of secondary data has been collected and compiled and used for nutrient budget calculations. He presented the nutrient flux budget of several river basins of western India. He informed that nutrient fluxes of rivers of eastern coast of India would be worked out soon in future.

Dr. K. P. Sharma, who presented the Nepal Country Report, emphasized the need to build capacity for monitoring, analysis of data and modeling in Nepal as these are the major constrains. He presented details of measurements facilities and available data in Nepal. He also outlined the issues like sedimentation, floods and water availability, which are crucial in Nepal's context.

Dr S.N.H. Rizvi presented the Pakistan Country Report informed the delegates that a large number of studies have already been carried out in Pakistan related to coastal zones (especially on the Sindh Coastal Zone) and an effort has already been started to compile and integrate them to synthesize useful information. One of the important parameters, which has not been studied so far in Pakistan and needs to be investigated, is atmospheric deposition in the coastal zones.

Dr Nalin Wikramanayake presented the Country Report of Sri Lanka. He summarized the work carried out so far in the Sri Lanka coastal zone and proposed to expend the team by involving other scientists and researchers interested in this study.

During the discussion session, participants emphasized the need for the generation of meta-data information. Dr Mitra informed that SASCOM would update its Directory of `Scientists of South Asia' by early next year, which would be available for every one to use.

The next session was devoted to the Sri Lanka Coastal Zone Management Programs in which Mr. Indra Ranasinghe of Coast Conservation Department presented the elements of Sri Lanka Coastal resource management Project and stressed the need of quality scientific inputs for framing viable policy by the governments. He also underlined the role of local bodies and stakeholders in implementation of policies.

Dr Johan Bentinck then provided the details of `Integrated Resources Management Project' undertaken in Muthurajawale Wetlands of Sri Lanka. This was followed by the panel discussion on research need and management. The general consensus emerged from the discussion was about the need to evolve a process in which stakeholders problems can be addressed with the scientific solutions through appropriate policy decisions.

In the next session, workshop participants were informed about the various ongoing international programs. Mr. Prashantha D. Abeygunawarena apprised about the UNEP Global Programme of Action in which seventeen `regional Seas Program' have been initiated involving 140 countries. The 'South Asian Sea Program' is the youngest among all of these and has become effective from 1998. The member countries of this program are India, Pakistan, Bangladesh, Sri Lanka and Maldives.

Dr V. Subramaniam apprised about the status of 'Global International Water Assessment (GIWA)' program, which is about the evolving of the project on the water bodies co-shared by different countries. The details about 'Indian Ocean Global Ocean Observing System (IOGOOS)' was provided by Dr Nalin who also informed that the proposals under this program are being under preparation presently and interested scientist can contact the respective leaders for different target areas for joining in this activity.

Dr Chris Crossland of LOICZ presented a detailed overview of LOICZ activities and informed about the 'new foci' for next phase of the LOICZ activities for next ten years.

A field visit was organized in the evening to the Negombo Lagoon area for the participants to have a feeling of actual situation in lagoon areas. Afterwards, participants continued to practice the LOICZ-CABARET model.

The fourth day's session started with the keynote address by Dr Charitha Pattiaraatchi of Council for Water Research of University of Western Australia on 'Remote Forcing of Estuarine System'. In his talk, he dwelled upon the issues of remote forcing by factors like storms which occur thousands of miles away on the estuarine systems.

Dr Laura David, next, clarified the issues related to LOICZ modeling which were raised by the participants during the 'hands-on' training sessions. This was followed by further work by the participants on their model outputs. Discussions also took place about the ranking and assessment of issues in the perspective of region. It was agreed that participants will work on these issue after their return to their respective countries through discussions with their national colleagues.

In the afternoon session, Dr Chris Crossland proposed to bring out two reports on 'bio-geochemical budget' comprising of the seven budget presented during this workshop and two budgets presented in first workshop of the project held in 2000 in Sri Lanka. This report will also include few papers presented on nutrient fluxes in this workshop. The other report proposed to be brought out will be in the form of regional assessment report based upon the papers and country reports presented in this workshop and would also include information available elsewhere. Two more regional workshop have been proposed to consolidate this endeavor for which funding will be explored. Dr Crossland assured of LOICZ help in these efforts.

The Workshop participants recommended that APN be requested to provide an extension of the project till June 2003 to help in achieving the project objectives in view of the very late receipt of the funds during this year, which hampered the project progress during current year. Dr Ratnasiri also invited the country leaders to work with him to approach other funding agencies to strengthen the institutional arrangements which has been developed as a result of this APN funding for which there was general agreement among the workshop participants.

Dr Ratnasiri closed the workshop, thanking the sponsors, APN and LOICZ, the resource persons and the participants, the Ministry officals and others for their time, efforts and valuable contributions.