LAND-OCEAN INTERACTIONS IN THE COASTAL ZONE (LOICZ)

Core Project of the International Geosphere-Biosphere Programme (IGBP) and the
International Human Dimensions Programme on Global Environmental Change (IHDP)

South Asia Basins:
LOICZ Global Change Assessment and Synthesis of River Catchment Coastal Sea Interaction and Human Dimensions

R. Ramesh, R. Purvaja, A. Lakshmi, A. Newton, H.H. Kremer and J. Weichselgartner

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South Asia Basins: LOICZ Global Change Assessment and Synthesis of River Catchment - Coastal Sea Interaction and Human Dimensions

Edited by

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Cover: The cover photograph shows human activities on the banks of the Ganges River (Photo by R. Purvaja)

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Preface

The LOICZ South Asia Basin Study provides a regional assessment of catchment-coast interactions adopting the Driver-Pressure-State-Impact-Response (DPSIR) framework to integrate the issues in natural and social sciences with feedback to and from policy and management. The study deals with the impact of human society via socioeconomic activities (drivers) on the material transport to the coast, including water, sediments, nutrients, and other pollutants. Thus it is possible to assess the impacts on coastal systems and helps develop rational management options. While the focus is on land-based processes, impact and change are being explored particularly along the coasts. The catchment-coast linked system is being reviewed as water continuum, an approach LOICZ employed for its first global synthesis published in 2005.

This work is another contribution to the underlying global study conducted by LOICZ since 2001 and which has gradually evolved to a fully interdisciplinary approach. It complements other international and regional efforts to improve our knowledgebase of catchment-coast interaction and change and to better inform an integrated management of rivers, catchments and the relating coastal systems. The latter in particular includes providing an overview of the institutional dimensions of human response and how current and future requirements for adequate institutions may look like. Thus the LOICZ Basins studies contribute to the efforts under UNEP GPA (the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities). Along their concept, the Integrated Coastal Area and River Basin Management (ICARM), a global sequence of case studies, has recently been published (ICARM Case Book), which initially addresses the catchment-coast system and will therefore be complemented by this study. LOICZ further contributes to the coastal activities under UNESCO-IOC and has made initial efforts to apply and test progress markers for integrated management developed by EUCC. This latter approach of gauging changes in human behavior however is still work in progress and will be published elsewhere.

The case studies from the South Asian rivers indicate that loss of biodiversity, sedimentation and erosion are the primary impacts characterizing the receiving coastal zones. In addition, pollution and eutrophication are observed. In fact, in some of the systems investigated the water management upstream, i.e. damming and irrigation, causes severe effects due to the reduction of water flow to the coast, which can occasionally come to a total standstill. Further major pressures include changes in sediment load, excess nutrient inputs, siltation, direct discharge of untreated sewage, deriving from poor land use pattern, dredging, and water diversion. In summary, it is obvious that the major drivers, i.e. socioeconomic activities and developments, are to be located in agricultural land use and urbanization in tandem with industrial development. Some 250 million people live in South Asian coastal areas, attracted by the development options and bound by the sea – a growing phenomenon of “Coastal Squeeze”. These drivers are exaggerated by changes in the hydrological cycle and tropical storms and hurricanes.

The DPSIR concept is applied in a table format to each system to provide better oversight and it includes an expert-based categorization of impact classes. Relying on quantitative or semi-quantitative data, we arrive at an expert judgment typology of coastal systems impacts and land-based drivers. This study goes back to a workshop held in Colombo, Sri Lanka, in October 2005, kindly hosted by the then LOICZ Regional Node South Asia, and subsequent continued synthesis work under the auspice of R. Ramesh at the Institute for Ocean Management, Anna University, Chennai, India.

Acknowledgements

South Asia basins predominantly build on two pillars. Firstly, there was an expert workshop and capacity building activity conducted in Waikkal, Sri Lanka, 16-19 October, 2005, and associated assessments carried out under the auspice of the then LOICZ Regional Node South Asia, Colombo, hosted by the National Science Foundation of Sri Lanka. Secondly, workshop results and initial findings have been further developed and undergone comprehensive scientific review and revision under the leadership of R. Ramesh at the Institute for Ocean Management, Anna University, Chennai, India, in collaboration with LOICZ, the IPO and SSC Chairperson.

LOICZ is very grateful for the generous support and scientific input and coordination provided by the Regional Node and staff supported by NSF in Colombo, by the Anna University in Chennai, and in particular all the contributing scientists and reviewers who have continuously contributed to the scientific edit and review of this assessment report. We specifically thank the staff of the GIS department of the Institute for Ocean Management, Anna University, Chennai, namely J. Rajkumar, RM. Narayanan, V.P. Sathiyabama, A. Priya and R. Kalpana for their great work on the comprehensive maps featured in this report. We also thank B. Senthilkumar for compiling the reference list and J. Weichselgartner for his post-editing efforts.

LOICZ acknowledges the financial support the South Asia Basins project has received from international partners, namely the Programme of Action for the Protection of the Marine Environment from Land-Based Activities (UNEP-GPA), the International Hydrological Programme (IHP) and the Intergovernmental Oceanographic Commission (IOC), both under UNESCO. The Asia-Pacific Network for Global Change Research (APN) has officially endorsed this activity and promoted it through its regional intergovernmental networks.

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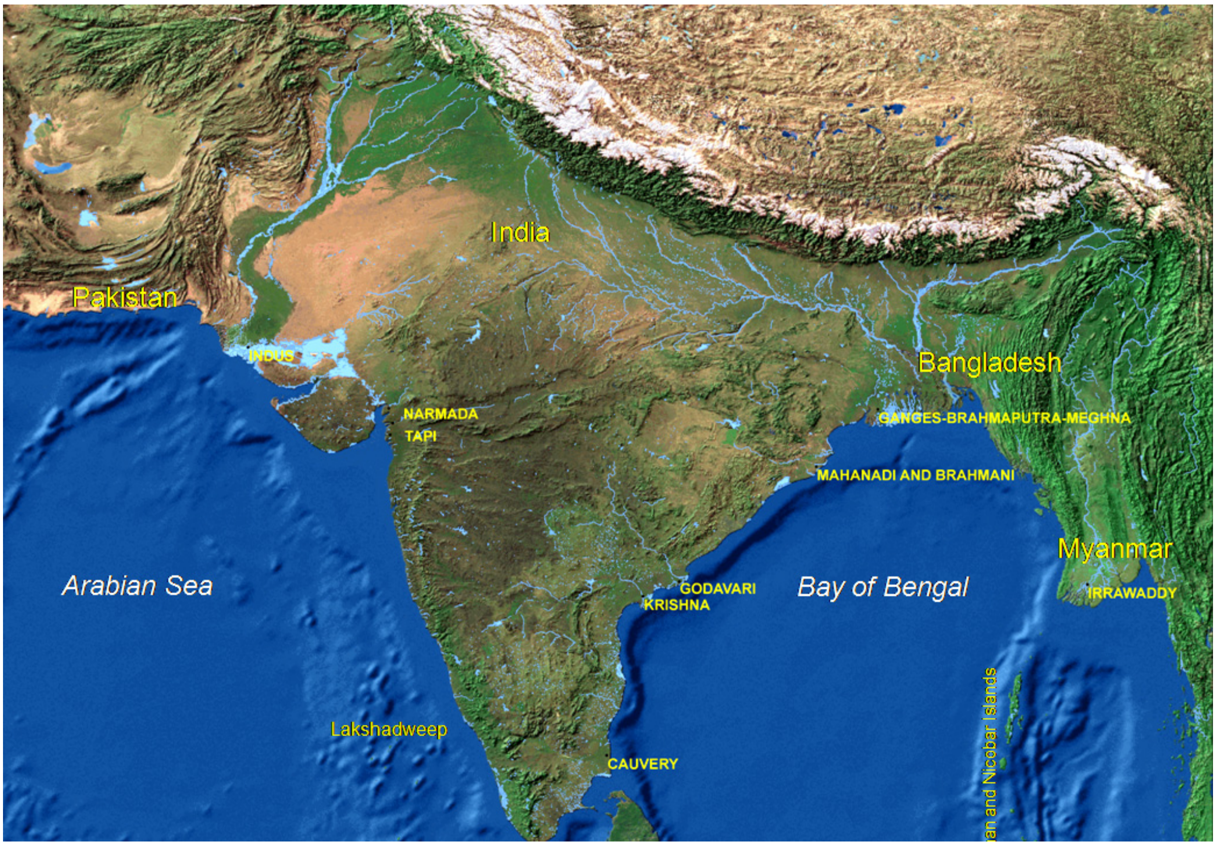
I. COASTAL GEOGRAPHY AND GEOLOGY

1 Coastal Geography and Geology of South Asia

South Asia is bordered in the south by the Indian Ocean, in the southeast by Bay of Bengal and in the southwest by the Arabian Sea. Occupying a major portion of the Indo-Malayan realm and a smaller portion of the Palaearctic realm, this region is representative of five of the fourteen major ecological regions (biomes), which demonstrate the biodiversity and vegetation patterns of the region as determined by climate, water, geology, soil and diverse topography[1]. South Asia's topography includes various landforms such as mountains, plateaus, dry regions, intervening structural basins, beaches, deltas and estuaries. Some of the world's largest river systems flow in South Asia. The countries that are included here are Myanmar (Burma), Bangladesh, India, Sri Lanka and Pakistan (Fig. 1).

***Fig. 1**: Map of South Asia* [2]



The Bay of Bengal is an arm of the Indian Ocean between India on the west and Myanmar and the Malay Peninsula on the east. A number of large rivers flow into the Bay of Bengal. These include Brahmaputra, Ganges, Mahanadi, Krishna, Godavari, Cauvery and Ayeyarwaddy. Due to the extensive riverine discharge, the Bay of Bengal has largely soft substrates off the mainland that are overlain by shallow, turbid waters.

Myanmar's coastline can be divided into three coastal regions: Rakhine, Gulf of Mottama (Ayeyarwaddy) and Tanintharyi – including 800 islands in Myeik archipelago of the Andaman Sea. The Rakhine coast, about 700 km long, is situated in the western part of Myanmar around the Bay of Bengal, and its northern part is built up of shallow sea with a chain of islands and some delta growth. The Ayeyarwaddy Delta forms the mouth of the Ayeyarwaddy River and its land boundary length is about 200 km. Sedimentation and annual delta growth lead to further shallow water sandbars in the Martaban Sea up to 50 km southward. The 900 km long Tanintharyi coast stretches as an almost straight line in north-south direction. The southern part of the Tanintharyi coastal line, from north of Dawei to Kawthaung, the southern end of Myanmar, is composed of a chain of islands called Myeik Archipelago[3].

Bangladesh is the downstream deltaic portion of a huge watershed with all major rivers flowing through it originating outside its borders. It has a low-lying, shallow accreting coastline and is unique in the region in that the influence of the sea is felt for a long distance inland. It is characterized by a vast deltaic network, an enormous discharge of sediment-laden water and numerous offshore sand and mud bars. The width of the continental shelf varies widely ranging from less than 100 km off the south coast to more than 250 km off the coast of Cox's Bazaar[4].

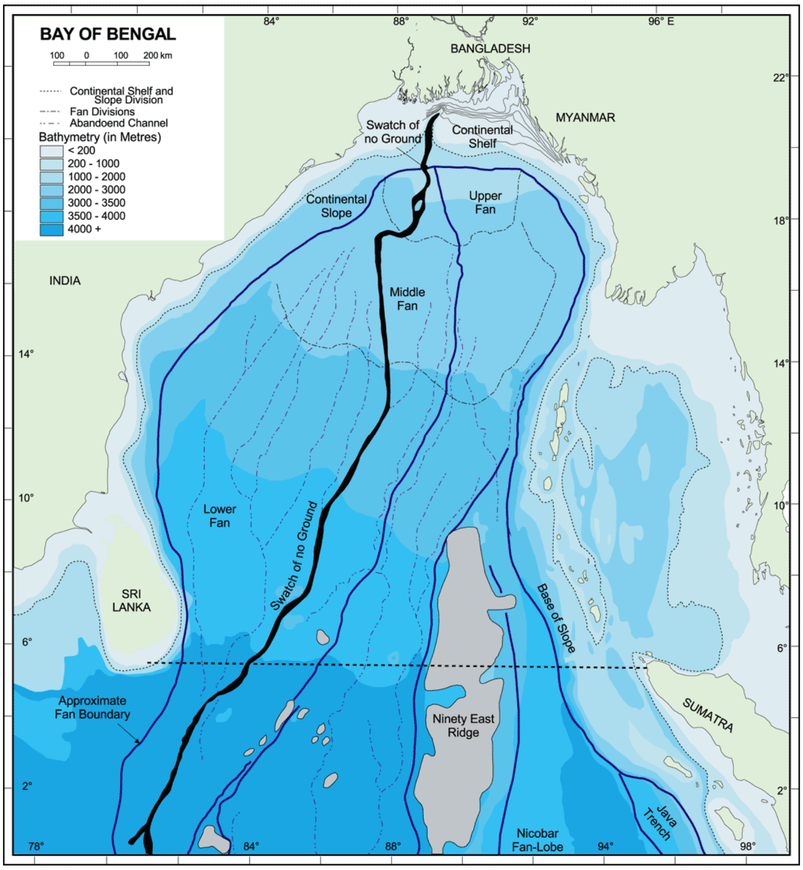


***Fig. 2**: The Bengal fan* [5]

The continental shelf of the eastern Indian coast (Bay of Bengal coast) is narrow (10-60 km) compared to the western coast (Arabian Sea coast) being 135 km (off Ratnagiri)[6]. The northern Indian Ocean has two major submarine fans: the Bengal fan (Bay of Bengal) and the Indus fan (Arabian Sea). These basins are filled with sediments derived mainly from the river systems. The Bengal fan is the largest deep-sea fan in the world covering ~3.0 x 10^6 km^2. It is ~3000 km in length, 1430 km at its maximum width, and 20 km at its maximum thickness. The Indus fan covers 1.1 x 10^6 km^2. It is 1500 km long, 960 km wide, and more than 10 km broad. While the Bengal fan receives sediments deriving mainly from the Himalaya, the Indus fan receives sediments from the alluvial soils of Pakistan and from Arabia[7].

The island of Sri Lanka lies in the Indian Ocean, to the southwest of the Bay of Bengal and to the southeast of the Arabian Sea. It is separated from the Indian subcontinent by the shallow Gulf of Mannar and the Palk Strait. A coastal belt only about thirty meters above sea level surrounds the island. Much of the coast consists of sandy beaches indented by coastal lagoons. In the Jaffna Peninsula, limestone beds are exposed to the waves as low-lying cliffs in a few places. In the northeast and the southwest, where the coast cuts across the stratification of the crystalline rocks, rocky cliffs, bays, and offshore islands can be found. These conditions have created one of the world's best natural harbors at Trincomalee on the northeast coast, and a smaller rock harbor at Galle on the southwestern coast. In Sri Lanka, rivers rise in the Central Highlands and flow in a radial pattern towards the sea. Most of these rivers are short and dry throughout most of the year except in the wet zone (mountains and southwest part of the country) where the water flow is perennial[8].

The Arabian Sea is the northwestern branch of the Indian Ocean. The region's largest river, the Indus, flows into this. The Arabian Sea has some of the most extreme climatic regimes due to seasonal fluctuations in air and water temperatures. West-flowing rivers include the Narmada, Tapi, Sabarmati, and the numerous rivers of Kerala on the western coast of the Indian peninsula. The Western Ghats, a chain of mountains, separate the narrow west coast from the rest of peninsular India. The west coast is known for beautiful beaches and backwaters. Table 1 gives a summary of coastal statistics of the South Asian countries.

***Table 1**: Coastal statistics of South Asian countries* [9]

Country	**Population** (million, July 2008 estimates)	**Total Sea Area**				**Length of Coastline** (km)
		Contiguous Zone (NM)	**Territorial Sea** (NM)	**EEZ** (NM)	**Continental Shelf** (NM)	
Bangladesh	154	18	12	200	Up to the outer limits of the Continental Margin	580
India	1148	24	12	200	200 or to the edge of the Continental Margin	7500
Pakistan	173	24	12	200	200 or to the edge of the Continental Margin	1046
Sri Lanka	21	24	12	200	200 or to the edge of the Continental Margin	1585
Myanmar	48	24	12	200	200 or to the edge of the Continental Margin	1930

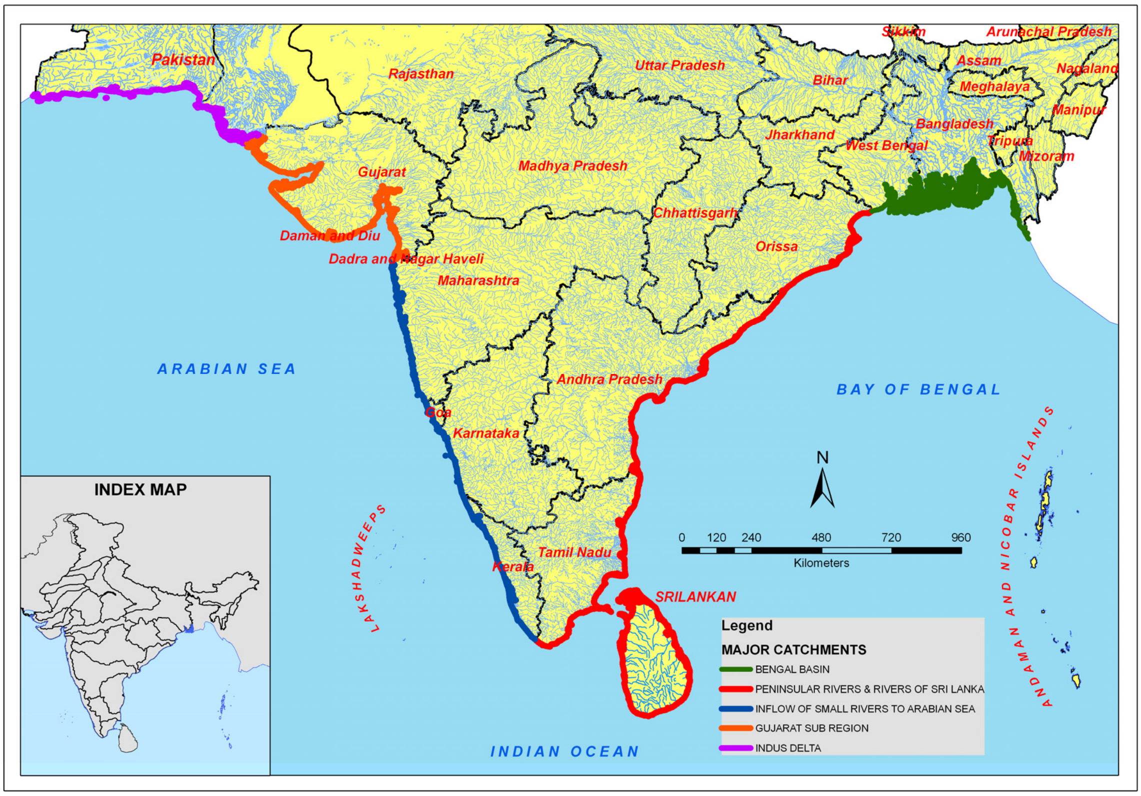
In this report, the river basins draining to the Bay of Bengal and the Arabian Sea coasts have been examined to arrive at an understanding of the drivers and pressures of catchment-based coastal change that are predominant in this region.

2 Catchments in South Asia

The major catchments addressed by the LOICZ Basins assessment in South Asia are from East to West (Fig. 3):

1. The Bengal basin
2. The Peninsular rivers (flowing into the Bay of Bengal) as well as the rivers of Sri Lanka
3. Small rivers flowing into the Arabian Sea
4. The Gujarat sub-region
5. The Indus delta

***Fig. 3**: Major catchments addressed by the LOICZ basins assessment in South Asia*



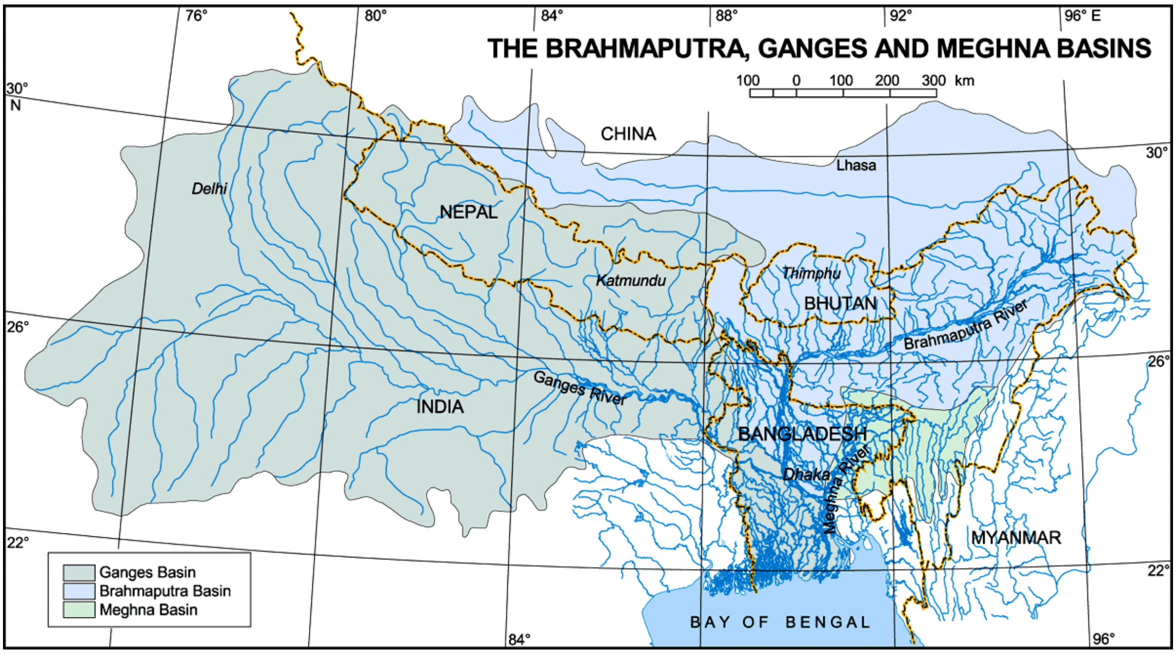
2.1 Bengal Basin

The Bengal basin (Fig. 4) lies partly in India with a substantial portion in Bangladesh. It is endowed with unique geographical features and a challenging terrain. It has one of the world's largest alluvial deltaic plains, accumulating the flow of three big rivers: the Ganges, the Brahmaputra, and the Meghna (GBM). Being vulnerable to atmospheric and oceanic adversities, the climate of the Bengal basin is sub-tropical monsoonal, experiencing moderate warm temperature and high humidity with heavy seasonal rainfall. During the tropical monsoon, the basin encounters widespread flooding, but in the dry months there is a shortage of drinking water supplies.

The GBM river basin covers an area of about 1.75 million km^2 stretching across Bangladesh (7.4 %), India (62.9 %), Nepal (8.0 %), Bhutan (2.6 %) and China (19.1 %). The mean annual precipitation is 1,200 mm and 2,300 mm in the Ganges and Brahmaputra-Meghna river basins, respectively. The system carries a peak flow of 141,000 m^3/s at its estuary, emptying about 1,150 billion m^3 of water into the Bay of Bengal. The Brahmaputra and Ganges rivers rank tenth and twelfth in the world, respectively, in terms of the discharge they carry. The estimated basin population is approximately 535 million (75.8 % in India; 20 % in Bangladesh; 3.5 % in Nepal; 0.2 % in Bhutan; and 0.5 % in China)[10]. The Himalayan rivers form large catchment basins. These rivers are perennial as they get water from monsoonal rainfall as well as the melting of ice from Himalayan glaciers. Nearly all of them create huge plains and are navigable over long distances.

In this geographical section we also include the Ayeyarwaddy basin, principally located in Myanmar. The Ayeyarwaddy River or Irrawaddy River Delta extends in a great alluvial fan in Myanmar, extending into the Bay of Bengal and Andaman Sea, 290 km to the south. On 2 May, 2008, the delta suffered extensive damage from Cyclone Nargis, a category 4 storm that caused large scale coastal flooding[11].

***Fig. 4**: Ganges-Brahmaputra-Meghna basin*



2.1.1 Brahmaputra

The Brahmaputra is a transboundary river and one of the major rivers of Asia. From its origin in southwestern Tibet as the Yarlung (“imperial blood”) River, it flows across southern Tibet where it is known as Dihang to break through the Himalayas in great gorges. It flows southwest through the Assam valley and south through Bangladesh as the Jamuna. There it merges with the Ganges to form a vast delta. About 2,900 km long, the Brahmaputra River covers a drainage area of 580,000 km^2 shared between four countries. Within India, the drainage area is distributed among six states. Table 2 shows the distribution of the drainage basin.

In the course of its journey, the Brahmaputra receives as many as 22 major tributaries in Tibet, 33 in India and three in Bangladesh[12]. In India, the principal tributaries of Brahmaputra are the Subansiri, Jia Bhareli, Dhansiri, Puthimari, Pagladiya and the Manas[13] while the Tista is the largest tributary in Bangladesh. The present channel of the Tista makes its entry into Bangladesh north of Dimla and travels 177 km before it meets the Brahmaputra. It varies between 300 m to 550 m in width. The Tista Barrage project which includes a 615 m long barrage, a 2,470 m long closure dam, and flood embankments of about 80 km was completed in 1997-98[14].

***Table 2**: Distribution of the drainage basin of the Brahmaputra* [15]

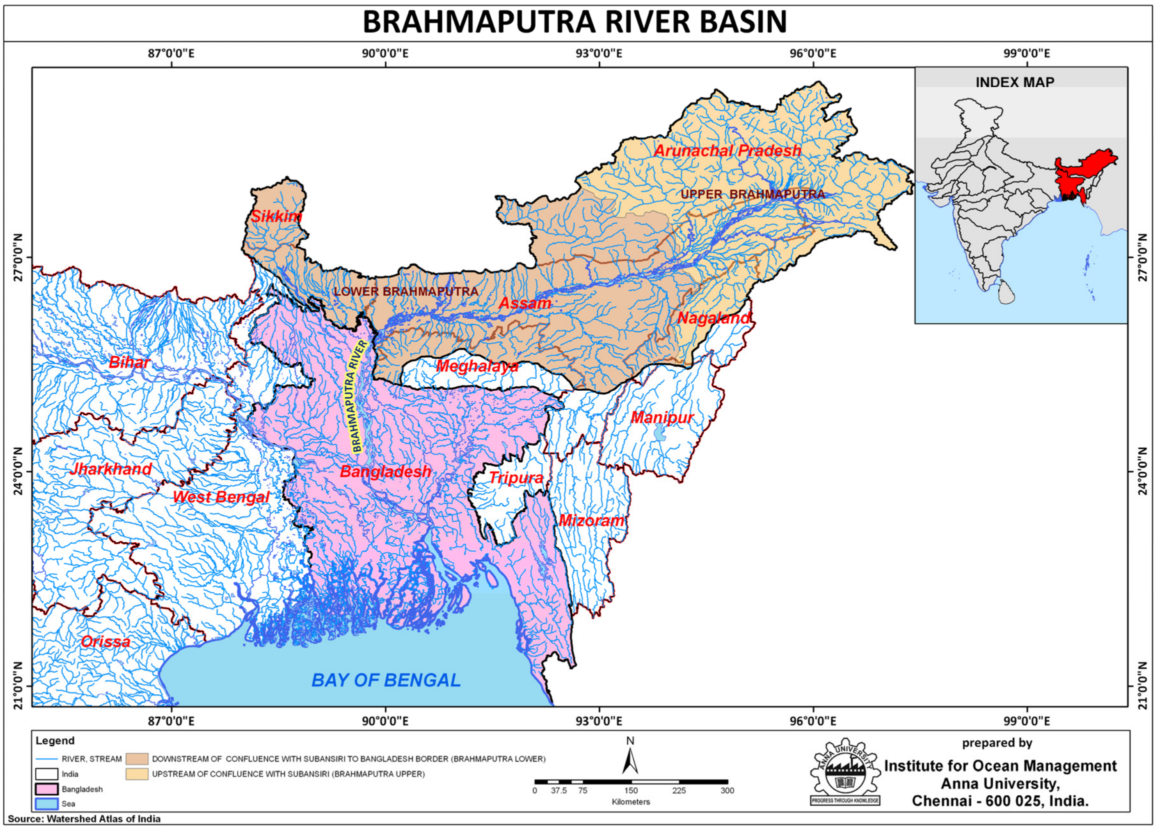
Brahmaputra bBasin Inter-National Distribution		Brahmaputra Basin Distribution within States of India	
China	50.5 %	Arunachal Pradesh	41.88 %
India	33.6 %	Assam	36.33 %
Bangladesh	8.1 %	Nagaland	5.57 %
Bhutan	7.8 %	Meghalaya	6.10 %
		Sikkim	3.75 %
		West Bengal	6.47 %

In the plains of Assam and Bangladesh, the Brahmaputra flows in a highly braided channel marked by the presence of numerous mid-channel and lateral bars and islands, while in the Himalayan section its channel is steep and narrow with gradients as high as 14.8 m/km. This is why there is sudden dissipation of energy and depositing of sediments while flowing downstream.

The Brahmaputra basin, excluding the Tibetan portion, forms an integral part of the southeast Asian monsoon regime with a mean annual rainfall of 2,300 mm. Distribution of rainfall over the basin varies from 1,200 mm in parts of Nagaland to over 6,000 mm on the southern slopes of the Himalaya. Monsoon rains from June to September account for 60-70 % of the annual rainfall in the basin, while the pre-monsoon season from March through May produces 20-25 % of the annual rainfall. Snowfall is experienced in the Brahmaputra in areas with elevations of 1,500 m and above. There are altogether 612 glaciers in the Brahmaputra catchment basin of which 450 are in the Tista sub-basin of Sikkim while 162 are in the Kameng river (upper Jia Bharali) sub-catchment basin of Arunachal Pradesh[16].

With an average annual discharge of 19,830 m^3/s at its mouth, the Brahmaputra ranks fourth among the large rivers of the world. High monsoon rainfall in the upper catchments and steep gradients are considered to be the major factors responsible for the high rates of unit discharge, which in turn help generate the high sediment yield from the catchment and significantly contribute to drainage congestion in the valley. The mean annual flood of the river, 48,200 m^3/s, has a recurrence interval of 2.2 years, while the maximum recorded flood of 72,726 m^3/s is likely to be repeated once in about every 133 years[17]. Monsoon rains from June to September account for 60-70 % of the annual rainfall.

***Fig. 5:** Brahmaputra basin* [18]



Source: Watershed Atlas of India

2.1.2 Ganges

The Ganges is primarily a meandering river. Figure 6 is a satellite image of the intersection of the two major rivers, the Ganges on the west and the Brahmaputra on the east. Their average annual combined discharge into the Bay of Bengal is approximately 29,692 m^3/s, with a maximum during flood of 80,984 m^3/s and 6,041 m^3/s during low water periods. The major floods occur during the months from June throughout September. The channels of both rivers are extremely unstable and bank lines can migrate as much as 400 m in a single season[19].

Sediment load is extremely high, with suspended sediment load during flood stage reaching as high as 13 million tons per day[20]. Bed load has never been measured, but is likely to be high and consists of fine and medium grained sand.

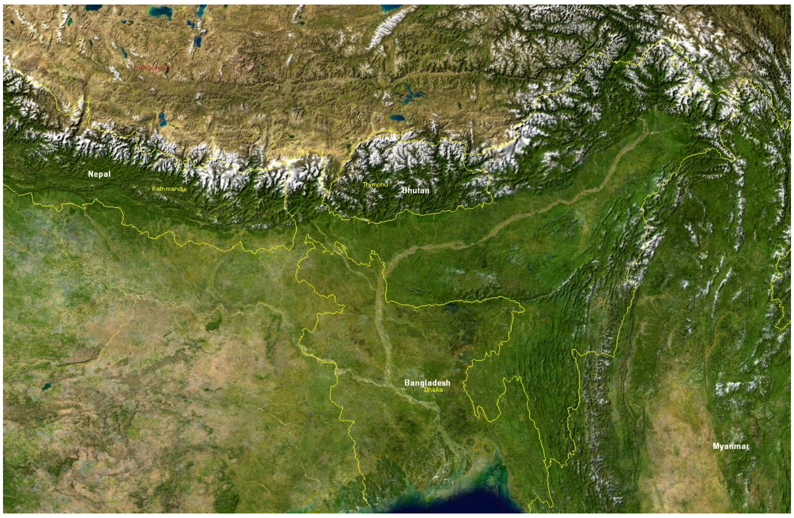


***Fig. 6**: View of the Ganges-Brahmaputra basin* [21]

Throughout Pleistocene times, the site of active deltaic sedimentation has switched. Today, the Ganges merges with the Brahmaputra, and the site of active sedimentation lies to the east, where large bell-shaped distributaries can be discerned (Fig. 7). The major area of abandoned deltaic plain lies to the west and is the site of one of the largest mangrove regions in the world, the Sunderban. The abandoned delta is approximately 1.6 times the size of the active delta plain. Numerous abandoned channel scars dominate the surface morphology of the abandoned delta plain. These scars are apparently remnants of former courses of the Ganges River and many of its distributaries. Most of the scars indicate that a meandering channel was dominant, now extensively modified by man. Channel scars are of similar size to channels presently active along the Ganges and its distributaries. Many of these former riverine channels are now dominated by tidal forcing[22].

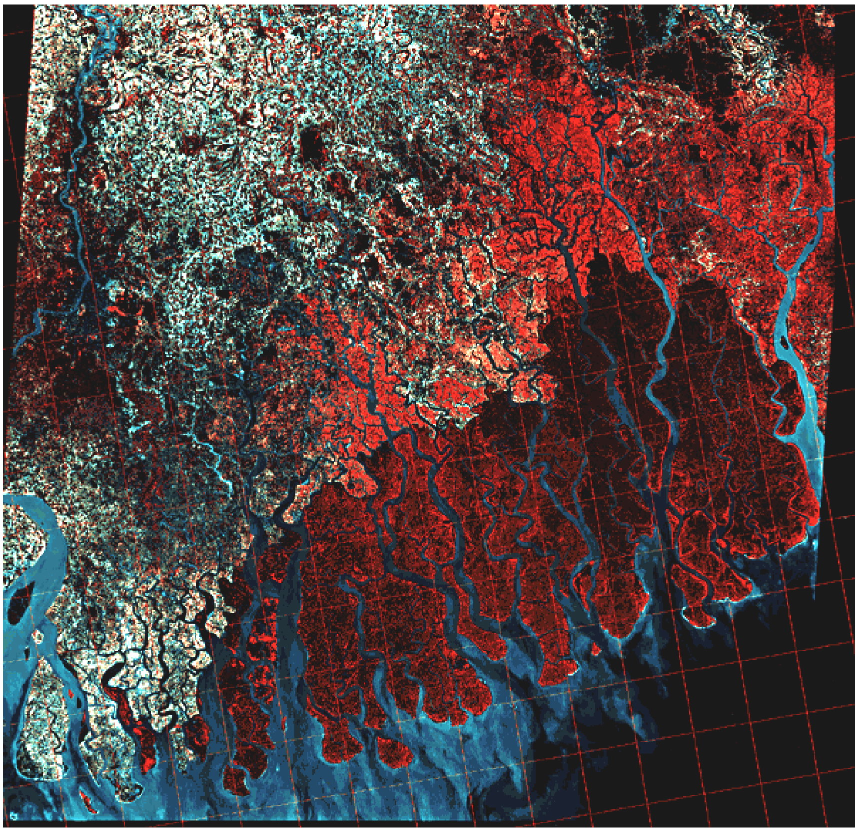


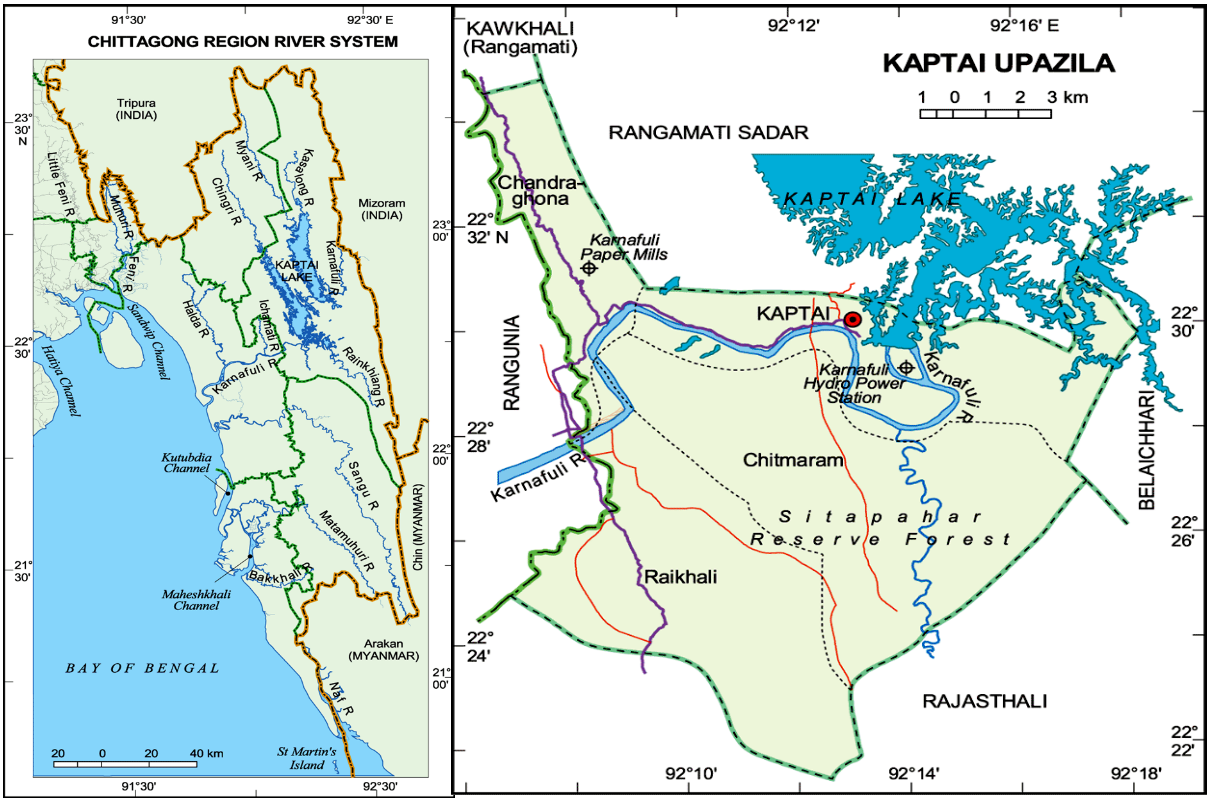
***Fig. 7**: Western Ganges/ Brahmaputra: the abandoned delta* [23]

2.1.3 Karnafuli

The Karnafuli River (Fig. 8) is a 667 km long river in the South Eastern part of Bangladesh. It is the largest and most important river in Chittagong and the Chittagong hill tracts. The river originates in the Lushai hills in Mizoram State of India. It travels through 180 km of mountainous wilderness making a narrow loop at Rangamati and then follows a zigzag course before it forms two other prominent loops, the Dhuliachhari and the Kaptai. The Rangamati and the Dhuliachhari loops are now under the reservoir of the Kaptai earth-filled dam. The hydroelectric dam is situated just before the entrance of the river into the Kaptai loop (Fig. 8). The river drains into the Bay of Bengal cutting across several hill ranges such as the Barkal, Gobamura, Chilardak, Sitapahar and Patiya of the Chittagong Hill Tracts and Chittagong.[24]

The Karnafuli is navigable at Barkal and Kaptai but above Barkal it is shallow. With the construction of the Kaptai dam, this river has been blocked, and a large artificial lake has been created, and the bed of the river has also been much widened. This man-made lake provides a network of all-weather navigable routes in the area. Downstream of the dam, the Karnafuli receives very little water in the dry season. The opening of the sluice gates of the dam creates water movement from the lake downstream.

***Fig. 8**: Karnafuli River (left) [25] and site of the Karnafuli hydro-power station (right) [26]*



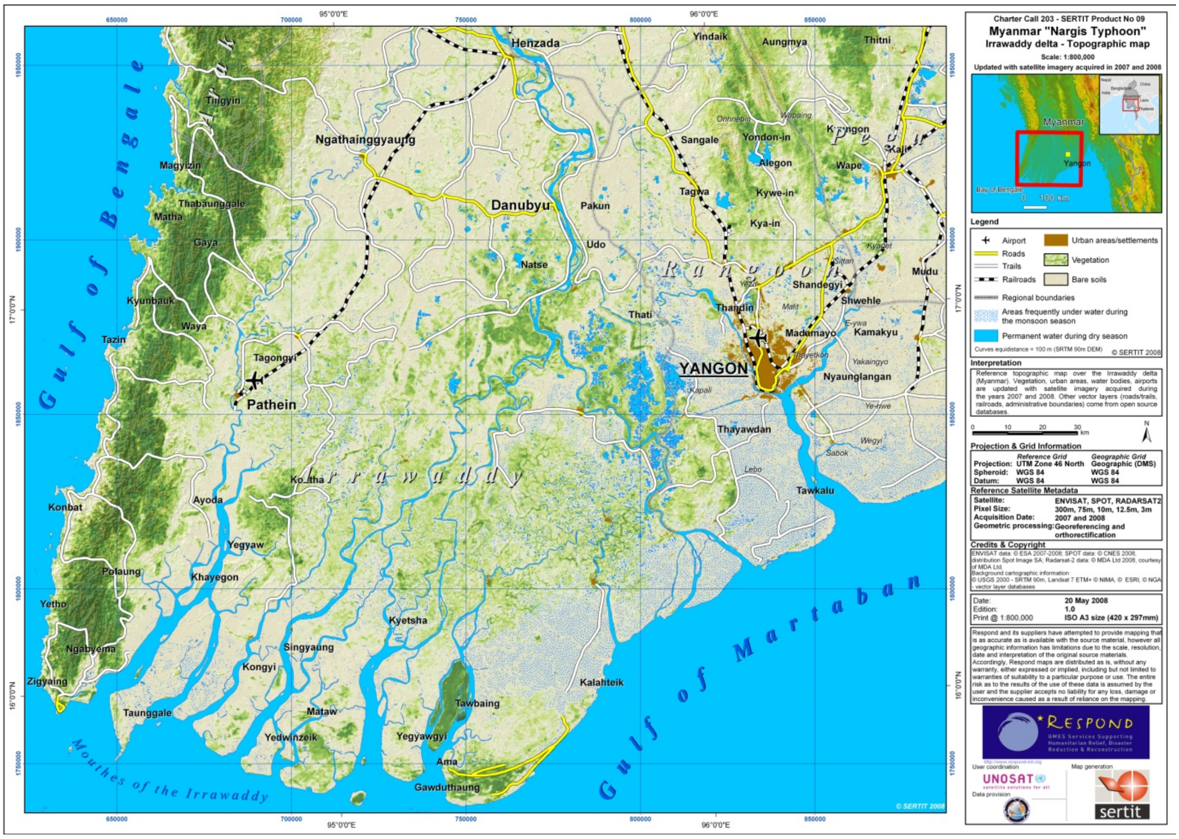
2.1.4 *Ayeyarwaddy*

The Ayeyarwaddy (Irrawaddy) delta (Fig. 9) is located at 16°55'-18°15'N, 94°15'-96°20'E from the limit of the tidal influence in the region of Myanaung, 70 km north of Henzada, to the outer islands along the coast in Myanmar in the Bay of Bengal and the Andaman Sea. The entire area is overlain by a thick layer of recent alluvium brought down by the Ayeyarwaddy river. Three main types of soil have developed: meadow gleyed clay soils, meadow swampy soils and saline gleyey soils. The flow in the Ayeyarwaddy is at its lowest in February and March with a sharp rise in April-May as a result of melting snow in the upper catchment, and a further steep rise in May-

June with the onset of the monsoon. The maximum flow occurs in July or August. Most waterways are natural water courses and the only major canal is the Twante that links Yangon (Rangoon) with the western part of the delta[27].

The upper and central portions of the delta are almost entirely under paddy cultivation. Until about 1850, much of this region comprised a complex of permanent and seasonal lakes, swamps and marshes, and vast areas of seasonally inundated plains and swamp forest. Following the rush of settlers from upper to lower Myanmar in the late 19th Century, there has been extensive construction of embankments and reclamation of land for agriculture. However, large tracts of land continue to remain flooded during the monsoon. The lower, seaward third of the delta, stretching 130 km from east to west is flat and subject to tidal inundation. The area is broken up into a large number of islands and peninsulas by a number of rivers. Drainage is directly into the Bay of Bengal through nine major river mouths: the Bassein, Thetkethaung, Ywe, Pyamalaw, Irrawaddy, Bogale, Pyapon, China Bakir, and Rangoon.

Fig. 9*: Ayeyarwaddy (Irrawaddy) delta* [28]



These rivers carry a heavy silt load, and their waters are very turbid. The delta is actively accreting seawards, and as a result the sea is very shallow for some distance. Water depths are less than 5.5 m across the whole coastline fronting the delta and up to 28 km offshore in the east. The present rate of advance of the delta is estimated at 5-6 km per 100 years, equivalent to about 1,000 ha per year. Several small islands, some of which are visible only at low tide, have developed offshore. With a total population of about 3.5 million people and a population density of 100 people/km^2, the Ayeyarwaddy Delta is one of the most densely populated parts in the country. Virtually all land not designated as *Reserved Forest* has been converted to intensive agriculture[29].

According to Bird et al.[30], the Ayeyarwaddy and Thanlwin catchments adjoin each other, flowing into the Indian Ocean over a length scale similar to the deltas of the Ganges-Brahmaputra or the Amazon and hence should be considered a single point source contributing to the global ocean. Their high organic carbon load is likely to be due to the strong monsoonal climate, the large area of highly productive forest and the comparatively small area of floodplain in the catchments.

2.2 Peninsular Rivers of India and Sri Lanka

The main peninsular river systems in India (going north to south) include the Mahanadi, Godavari, Krishna, and Cauvery rivers. The peninsular rivers flow through shallow valleys. A large number of them are seasonal as their flow is dependent on rainfall. The intensity of erosion is comparatively low because of the gentler slope. The hard rock bed and lack of silt and sand does not allow any significant meandering. Many rivers therefore have straight and linear courses.

2.2.1 Mahanadi

The Mahanadi rises in the highlands of the state of Chhattisgarh. It flows through Orissa to reach the Bay of Bengal. The length of the river is about 860 km. Its drainage basin is shared by the states of Maharashtra, Chhattisgarh, Jharkhand, and Orissa (Fig. 10). The delta extends over an area of 141,589 km², which is nearly 4.3 % of the total area of the country. Its main tributaries are the Seonth, the Jonk, the Hasdeo, the Mand, the Ib, the Ong, and the Tel. Physiographically, the delta can be divided into four regions: the Northern Plateau, the Eastern Ghats, the Coastal Plain and the Erosional Plains of the central table land. The first two are hilly regions. The coastal plain is the central interior region of the delta, traversed by the river and its tributaries.

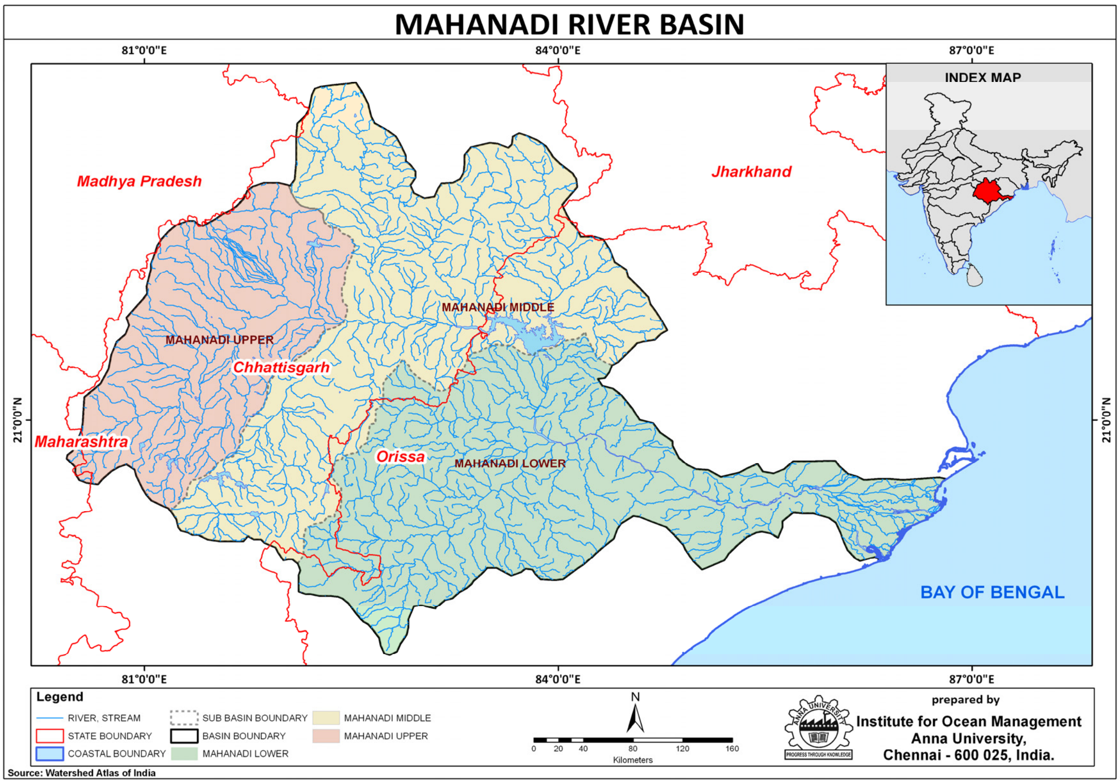
***Table 3**: Distribution of the drainage basin of the Mahanadi*

State	**Extent of Basin** (km^2)
Chhattisgarh	75,136
Orissa	65,580
Bihar	635
Maharashtra	238

An average annual surface water potential of 66.9 km³ has been assessed in this catchment basin. Out of this, 50 km³ is utilizable water. Cultivable areas in the basin comprise about 80,000 km², which is 4 % of the total cultivable area of India. In the region of the Mahanadi River, the climate is predominantly sub-tropical with summer temperatures of around 29°C and winter temperatures of 21°C. The Hirakud Dam, the first multipurpose post-independence river valley project in India, has been constructed across the Mahanadi. It forms a 55 km long lake. The population density is about 192 people/km^2. Rainfall is dominated by the summer monsoon (June -

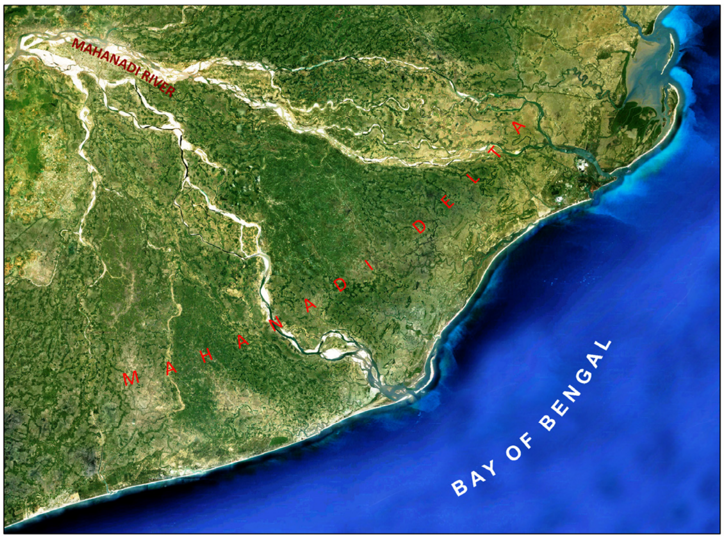
September) with an average annual rainfall in the basin being 1463 mm (1331-1663 mm). During the rest of the year, rainfall is extremely low, rarely exceeding 30 mm per month.

***Fig. 10**: Mahanadi basin* [31]



Source: Watershed Atlas of India

***Fig. 11**: Satellite view of the delta of the Mahanadi River, Orissa, India* [32]



The alluvial valley is poorly defined and the channel is predominantly meandering in nature. The average annual discharge is 1,895 m^3/s, with a maximum of 6,352 m^3/s during the summer monsoon. Minimum discharge is 759 m^3/s and occurs during the months October through June. The river is one of the most active silt-depositing streams in India. The area of the delta is 10,589 km^2. The delta is extremely complex with numerous abandoned delta lobes. The presently active delta lobe lies to the south and at least two other abandoned delta lobes are located to the north (Fig. 11). The obviously older delta lobe to the north is now dominated by tidal influence and numerous tidal channels are apparent on the image.

Mangrove is the most common type of vegetation along the seaward edges of the delta plain. The delta plain is a major rice-growing region in India and population density is extremely high. Numerous lakes and bays are present on the delta plain, many of them the remnants of former river courses. Wave energy is quite high along the delta front and well-developed beaches and barrier islands are present along the coast[33].

2.2.2 Chilika Lagoon

Chilika is the largest lagoon along the east coast of India, situated between 19° 28' and 19° 54' latitude N and 85° 05' and 85° 38' longitude E spread over three districts (Puri, Ganjam and Khurda) in the state of Orissa. The lagoon is a unique assemblage of marine, brackish and fresh water ecosystems with estuarine characters. It is one of the hotspots of biodiversity and shelters a number of endangered species listed in the IUCN red list of threatened species including the Irrawaddy dolphin, dugongs, green sea turtles and spoonbills. The water surface area of the lagoon varies between 1,165 and 906 km^2 during the monsoon and summer respectively. A 32 km long, narrow, outer channel connects the lagoon to the Bay of Bengal, near the village Motto; recently a new mouth was opened by the Chilika Development Authority[34]. A satellite image of the lagoon is presented in Fig. 12.

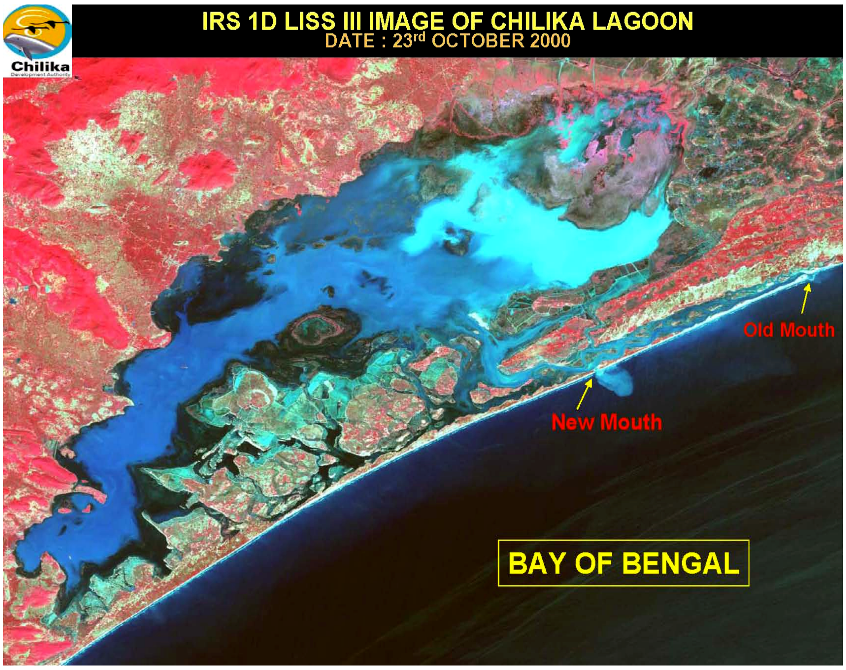


***Fig. 12**: Satellite image of Chilika lagoon* [35]

The drainage basin of Chilika lagoon lies between the rivers flowing into Mahanadi and Chilika in the north while in the northeast areas draining into the Bhargavi River make up the watershed. To the west and south-west, the watershed boundary lies between streams flowing into the Rishikulya River and those flowing into Chilika. Many other smaller rivers, rivulets, and tributaries also flow through the area. In addition to the 1,100 km^2 area of the lake itself, the drainage basin of Chilika includes 2,325 km^2 of agricultural land (mostly dry land), 526 km^2 of forests, 192 km^2 of permanent vegetation predominantly used for plantations, 71 km^2 of swamps and wetlands, and 91 km^2 of grassy mud flats in the northeast of the drainage basin. Only 52 km^2 of the basin are occupied by human settlements, roads, railways, and other infrastructure[36].

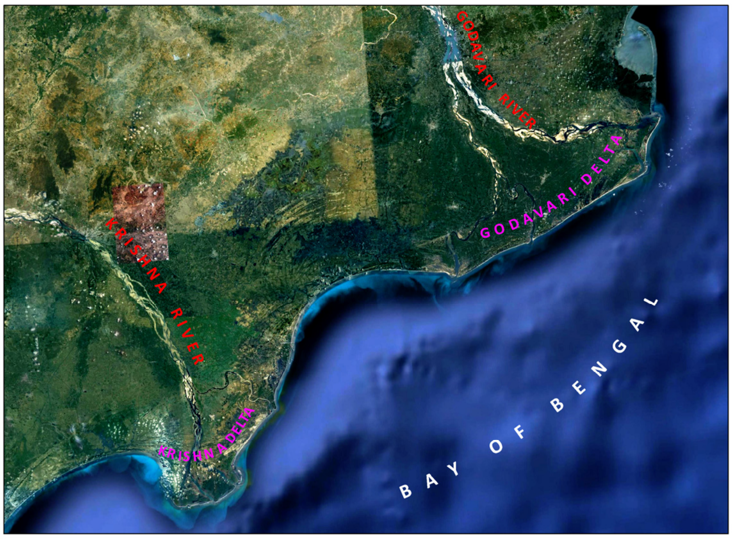
***Fig. 13**: Phragmites-dominated northern zone of the Chilika Lake (Photo: Purvaja 2007)*

In the past, the lagoon – once part of the Bay of Bengal – provided excellent port facilities to commercial boats. A number of islands are situated within the lagoon and these offer attractive locations for tourism development. Currently, the lagoon sustains the livelihood of 200,000 fishermen and over 800,000 people living in the peripheral watershed areas and generating their income from farming activities.

2.2.3 Godavari

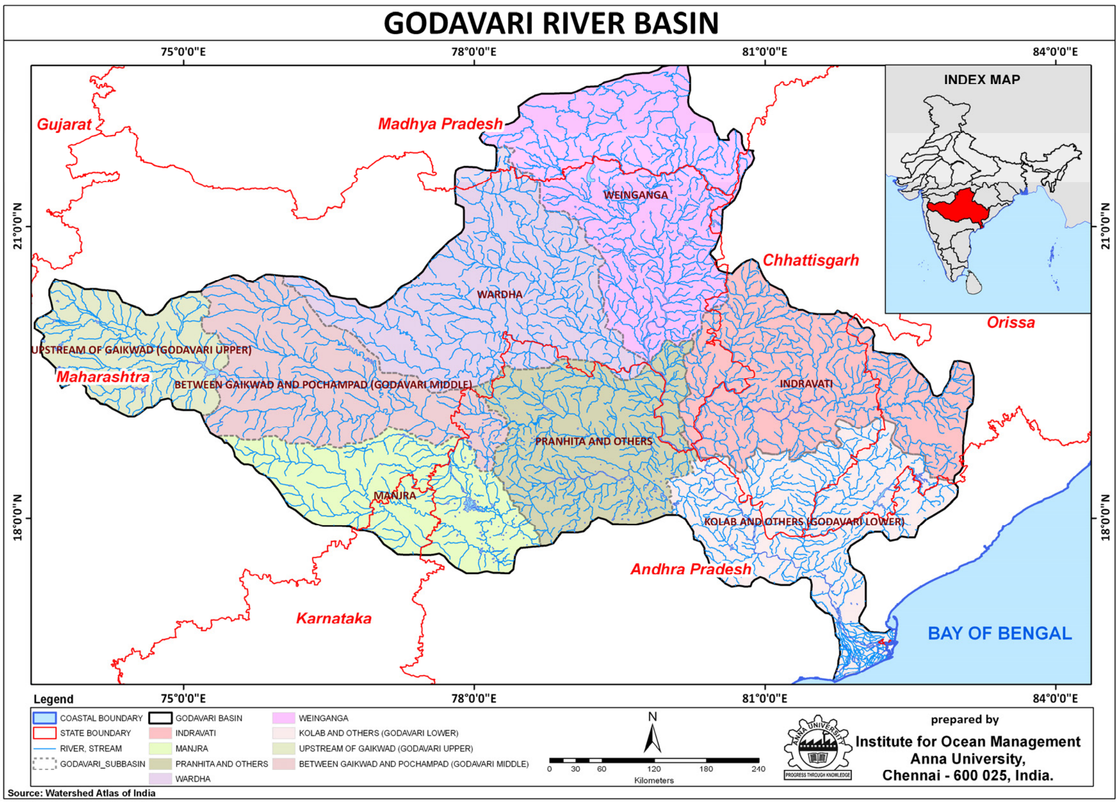
The second largest river in India, Godavari is often referred to as the Vriddh (Old) Ganga or the Dakshin (Southern) Ganga. The Godavari originates near Triambak in the Nashik district of Maharashtra, and flows through the states of Madhya Pradesh, Karnataka, Orissa and Andhra Pradesh. The Godavari drainage basin extends over an area of 312,812 km^2 which is nearly 10 % of the total area of the country (Fig. 14 and Fig. 15). Although its point of origin is just 80 km away from the Arabian Sea, it flows 1,465 km eastwards to drain into the Bay of Bengal. Some of its tributaries include Indravati, Manjira, Bindusara and Sarbari. Important urban centers on its banks include Nashik, Aurangabad, Nagpur, Nizamabad, Rajahmundry, and Balaghat.

***Fig. 14**: Krishna-Godavari delta[37])*



Just above Rajahmundry, a dam provides water for irrigation. Below Rajahmundry, the river divides into two streams that widen into a large river delta which has an extensive navigable irrigation-canal system, Dowleswaram Barrage that links the region to the Krishna River delta to the southwest. The Godavari River has a drainage area in seven states, namely Maharashtra, Andhra Pradesh, Karnataka, Madhya Pradesh, Chhattisgarh and Orissa.

***Fig. 15**: Godavari Basin* [38]

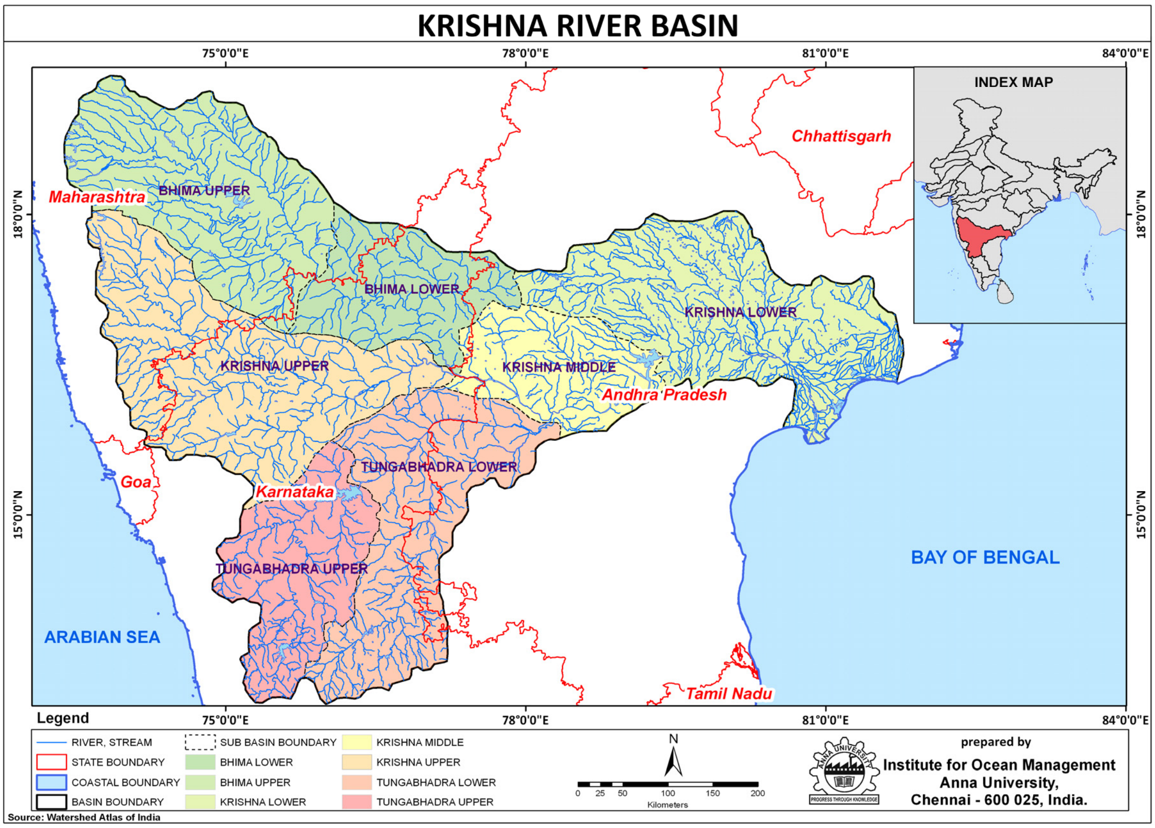


Source: Watershed Atlas of India

2.2.4 Krishna

The River Krishna rises in the Western Ghats at an elevation of about 1,337 m just north of Mahabaleshwar, about 64 km from the Arabian Sea, flows eastwards for about 1,400 km before joining the Bay of Bengal at Hamasaladeevi in Andhra Pradesh, on the East coast. The Krishna catchment basin (Fig. 16) extends over an area of 258,948 km² which is nearly 8 % of total geographical area of the country[39]. The basin lies in the states of Karnataka (113,271 km²), Andhra Pradesh (76,252 km²) and Maharashtra (69,425 km²). The principal tributaries joining Krishna are the Ghataprabha, the Malaprabha, the Bhima, the Tungabhadra and the Musi. Most part of this basin comprises rolling and undulating country except the western border which is formed by an unbroken line of ranges of the Western Ghats. The important soil types found in the basin are black soils, red soils, laterite and lateritic soils, alluvium, mixed soils, red and black soils and saline and alkaline soils. The Krishna River drains mineralized areas upstream, while it is extensively used for agriculture downstream. It is one of the most intensively utilized rivers in India. The river carries very little sediment load (<4 million t/yr) perhaps because of the predominance of Precambrian hard rocks, which cover nearly 80 % of the basin area[40]. An average annual surface water potential of 78.1 km^3 has been assessed in this basin. Out of this, 58 km^3 is utilizable water. Cultivable area in the basin is about 203,000 km^2, which is 10.4 % of the total cultivable area of the country.

***Fig. 16**: Krishna basin* [41]



Source: Watershed Atlas of India

The delta of the river covering about 6,322 km^2 is one the most fertile regions in India. After cutting through the Eastern Ghats, the river forms a deltaic plain some 95 km wide before its four distributaries flow into the Bay of Bengal. The first channel of the river starts near Avanigodda, but the three main distributaries of the modern river splits into the Golumuttapaya, Nadimieru and Main channels. A dam (weir) at the head controls the flow within the deltaic plain. Vast amounts of material have been added during the past 50 years at the mouths of the distributaries with the formation of river mouth bars and barrier islands with associated back island lagoons. As the delta prograded, these lagoons were filled with finer grained sediments. From Vijayawada to the Bay the average slope is 20 cm/km.

Two big dams have been constructed regulating the river, one at Srisailam and the other at Nagarjuna Hill. The latter, the Nagarjuna Sagar dam, is considered to be the tallest earth dam in the world with a reservoir having a water spread of 285 km^2 [42]. The Krishna delta has large tracts of mangrove swamps along the coast with maximum concentration surrounding the three main distributaries. Tidal flats occupy a considerable area of the lower deltaic plain, especially between the Golumuttapaya and Avanigodda distributaries (Div island), although the tidal flats may be the product of a degraded inter-distributary bay between two, now abandoned, former channels.

There is a very narrow continental shelf (~15 km.) off the present Krishna delta when compared to adjoining portions of the coastal margin. This is presumably a result of rapid progradation. The hypsometric integral for the Krishna Delta is 0.36 which means the offshore slope is slightly concave suggesting a slight dominance of wave power over the discharge effectiveness of the river. This value is similar to the Nile delta which has a hypsometric integral of 0.37. The volume of the Krishna bulge is 9.93 km^3 (using the Wright and Coleman formulae) and there is a skewness ratio of 1.37 which indicates a pronounced littoral drift from the northeast towards Nizampatnam Bay[43].

2.2.5 Cauvery

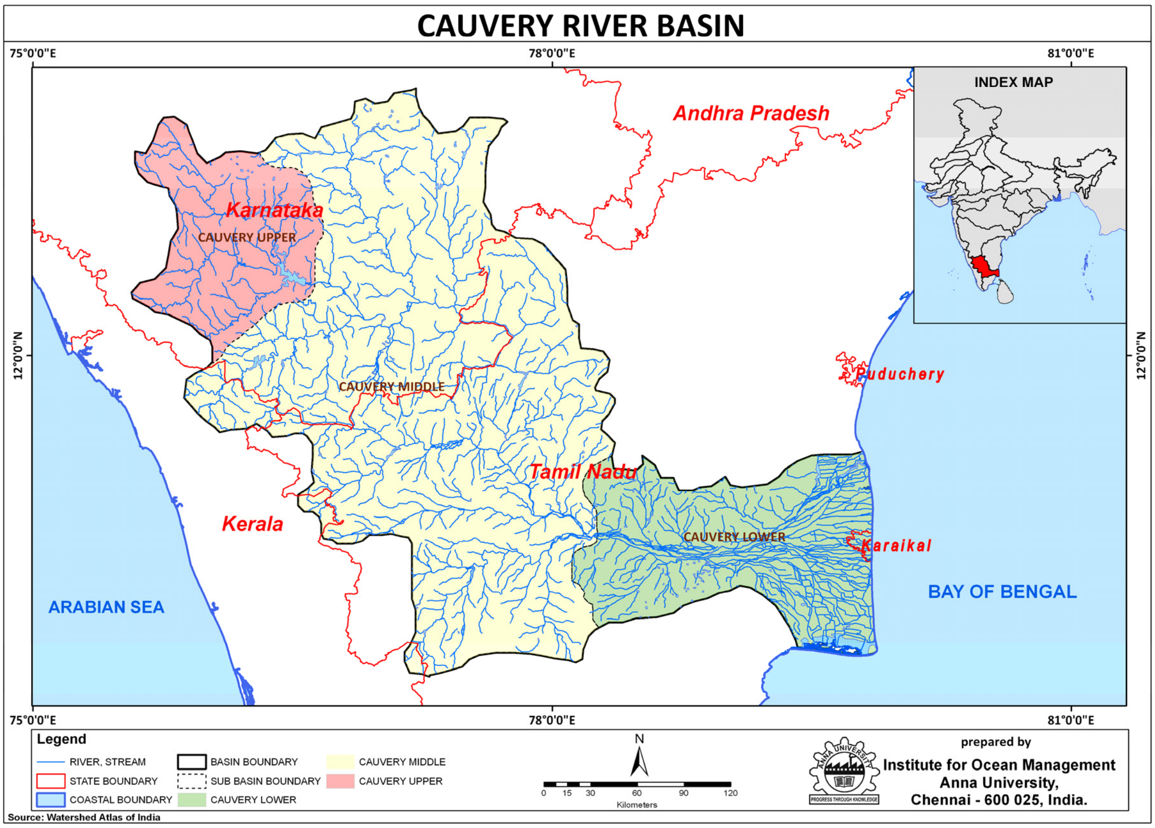
The Cauvery rises at Talakaveri on the Brahmagiri Range of Hill in the Western Ghats, presently in the Coorg district of the state of Karnataka, at an elevation of 1,341 m above mean sea level. The catchment area of entire Cauvery basin is 81,155 km^2, spread over three states and a union territory (Table 4)[44]. As the fourth largest river of the southern region, it starts its 800 km long journey from the Western Ghats; traverses through Mysore plateau and finally forms a delta on the eastern coastline of the subcontinent before falling into the Bay of Bengal (Fig. 17). The delta region of River Cauvery is extremely mature, that the main river has almost lost its link to the sea, because it is believed that the tributary of Cauvery-Coleroon River carries most of the freshwater. Ironically, the freshwater flow into the Coleroon River has also dwindled in the recent past, due to the construction of dams across the river.

***Table 4**: Distribution of the drainage basin of the Cauvery*

S. No.	Name of the State Basin	Catchment Area (km^2)
1	Karnataka	34,273
2	Kerala	2,866
3	Tamil Nadu	43,868
4	Karaikal region of Puducherry UT	148
	Total	81,155

The principal tributaries of Cauvery in Karnataka are the Harangi, the Hemavathy, the Lakshmanathirtha, the Kabini, the Shimsha, the Arkavathi and the Suvarnavathy. All these rivers except the Kabini River, Arkavathy River and Suvarnavathy River rise and flow fully in Karnataka. Geologically, the basin forms a part of the South Indian shield. The basin is characterized with a unique forest with some of very distinct fauna and flora and is home to many sanctuaries and national parks. Average density of the population is around 192 people/km. An average annual surface water potential of 21.4 km^3 has been assessed in this basin. Out of this, 19 km^3 is utilizable water. Cultivable area in the basin is about 5.8 million ha, which is 3 % of the total cultivable area of the country. The present use of surface water in the basin is 18 km^3. The hydropower potential of the basin has been assessed as 1,359 MW at 60 % load factor[45].

***Fig. 17**: Cauvery basin* [46]



Source: Watershed Atlas of India

During the monsoon period, 75 % of the annual rainfall, 73 % of the annual water discharge and 85 % of the annual sediment transport takes place in the Cauvery River. Basin geology and river water discharge, greatly influenced by the two major dams built across the river are the major factors controlling the sediment transport. The coarse sediments were found to be selectively retained at the dam sites[47]. The chemical composition of Cauvery River water was found to be dominated by Na and HCO_3. The river water chemistry strongly reflects the dominance of continental weathering and impact by atmospheric precipitations. The river water composition was found increasingly dominated by Na and Cl in the downstream region of the river, indicating the influence of airborne salts with oceanic affinities[48].

Located in the delta is the luxuriant Pichavaram mangrove forest. Known for its unique mangrove ecosystem, Pichavaram is located in the northernmost part of the Cauvery delta, in the Vellar-Coleroon estuarine complex, and has many islands separated by intricate water-ways. Covering an area of over 400 hectares, it is traversed by a large number of channels and creeks which connect the Coleroon Estuary in the South and Vellar estuary in the north. It consists of a number of small and large islets surrounded by numerous creeks, canals and channels. The Pichavaram mangrove wetland consists of three reserve forests: Killai, Pichavaram, and Pichavaram extension area. The dense mangroves (Pichavaram mangroves) present in the Cauvery delta are currently experiencing severe freshwater shortage.

***Fig. 18**: Pichavaram mangroves of Cauvery delta (Photo: IOM, Anna University Chennai, India)*

In regions where these coastal fringe forests have been cleared, tremendous problems of erosion and siltation have arisen, and sometimes terrible losses to human life and property have occurred due to destructive storms. When the tsunami struck Tamil Nadu, areas in Pichavaram and Muthupet with dense mangroves suffered fewer human casualties and less damage to property compared to areas without mangroves – an expression of mangrove ecosystem service values for society.

2.2.6 Walawe Basin (Sri Lanka)

In the Indian Ocean, Sri Lanka lies off the southeastern tip of the Indian subcontinent. The Palk Strait and Gulf of Mannār separate Sri Lanka from India. The Arabian Sea lies to the west, the Bay of Bengal to the northeast, and the Indian Ocean to the south. Colombo, situated on the western coast, is the largest city and the capital of Sri Lanka. Much of Sri Lanka is arid and has only a few permanent rivers. However, the southwestern region's "wet zone" is characterized by numerous rivers that arise in the high mountains of the central part of the island[49]. From there they descend to the plains and empty into the sea. The rivers are typically un-navigable in their higher reaches, where they flow swiftly and turbulently over steep cliffs and through highly eroded passages forming spectacular waterfalls before reaching the plains where they slowly meander through flood plains and deltas. These diverse river basins support endemic populations of aquatic plants, bivalves, and fish.

The Walawe River basin (Fig. 19) is the largest basin in southern Sri Lanka and covers a total area of 2,442 km^2. The basin spreads over the Ratnapura, Badulla, Moneragala and Hambantota administrative districts. The Walawe River originates in the southern edge of the central uplands of the country and flows southward, reaching the sea at Ambalantota. The upper Uda Walawe basin is a mountainous area with a maximum elevation of 2,395 m and, together with the western fringe of the basin, it constitutes the "water tank" of the basin. Annual rainfall varies from close to 4,000 mm in the higher parts of the basin to around 1,000 mm in the southernmost part.

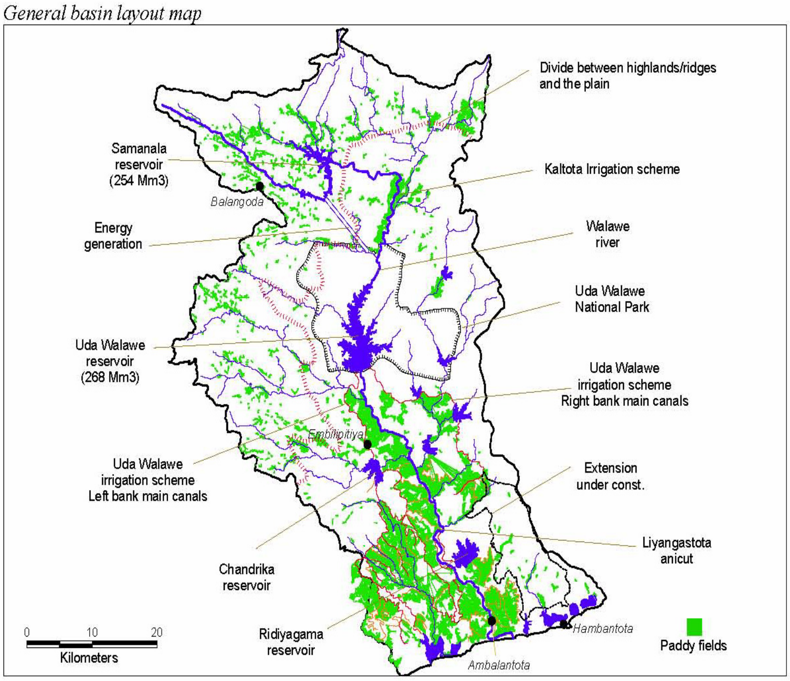


***Fig. 19**: Walawe River basin* [49]

Three-quarters of the basin lies in the dry and intermediate zones. Average daily evaporation is 6 mm in the dry seasons and 4 mm in the wet season. The average relative humidity is 70-82 % and the average annual temperature is 27.5 °C. The population in the upper basin tends to be concentrated along both waterways and roads, and villages are more of the ribbon type than of the cluster type. Population densities (175 people/km^2) are lower than the basin average (244 people/km^2) but this is because of the large portion of the land is under state reservation or on too steep a slope to be cultivated[50].

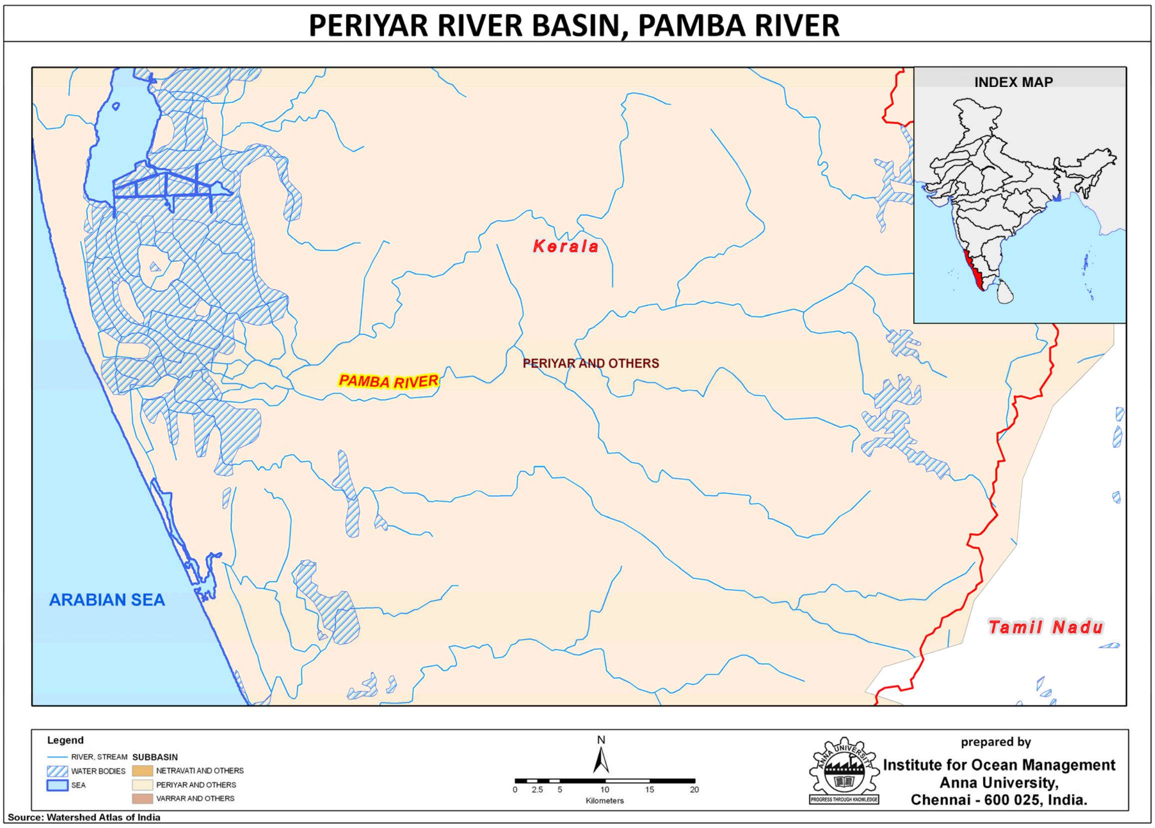
2.3 Inflow of small rivers into the Arabian Sea

There are 44 rivers in the state of Kerala of which 41 originate from the Western Ghats and flow west and either flow into the backwaters in the coast or directly into the Arabian Sea. As the Western Ghats are in no place more than 120 km from the sea, all these rivers are comparatively short. Three tributaries of Cauvery (Kabini, Bhavani and Pambar) flow east into the neighboring states of Karnataka and Tamil Nadu[51].

2.3.1 Pamba Basin

The river Pamba, the third longest river in Kerala, rises at an altitude of 1,650 m in the Peermade Plateau in the Idukki district of Kerala. It is formed by the confluence of Pamba Ar, Kakki Ar, Arudai Ar, Kakkad Ar and Kall Ar. The Pamba Ar in turn is formed by several streams having their origin in the Pulichimalai, Nagamalai and Sundaramalai in the Peermade plateau. It flows through Pandanad, Veeyapuram, Thakazhy, and Champakulam through a distance about 177 km and plunges into Vembanad Lake through several branches such as Pallathuruthi Ar, Nedumudi Ar and Muttar.

Fig. 20: *River Pamba* [52]



Source: Watershed Atlas of India

The river has a length of 117 km and is navigable to a length of 73 km. The catchment area of this river is 1987.17 km^2. The main tributaries of the river are Pamba Ar, Kakki Ar, Arudai Ar, Kakkad Ar and Kallar[53]. The entire catchment area lies in Kerala state. The basin is bounded on the east by the Western Ghats and on the west by the Arabian Sea. Manimala basin forms the northern boundary of the basin while Achankovil basin forms the southern boundary[54]. Kuttanad, an important rice cultivating area in Kerala gets irrigation water from the Pamba River.

Eighty percent of the rainfall is during the south-west monsoon (June-September), with the rest during the north-east (October - December). The rainfall distribution in the Pamba basin is mainly influenced by the geographical disposition and the physical features of the area within the catchment basin. The Western Ghats forming the eastern boundary of the basin receives fairly high rainfall ranging from 4,307 mm to 3,659 mm. There is reduction in the quantum of rainfall with the increasing distance from Western Ghats towards the coast to 2,900 mm near the coast[55]. The climate is tropical with little variation in temperature. Table 5 shows some characteristics of the Pamba River. Like the other southern rivers, the sediment load is higher during the North-East monsoon.

***Table 5**: Characteristics of the Pamba River basin* [56]

River	Annual rainfall	River basin area (km^2)	Length (km)	Slope (m/m)	Annual discharge (million m^3)	Average annual sediment load (ton)	Max observed sediment concentration
Pamba	3,600	1,654	176	0.009	4,016	156,851	896

***Fig. 21**: Cooking mussels for shell extraction at the Pamba River banks of Vembanad Lake (left) and weeds covering the entire surface water of the Vembanad Lake (right; Photos: Purvaja 2008)*

2.3.2 Vembanad Lake

The Vembanad Lake (Vembanad Kayal or Vembanad Kol) into which the Pamba drains is India's longest lake and one of the three Ramsar sites in Kerala[57]. Spread over the districts of Alappuzha, Kottayam, Ernakulam and Thrissur, it is a complex aquatic system of 96 km long coastal backwaters, lagoons, marshes, mangroves and reclaimed lands, with intricate networks of natural channels and man-made canals extending from Kuttanad in the south to the Kol lands of Thrissur in the north. The total area of the wetland system is 1,521.5 km^2, approximately 4 % of the state's geographic area. The wetland is mostly waterlogged with depths ranging from 0.6 m to 2.2 m and is typically divided into two distinct segments: the freshwater dominant southern zone and the saltwater dominant northern zone. The estuarine zone and organics-rich sedimentary substratum of the inshore region makes it a highly preferred and desirable habitat for shrimp and clams. The waterways formed by backwater, estuaries, lagoons and canals, spread over 196 km in the north-south and 29 km in the east-west directions and play an important role in the transportation system of the Vembanad region.

***Fig. 22**: Vembanad Lake eutrophication (Photo: Purvaja 2008)*

***Fig. 23**: Thannermukkom salt water barrier* [58]

A unique characteristic of the lake is the location of the Thanneermukkom salt water barrier (Fig. 23). This was constructed as a part of the Kuttanad Development Scheme to prevent tidal action and intrusion of salt water into the Kuttanad low-lands. It is the largest mud regulator in India. This barrier essentially divides the lake into two parts: one with brackish water perennially and the other half with fresh water fed by the rivers draining in to the lake. This barrier has helped the farmers in Kuttanad, where farming is done below sea level. However, it has also created ecological problems, primarily, the rampant propagation of the Water Hyacinth in fresh water[59].

2.3.3 Zuari and Mandovi Rivers

There are nine major rivers flowing through the state of Goa, but the Mandovi (1,580 km^2) and Zuari (973 km^2) together drain 2,553 km^2, about 70 % of the total geographical area of Goa[60]. The 34 km long Zuari originates at Hemad-Barshem in the Western Ghats and flows in the south-west through Tiswadi, Ponda, Mormugao, Salcete, Sanguem and Quepem. River Mandovi, 81 km long, described as the lifeline of the state of Goa, emerges from Bhimgad in the Sahyadri range of mountains in Karnataka. The Cumbarjuem Canal, linking the two rivers has enabled ships navigate to the interior regions to the iron ore mines. The waters of the Mandovi and Zuari both flush out into the Arabian Sea at Cabo Aguada, a common point forming the Marmogoa harbor. The port city of Vasco da Gama lies on the mouth of the Zuari River. Panaji, the state capital and Old Goa, the former capital of Goa, are both situated on the left bank of the Mandovi. The Mapusa River is a tributary of the Mandovi.

The Mandovi and Zuari estuaries are typical of the west coast estuaries where the freshwater content of the estuarine waters is high during the monsoon and the water level in the upstream part of the estuarine channels is controlled by the amount of run-off in the channel. The water level at the downstream end of the estuarine channel is controlled throughout the year by the astronomical tide at the coast. After withdrawal of the monsoon, the flow imposed by the tide at the mouth of the channel becomes the sole driving mechanism for transport in the estuarine network. Hence, oceanographic processes in these networks differ significantly between the wet monsoon season, when run-off is high, and the dry season, when run-off is negligible and the tide dominates circulation and mixing in the estuaries[61].

2.4 Gujarat Sub-Region

While there are a number of rivers that drain peninsular India, even if they originate close to the west like the Godavari, the Narmada, Tapi and Mahi are major rivers originating in the east and join the west coast of India (Arabian Sea).

2.4.1 Narmada Basin

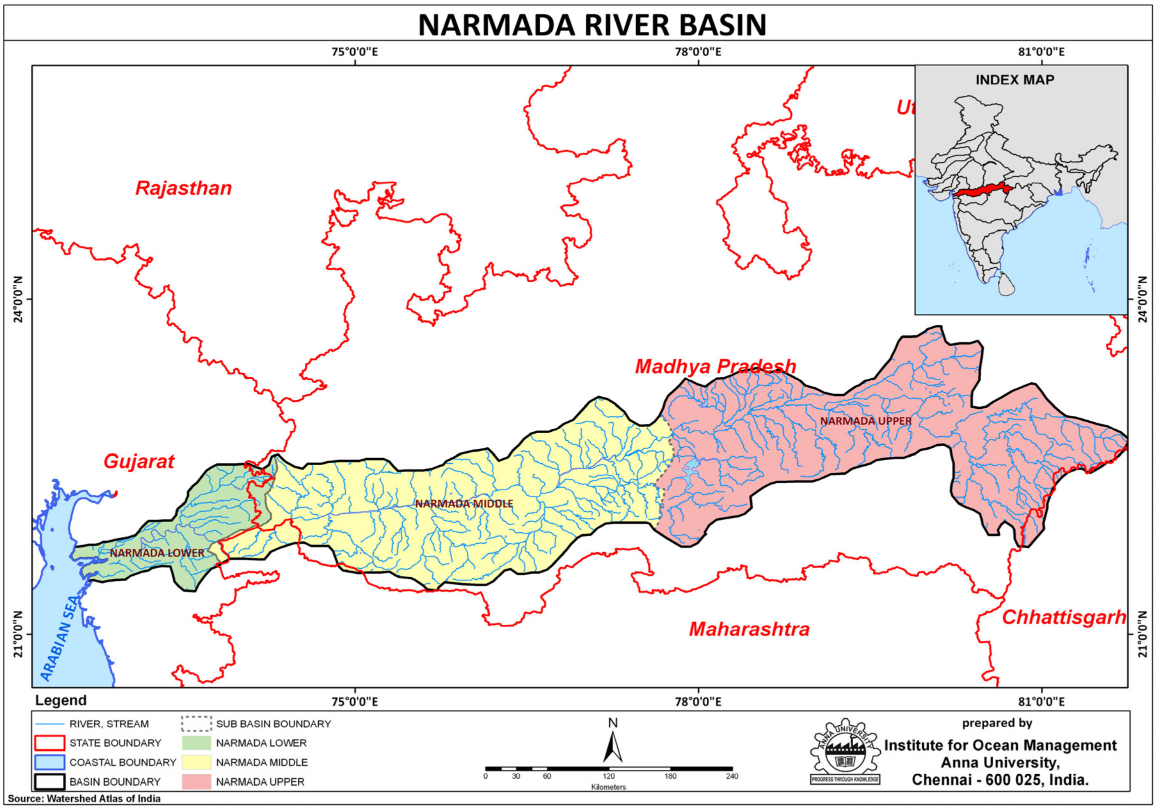
The Narmada, the largest river flowing westward, rises near the Amarkantak range of mountains in Madhya Pradesh (Fig. 24). It is the fifth largest river in the country and the largest one in Gujarat. It traverses Madhya Pradesh, Maharashtra and Gujarat and meets the Gulf of Khambat.

***Table 6**: Catchment distribution of Narmada River*

State	Catchment Area (km^2)	Catchment Area (%)
Madhya Pradesh	85,858	86.18
Gujarat	9,894	11.60
Maharashtra	1,658	1.50
Chhattisgarh		0.72

The basin is bounded in the north by the Vindhyas, in the east by the Maikala range, in the south by the Satpuras and in the west by the Arabian Sea. The river has 41 tributaries of which 22 are on the left bank (south) and 19 on the right bank (north). Around 35 % of the basin area is under forest cover, 60 % under arable land and 5 % is grassland, wasteland, etc[62]. The climate of the basin is humid tropical, although at places extremes of heat and cold are often encountered. Average rainfall of the basin is 1,178 mm, whereas annual rainfall for the entire basin varies from 800-1,600 mm. A major portion of the precipitation in the basin takes place during the southwest monsoon (July - September), which accounts for about 85-95 % of the total precipitation.

***Fig. 24:** Narmada basin* [63]



Source: Watershed Atlas of India

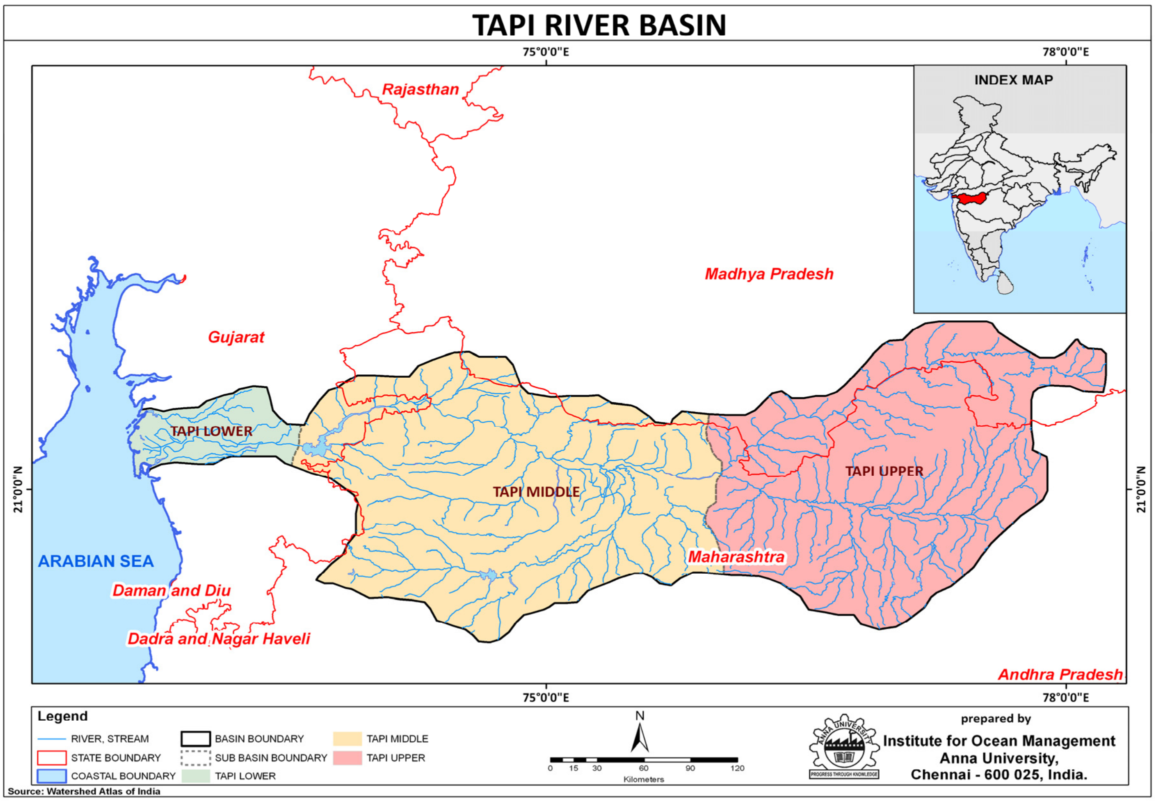
Of the 30 large dams planned on river Narmada, the Sardar Sarovar Project (SSP) is the largest multipurpose project involved in the construction[64]. The total length of the river from source to sea is 1,312 km while the length up to the Sardar Sarovar dam site is 1,163 km. The project involves the construction of a concrete gravity dam, 1,210 meters in length and with a maximum height of 163 meters above the deepest foundation level. The width of the river channel at dam site during high floods is 488 m and that during summer is 45.7 m. The maximum recorded flood in 1994 was 2.5 million m^3/s while the minimum flow recorded in summer was 300 m^3/s [65]. The drainage area up to dam site is 88,000 km^2. The mean annual rainfall in the basin is 1,120 mm.

The Narmada River flows through the Deccan Volcanic Province – a large igneous province located on the Deccan Plateau of west-central India and one of the largest volcanic features on Earth – and transports water and sediments to the adjacent Arabian Sea. Water flow in the river is a major factor influencing sediment loads in the river. The monsoon season, which accounts for 85-95 % of total annual rainfall in the basin, is the main source of water flow in the river. Almost 85-98 % of annual sediment loads in the river are transported during the monsoon season (June - November). The average annual sediment flux to the Arabian Sea at Garudeshwar (farthest downstream location) is 34.29×10^6 t/yr with a water discharge of 23.57 km^3/yr [66]. Based on ten years' data (1990-2000), Gupta and Chakrapani[67] report that Bargi dam in the upper Narmada basin shows entrapment of more than 40 %, whereas Sardar Sarovar shows approximately 30 % trapping of annual load carried by the river. The authors conclude that rainfall, its intensity and periodicity control both water flux and sediment load in the basin, whereas the reservoirs act as efficient systems for entrapment of suspended sediment load.

2.4.2 Tapi Basin

The River Tapi (Tapti) is an inter-state river flowing through Madhya Pradesh, Maharashtra and Gujarat (Fig. 25). The total length of the river is 724 km with a drainage area of 64,874 km^2. Out of this, 9,804 km^2 lie in Madhya Pradesh, 51,100 km^2 in Maharshtra and 3,970 km^2 in Gujarat. The river rises near Multai town in Betul district of Madhya Pradesh at an elevation of about 760 m at latitude 21°04' 00" N and longitude 78°21' 00" E. It flows through Madhya Pradesh for a length of about 332 km, 217 km in Maharashtra and for about 175 km in Gujarat before joining the Arabian Sea near Surat[68]. The principal tributaries of Tapi River are Purna River, Girna River, Panzara River, Waghur River, Bori River and Aner River.

***Fig. 25**: Tapi basin* [69]



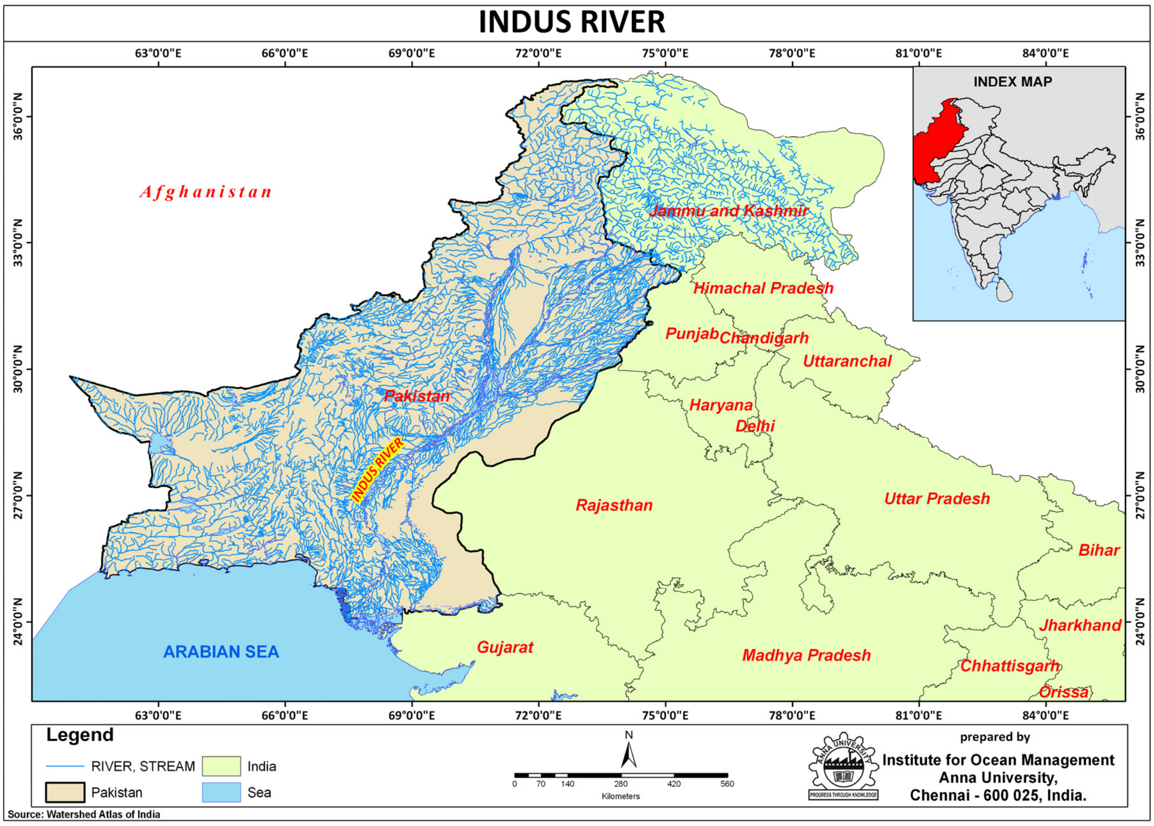
Source: Watershed Atlas of India

2.5 Indus Delta

The Indus originates from the Lake Ngangla Ringco on the Tibetan Plateau, flows 3,200 km creating a wide delta of swamps, streams and extensive mangroves in Pakistan before flowing into the Arabian Sea near the port city of Karachi. The delta covers an area of about 41,440 km², and is approximately 208 km across where it meets the sea (Fig. 26). Unlike many other deltas, the Indus River delta consists of clay and other infertile soils, and is very swampy[70,71]. The river has a total drainage area exceeding 1,165,000 km^2 and an estimated annual flow of about 207 km^3. Beginning at the heights of the world with glaciers, the river feeds the ecosystem of temperate forests, plains and arid countryside.

The ultimate source of the Indus is in Tibet. It begins at the confluence of the Sengge and Gar Rivers that drain the Nganglong Kangri and Gangdise Shan mountain ranges. The Indus then flows northwest through Ladakh-Baltistan into Gilgit, just south of the Karakoram range. The Shyok, Shigar and Gilgit streams carry glacial waters into the main river. It gradually bends to the south, coming out of the hills between Peshawar and Rawalpindi. The Indus passes through gigantic gorges 4,500-5,200 m high near the Nanga Parbat massif. It swiftly flows across Hazara, and is dammed at the Tarbela reservoir. The Kabul River joins it near Attock. The remainder of its route to the sea is in plains of the Punjab and Sind, and the river becomes slow-flowing and highly braided. It is joined by Panjnad River at Mithankot. Beyond this confluence, the river, at one time, was named as Satnad River (sat = seven, nadi = river) as the river was now carrying the waters of Kabul River, Indus River and the five Punjab rivers. Passing by Jamshoro, it ends in a large delta to the east of Thatta. Together with the rivers Chenab, Ravi, Sutlej, Jhelum, Beas and the extinct Saraswati River, the Indus forms the Sapta Sindhu ("Seven Rivers") delta in the Sindh province of Pakistan. It has twenty major tributaries.

***Fig. 26**: The Indus watershed* [72]



Source: Watershed Atlas of India

The Indus is one of the few rivers in the world that exhibit a tidal bore. The Indus system is largely fed by the snows and glaciers of the Karakoram, Hindu Kush and Himalayan ranges of Tibet, Kashmir and Northern Areas of Pakistan. The flow of the river is also determined by the seasons – it diminishes greatly in the winter, while flooding its banks in the monsoon months from July to September[73]. There is also evidence of a steady shift in the course of the river since prehistoric times – it has deviated westwards from flowing into the Rann of Kutch. The Indus River feeds the Indus submarine fan located in the Arabian Sea, which is the second largest sediment body on the Earth with about 5 million km^3 of material eroded from the mountains.

Studies of the sediment in the modern river indicate that the Karakoram Mountains in northern Pakistan are the single most important source of sediment, with the Himalaya providing the next largest contribution, mostly via the large rivers of the Punjab. Analyzing sediments from the Arabian Sea, Clift and Blusztajn demonstrated that five million years ago the Indus was not connected to these Punjab rivers which instead flowed east into the Ganges and were captured after that time[74]. Earlier work showed that sand and silt from western Tibet was reaching the Arabian Sea 45 million years ago, implying the existence of an ancient Indus River by that time. The delta of this proto-Indus River has subsequently been found in the Katawaz basin, on the Afghan-Pakistan border. Most recently, the Indus was paralleled by the ancient Saraswati River, which the Rig Veda suggests flowed from the Himalaya between the Sutlej and the Yamuna Rivers, close to modern day Chandigarh. Reportedly, the Saraswati River was totally dry by 1900 BCE as confirmed by archeological-hydrological radio carbon dating.

The Indus provides the key water resources for the economy of Pakistan, especially the breadbasket of Punjab province, which accounts for most of the nation's agricultural production, and Sindh. The waters are used primarily for irrigation of agricultural crops. Dams have been built to provide flood control and hydroelectricity. It also supports many heavy industries and provides the main supply of potable water in Pakistan.

3 Coastal Ecosystems and Pollution in South Asia

South Asia's rich marine resources have for long been central to its development. At the turn of the century, many countries in South Asia relied almost exclusively on inland and marine fisheries as their sole source of protein and, in some cases, foreign exchange. In the latter half of the century, the rapid expansion of fisheries, coupled with population and industrial growth, resulted in increased migration to coastal cities and the expansion of coastal settlements. Today, about one-quarter of the world's 75 largest cities are situated along the region's coastline. The coastline of South Asia in particular is under pressure from a range of drivers, which include:

- Population growth (both migration towards the coast and natural growth)
- Industrial development
- Tourism development
- Aquaculture development
- Deforestation in upstream / mountain areas
- Climate change.

These drivers have resulted in state changes such as:

- Increased domestic and industrial effluents causing changes in water quality (both water movements, e.g., flooding and drainage patterns, salinity and sediment loads)
- Change in coastal geomorphology due to dredging and changed land use patterns
- Habitat destruction (particularly of sensitive environments such as mangroves and coral reefs), e.g., the expansion of aquaculture production at the expense of mangrove forests
- Climate-related impacts (including sea-level rise and changes in coastal weather), declining resources
- Loss of biodiversity.

These changes are indicated by:

- Increased domestic and industrial effluent causing changes in water quality
- Changes in water movements, e.g., flooding, drainage patterns (run-off/seasonality) and sediment loads
- Changes in salinity
- Declining oxygen conditions
- Shoreline changes, especially erosion
- Loss of coastal biodiversity.

In many parts of the region, economic development has been most active in coastal zones, and is the main driver of change in coastal ecosystems. Offshore mineral exploration and production activities are further sources of pollutants. A few of the most critical socioeconomic drivers of the degradation of the coastlines in South Asia are given in Table 7.

***Table 7**: Some critical socioeconomic drivers of the South Asian coastlines* [75]

Driver	Pressure	Impact
Agriculture	• Reclamation of coastal wetlands • Use of fertilizers and pesticides • Abstraction of water / large irrigation schemes	• Water quality impairment due to nutrients resulting in eutrophication • Loss of biodiversity • Reduction in freshwater flow
Aquaculture	• Conversion of mangroves, agricultural lands into aquaculture farms • Use of biocides, nutrients	• Loss of biodiversity • Water quality impairment due to nutrients resulting in eutrophication
Fisheries	• Coastal and deep-sea fisheries	• Reduction in catch due to over-exploitation of resources
Forestry	• Mangrove forest products harvesting; • Large-scale upland deforestation	• Loss of biodiversity • Increased erosion during rains and higher sediment load in water
Energy	• Coastal and offshore oil and gas exploration and operation • Coastal power generation • Large inland hydroelectric dams	• Oil pollution • Impaired water quality due to water release at higher temperatures from power plants • Reduction in freshwater flow • Reduction in sediment load
Industry	• Coastal industrial plants • Coastal and marine mining (e.g., sand) • Salt extraction • Industrial waste disposal	• Impaired water quality due to release of untreated/partially treated effluents containing metals and other chemicals
Tourism	• Coastal hotels and recreation facilities • Sewage and waste disposal	• Waste discharges and microbial pollution • Change in land use due to constructions, changes in drainage patterns • Loss of biodiversity due to land use changes
Transportation	• Ports and harbors • Channel construction and maintenance dredging • Dredge spoil disposal • Coastal roads, railroads and bridges	• Water quality impairment due to disposal of dredging spoils • Increased water turbidity • Water quality impairment due waste disposal • Shoreline changes, changes in land use patterns
Urbanization	• Shoreline modification • Waste disposal (e.g., landfills) • Water and sewerage development • Urbanization of coastal areas in natural or semi-natural state, upland watersheds • Groundwater abstraction	• Water quality impairment due to higher nutrient loads, suspended solids, organic loads • Impact on coastal ecosystems, e.g., coral reefs, sea grass beds due to suspended solids, higher turbidity, reduced photosynthesis • Subsiding cities due to soil compaction • Loss of biodiversity • Water quality impairment due to trace metals and microbial pollution • Health impact for coastal people due to arsenic and fluoride intake

The four major impacts of land based activities on the coastal marine environment include:

i) Changes in freshwater flow/sediment load; siltation/erosion/soil compaction

ii) Water quality impairment due to excess nutrients

iii) Water quality impairment due to chemical/metal pollution

iv) Loss of biodiversity due to loss of habitat.

These issues are now discussed in detail.

3.1 Change in Freshwater Flow

Freshwater shortage in the sub-continental South Asian region, excluding Sri Lanka, associated with the Bay of Bengal has both international as well as national (inter-state, inter-province) transboundary implications. The international transboundary implications pertain to Bangladesh, Bhutan, India, Nepal, and eventually the Bay of Bengal. The national 'transboundary' implications pertain mainly to inter-state conflicts over water use in shared rivers within India. The geographic situation of Bangladesh results in about 90 % of its stream flow arriving from its neighbors. This also means that the huge volume of water arriving from the immense watershed of the Ganges-Brahmaputra-Meghna (GBM) river system is funneled into the Bay of Bengal through the 540 km stretch of Bangladesh's coastline. Therefore, water management, especially in India and in Nepal, has consequences for Bangladesh and the Bay of Bengal. Inadequacy of freshwater flows has resulted in salinity intrusion more than 300 km inland that has aggravated the initial freshwater shortage[76].

A reduction is seen in the quantity and quality of water flow of many rivers as a result of human interventions on a local/regional scale over the last three-four decades. The freshwater shortage experienced in Bangladesh as a consequence of the construction of the Farakka Barrage across the Ganges in 1975 in India, is substantiated by the flow measurements made at Hardinge Bridge, Bangladesh. This measuring point is situated on the Ganges, in Bangladesh near the border with India. The data shows that the dry season flows after construction of the Farakka Barrage during some months have diminished by as much as 60 % relative to the average flows for the period 1934-1975[77]. Nevertheless, the wet season flows remain undiminished.

The northeastern part of India associated with the rivers Ganges and the Brahmaputra are better endowed with water resources than the states in peninsular India. The total catchments of the rivers in peninsular India are smaller than that of the GBM system. Peninsular India supplied by these rivers is drought prone and faces regular and serious water shortages. To an extent, these shortages are attributed to alteration of stream flow in some of the major rivers such as the Cauvery and Krishna. While these do not have international transboundary implications, serious inter-state conflicts exist with regard to the inadequacy of water to the downstream state, Tamil Nadu, because of excessive draw off by the upstream states. The shortages of stream flow in these rivers have serious consequences for the flushing of estuaries associated with coastal cities bordering the Bay of Bengal.

Modification of stream flow in Sri Lanka has a long history dating back 2,500 years freshwater shortage in Sri Lanka is becoming a significant problem in the dry zone, the major food producing area of the country. Both domestic and agricultural freshwater shortage is attributed mainly to alterations to stream flow from the construction of inadequately integrated multi-purpose reservoirs and canal systems.

3.2 Siltation

India has about 4,050 dams and a few more are under construction. The flooding monsoon waters erode and transport soil. In the Himalayan region, sediment concentrations of up to 80,000 µg/g have resulted in the accumulation of millions of tons of silt in the reservoirs. In the Himalayan region, sediment gets multiplied due to the young geology and the glacial silt in snow melt region[78]. The main sources of sediment in Himalayan rivers are glacial deposits, landslides and intensively cultivated hill slopes. However, little qualitative or quantitative information is available on the sediment released from these sources. To combat further degradation of water resource by the river sediment, detailed knowledge is needed of the rate of supply, the characteristic size and shape of the sediment particles, hill slope, channel storage, downstream transport and attrition particles[79]. In the case of Ganges and Brahmaputra, 55 % of their combined annual sediment load (1.1 billion t/yr) is retained by their delta, with only 36 % reaching the shelf and 9 % reaching the deep sea[80].

Evidence from longer-term sediment load records indicates that river sediment fluxes are sensitive to many influences, including reservoir construction, land clearance and land use change, other forms of land disturbance, including mining activity, soil and water conservation measures, sediment control programs, and climate change. Some of these influences cause sediment loads to increase, whilst others, namely soil and water conservation, sediment control programs and reservoir construction, may cause significant decrease in sediment fluxes[81]. Humans have increased the quantity of sediment in global rivers through soil erosion (by 2.3 ± 0.6 billion metric tons per year), while simultaneously reducing the flux of sediment reaching the world's coasts (by 1.4 ± 0.3 billion metric tons per year) because of retention within dams and reservoirs. Over 100 billion metric tons of sediment and 1-3 billion metric tons of carbon are now sequestered in reservoirs constructed largely in the past 50 years. African and Asian rivers carry a greatly reduced sediment load; Indonesian rivers deliver much more sediment to coastal areas[82].

3.3 Suspended Sediment Load

The GBM river system delivers 30 % of the world's total load of river sediment[83]. The high turbidity in the coastal waters of the Bay of Bengal is visible in satellite photos. The absence of coral reefs of any significance in the continental shelf area associated with the Bay of Bengal bears evidence of attenuated light penetration in these waters which is inimical to the development of coral species. Effluent plumes from coastal sites or effluent discharge from polluted estuaries associated with major cities such as Chennai do not penetrate beyond 500 m in coastal waters. These plumes are deflected by longshore currents in a manner that eliminate the possibility of transboundary impact.

Suspended solids are recognized as a problem common to the entire Bay of Bengal including the Andaman Sea. The levels of suspended solids change seasonally, increasing to higher levels during the monsoon rains. Some of the eroded sediment is trapped by hydroelectric dams with adverse consequences on reservoir storage capacity. The sediment load in the GBM river system measured in Bangladesh greatly exceeds the limit of 10 mg/l set for drinking water. Data for the coastal areas reveal loads of 1.3-2.2 g/l, which results in heavy sedimentation[84].

The GBM river system conveys an enormous amount of sediment from the mountains to the plains, compounded by the adverse effects of floods. The Kosi and some tributaries of Brahmaputra are particularly notable in this regard (Table 8). Most of this sediment load passes into the Bay of Bengal while a part of it is deposited on the floodplain during overbank spilling. This process has gradually changed the valley geometry and floodplain topography, often reducing the water conveyance capacity of the drainage channels[85].

***Table 8**: Total suspended and chemical load entering the Bay of Bengal from six major Indian rivers* [86]

River	**Discharge**	**Drainage Area**	**Load** (10^6 tons/yr)		
	(km^3/yr)	(km^2x10^3)	Chemical	Sediment	Total
Ganges	493	750	84.0	329.00	413.00
Brahmaputra	510	580	51.0	597.00	648.00
Krishna	30	251	0.4	4.00	14.40
Mahanadi	67	42	9.6	1.90	11.50
Godavari	90	310	17.0	170.00	187.00
Cauvery	21	88	3.5	0.04	3.54

3.4 Nutrient Pollution

Rivers of South Asia are heavily contaminated with municipal sewage, industrial effluent, agricultural run-off and sediments. One of the most serious impacts is the decline in water quality caused by rising levels of nutrients from land-based sources. Expansion of intensive agricultural practices has resulted in increased agrochemical pollution, particularly in developing countries of the region. In terms of N+P+K, fertilizer consumption in India was about 18,128.93 x 10^3 tons in 2000. However, according to the National Centre for Integrated Pest Management[87], pesticide consumption in India has declined from 61,260 MT in 1995-96 to 41,350.4 MT in 2004-2005.

Measurable pollution is evident in most Indian rivers associated with large population centers, although quantitative differences exist. Some Indian river tributaries, reportedly, receive municipal waste from urban centers and become sewers seasonally as low stream flow becomes inadequate for flushing the waste load. In coastal cities such as Chennai and Calcutta, inadequate flushing associated with diminished freshwater flows result in severe pollution and associated health issues. Few cities and towns have centralized wastewater collection and treatment systems and hence untreated or inadequately treated wastewater directly reaches the river systems. The health impacts stemming from inadequate stream flow for flushing sewage has severe health consequences predominantly for the poor who live in slum districts of the major cities in India and in Bangladesh.

***Table 9**: Water chemistry in the GBM river system measured in Bangladesh (mg/l)* [88]

River	**Ca**	**Mg**	**Na**	**K**	**Cl**	**SO_4**	**HCO_3**	**SiO_2**
World average	14.70	3.70	7.20	1.40	8.30	11.50	53.00	10.40
Ganges near Rajshahi	35.00	3.00	3.12	2.30	7.10	6.99	110.00	ND
Brahmaputra near Kurigram	25.00	3.60	2.34	3.50	14.20	3.40	79.00	ND
Meghna near Bhairab Bazzar	20.00	3.00	3.90	1.53	7.10	4.09	49.00	ND

Regular monitoring of all water bodies in India is carried out by the Central Pollution Control Board. The monitoring results obtained during 2007 indicated that organic pollution continued to be the predominant pollution of aquatic resources[89]. The organic pollution measured in terms of bio-chemical oxygen demand (BOD) and Coliform bacterial count gives the indication of extent of water quality degradation in different parts of the country. Many river basins in India go dry during summer leaving no available water for dilution of wastewater discharged into them.

3.5 Metal Pollution

The GBM basin countries are increasing their industrial activities at rapid rate. According to the UN World Water Development Report[90], approximately 300-500 million tons (272-454 billion kg) of heavy metals, solvents, toxic sludge, and other wastes are discharged each year from industrial activities, most of which enter the freshwater sources. In the GBM basin, 70 % of the industrial wastes are dumped untreated into surface waters. The total volume of wastewater discharged into the Indus River system is about 19 % of the available water resources, with 90 % of the wastewater originating from agricultural areas. Many industries in India discharge wastes directly into rivers or streams despite the fact that they are supposed to have effluent treatment plants. Similarly, about 6,000 large and medium scale industries and about 24,000 small scale industries operating in Bangladesh send their untreated waste directly into the GBM river system.

Surface water shortage in Bangladesh and India, particularly in drought prone areas, has driven intensive extraction of ground water. Arsenic and fluorides mobilized from minerals by extracting groundwater below a threshold depth has now become a serious problem. Prolonged consumption of arsenic and fluorides in groundwater is recognized as a severe health problem among rural communities[91]. Arsenic contamination in West Bengal, India and in Bangladesh is now recognized as a transboundary issue. At present many millions of people living in rural Bangladesh are exposed to the risk of arsenic poisoning. People in 61 out of 64 districts across Bangladesh are now considered to be at risk. Arsenic contamination of groundwater was first reported in 1996 from Bangladesh districts bordering the Indian state of West Bengal. By end of 2001, Bangladesh health officials reported that about 80 million people, more than 65 % of the population of the country, live in arsenic contaminated areas.

Studies carried out by the School of Environmental Science, Jadavpur University, Kolkata, India reported that oxidation of arsenic rich minerals in silt-clay deposits at depths of 30-80 m was the primary cause. The problem originated with intensive tapping of groundwater in West Bengal for irrigation. The arsenic rich minerals are distributed in an area of about 35,000 km^2 extending from West Bengal, India to the Ganges Delta in Bangladesh. Bangladesh is particularly vulnerable because the Ganges Delta is hydrologically connected to soil with similar depositional history in West Bengal, India.

3.6 Oil Pollution

This arises from various sea-based activities, including marine transportation as well as offshore mineral exploration and production activities. Beach tar is also considered a severe problem along the west coast of India, with total deposits of up to 1,000 tons a year[92]. The Western part of the Indian Exclusive Economic Zone (EEZ); Lakshadweep and the Nicobar Islands, lie close to one of the major oil tanker routes, originating from the Gulf countries to reach South East Asia. Nearly 500 million tons of crude oil is carried by about 3,500 tankers along this route. Any major oil spill occurring in the Arabian Sea and Bay of Bengal can lead to large scale damage to marine environment and hence the Indian government has developed oil spill modeling and mapping of oil spill areas[93]. Off shore platforms for oil production also exist in the Godavari, Krishna and Cauvery basins and there are spills from operations here. These, however, cannot be associated with transboundary impacts.

3.7 Loss of Biodiversity

Wetlands including estuaries and lagoons have been severely affected by pollution and siltation from diverse coastal and catchment land uses. These estuaries and lagoons serve as nurseries for fish and shellfish species that contribute substantially to income, livelihood and food security of small-scale and subsistence fisher communities inhabiting the coastal areas of the Asian river deltas. Coleman et al.[94] used satellite imagery to estimate the total conversion of wetlands to open water and agricultural lands during the 1989-2001 in the GBM delta and found it to be 4,290 km^2. In the case of river Indus, they found an average annual rate of wetland loss of 79 km^2/yr.

Floodplains have diminished because of diverse interventions for water management. However, the magnitude and intensity of floods that cause serious damage to life and property are sometimes associated with these river 'training' interventions. The diminishment of flood plains has adverse consequences on incomes of inland fisher families.

West Bengal in India and the Ganges-Brahmaputra delta of Bangladesh include the largest continuous mangrove tract in the world, the Sunderban. Apart from the Sunderban, mangrove ecosystems of significance also exist on the east coast of India, Andaman and Nicobar Islands, and the coastal deltas of Myanmar. Mangroves are known to trap sediment and thereby to reduce the suspended sediment load into the coastal waters. Recent satellite images demonstrate that the turbidity plumes associated with the Sunderban extend through the northern Bay of Bengal. One possible consequence of the existing trend in the destruction of the mangrove ecosystem would be aggravated sediment loads that shade the critical coastal vegetation such as sea grasses that grow in shallow water. Sea grass species die in the absence of adequate light for photosynthesis. Loss of sea grass entrains a reduction in coastal fish stocks.

***Table 10**: Sunderban mangroves, West Bengal* [95]

Area (km^2)	lat. 21°32' – 22°40' N; long. 88°85' – 89° 00' E
Ecological significance	The Sunderban (meaning "beautiful forests") account for over 10 % of the mangrove forests in the world, making them the largest single mangrove unit globally. They cover an area of 12,000 km^2 of which approximately one third lies in India and the rest along the Bangladesh coast. It is the largest mangrove forest in India, which consists of diversified mangrove flora including some endangered species.
Flora and fauna	A total of 69 floral species have been recorded which includes 34 species of true mangroves. The fauna of this area includes 250 species of fishes, 8 species of amphibians, 57 species of reptiles, 161 species of birds and 40 species of mammals besides several other benthic organisms.
Socioeconomics	Timber extraction, honey collection, fire wood and fodder collection, and rich local fishery.
Conservation status	World heritage site, biosphere reserve for preservation of mangrove genetic resources, royal Bengal tiger project site, protection site for salt water crocodiles.

An annual loss of about 30 % of mangroves was reported in Bangladesh. However, loss of mangrove habitat in some populous locations is compensated by the natural expansion of mangroves in other areas. The balance between loss and natural gain may require future assessment. The positive role of mangroves as nursery habitat for coastal fish stocks on which some two million coastal fisher families depend in the Bay of Bengal sub-region is adequately recognized. Excessive removal of mangroves along the Orissa coast has resulted in shifts in composition of marine stocks. The predominant catch in coastal fishery has shifted from finfish to non-finfish species. The dominant catch now consists of squids.

The relationship between mangrove depletion and expansion of shrimp aquaculture was regarded as a serious concern that has severe consequences for traditional coastal fisher folk. It was noted that habitat modification associated with natural causes is significant for coral reefs. The coral reef extents are relatively small, but the impact is significant. These can occur on a much larger scale than those attributable to human impact. The better developed and more extensive coral reefs occur in the Andaman Sea.

4 Summary

The rich coastal and marine environment in the South Asia region is subjected to great pressure through over-extraction of resources, enhanced pollution and physical alterations of coastal and river-catchment ecosystems. Some of the key drivers/pressures resulting in the degradation of coastal ecosystems in South Asia are summarized below:

- Freshwater interceptions for agricultural schemes have severely affected mangroves and other coastal habitats
- Marine-based tourism leads to environment degradation through the construction of hotels, beach clubs and marinas involving infilling, dredging and re-suspension of contaminated silts
- Sediment loads in the coastal zones of South Asia is high, mainly arising from soil erosion due to poor land use practices
- Major industrial cities and towns are situated on or near to the coastline and they discharge large amounts of untreated effluents daily
- Mangroves have been exploited for timber, fuel wood and other purposes, while large areas have been cleared for agricultural activities and for shrimp farming
- Limited institutional capacity and resources continue to be the major impediments to the implementation of coastal environmental management plans.

The major underlying causes include:

- Increasing population pressures and pollution due to land-based (and river catchment-based) activities such as disposal of untreated or improperly/partially treated wastes from municipal and industrial sources directly into receiving waters

- Intensive agriculture development, especially the damming of rivers for irrigation and power generation
- Climate change and associated natural disasters
- A disconnect between catchment and coastal management.

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II. LOICZ-DPSIR Framework

1 Introduction

The LOICZ Basins approach for studies of river catchment-based coastal changes gives a comprehensive assessment of key natural processes and coastal states that are impacted by both natural and anthropogenic forcing. Rivers and their lower reaches in general have great significance in coastal development because of exchange of energy, sediments and water runoff, and impact on biodiversity, attractiveness of shores for human habitation, recreation and economic activity in South Asia as well as on global scale. For natural and social scientists, the LOICZ Basins studies expand their understanding of the socio economic drivers of coastal environmental changes and transformations, and give a new vision of links between the elements of coastal ecosystems. The coastal zone may be considered as the interface area between continents and oceans but everything that happens in the coastal zone is affected considerably by spatial and temporal processes originating far beyond their borders, in the catchment. Thus LOICZ applies a "water continuum perspective" to changes in the coast which considers a source to sea ocean and atmosphere driver, pressure, state, impact, response, DPSIR, concept.

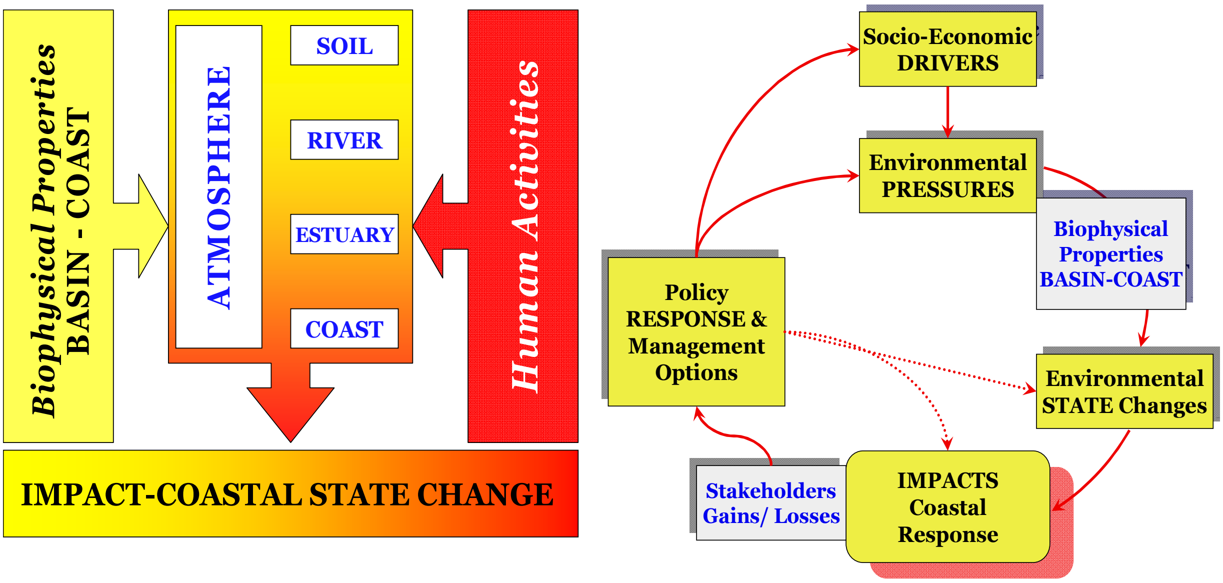
This report addresses the following questions:

a. What are major drivers/pressures in the South and (partly) South-East Asia region and what are the observed related coastal impacts?
b. How close are South and South Eastern coasts to a critical threshold of system functioning?
c. What are major driver/pressure settings on river catchment level that are causing coastal changes and impacts?
d. Can we identify spatial scales on which certain driver/pressure settings dominate coastal issues?
e. What are future trends (based on hard data or expert judgment)?
f. What are major driver/pressure settings on country or sub-regional level causing coastal impact observed?
g. What is the current status of response taken at scientific, policy and/or management levels to tackle the major coastal issues in the region?
h. What are major gaps in our current understanding of river catchment-coastal sea interaction?
i. Which "hot spots" should be addressed by future integrated scientific effort (collective research of natural and social science disciplines)?

2 DPSIR Framework

The LOICZ approach has traditionally focused on the changes in biogeochemical cycles as a major indicator of land ocean interactions. The LOICZ-Basins project is dealing with the impact of human society on the material transport to the coast, including water, sediments, nutrients, heavy metals and man-made chemicals. It assesses their impacts on the coastal systems and tries to identify and inventory rational management options. Since the changes in fluxes originate mostly in the various activities along the rivers, the catchment-coastal system is treated as a single "water continuum" unit.

Fig. 27: *LOICZ basins[1]: the catchment-coast continuum as one system (left) and the DPSIR framework (right)*



In practice, this requires taking into consideration activities such as tourism, fisheries, agriculture, mining, urban development, industry and transport, as well as morphological modifications to the catchment, including construction of dams, irrigation channels and flow diversions. In LOICZ basins studies, critical load and threshold concepts are adopted and extended to the marine environment where data allow. The systems approach is used for cost-benefit analysis of management options.

3 DPSIR Framework Terminology

In this report, efforts have been made to apply the DPSIR (Driver-Pressure-State-Impact-Response) framework to South Asian river basins. This multidisciplinary approach originally promoted by OECD in 1993 and further developed within the LOICZ project (Turner et al.[2], Ledoux et al.[3], Crossland et al.[4]) allows combining the knowledge and experience of natural and social scientists. Data and information are reviewed in such a way as to produce a complex picture of interactions of economic sectoral activities that affect coastal zone ecosystems and social processes, and to reveal further indicator functions and impacts on natural and social values of the coastal zone. The analysis assesses the response of society on environmental and anthropogenic changes in the coastal zone.

Drivers: the sectoral economic activities in the catchment and coast affecting the coastal zone of South Asia include:

- *Agriculture*
- *Forestry*
- *Fisheries*
- *Aquaculture*
- *Port facilities and urbanization*
- *Land-use change (e.g. urbanization, plantation, industry, agriculture)*
- *Mining and refining industry*
- *Oil and natural gas exploration/exploitation driven by demand for energy*
- *Industrial developments*
- *Shipping operations.*

Pressures: processes affecting key ecosystem and social system functioning in South Asia are:

- *Dams and other constructions that regulate water flow*
- *Irrigation, river diversion and water abstraction*
- *Discharge of industrial effluents (industrialization), agricultural and domestic wastes*
- *Navigation and dredging for navigation*
- *Extraction of river-bottom sediments (building materials)*
- *Sea level rise induced by land-based activities affecting the coastal zone (e.g., sediment retention, ground water abstraction).*

State and State Change: the measurable indicator functions and how they are affected in South Asia include:

- *Water, nutrient and sediment transport (including contaminants where appropriate) observed in the coastal zone indicating trans-boundary or catchment based pressures*
- *Geomorphologic settings, erosion, sequestration of sediments, siltation and sedimentation*
- *Economic fluxes relating to changes in resource stocks and flows from coastal systems, their value and changes in economic activity including the valuation of natural resources, goods and services.*

Impacts: on system characteristics and provision of goods and services

- *Environmental impact*
- *Ecological impact*
- *Economic impact*
- *Social impact.*

Response: action taken

- *Law and policy*
- *Management*
- *Scientific research do expand the knowledge base and inform improved management*
- *Technological responses.*

4 Indicators of Coastal Change

Critical load provides key information about the development and application of indicators for monitoring purposes as required. An example is the implementation of the Coastal Global Observation System (C-GOOS) – now the COOP-Coastal Ocean Observing Panel of UNESCO-IOC. The LOICZ Basins, subject to the availability of data, employ different approaches to identify targets and indicators for coastal responses:

- A simple “policy-oriented” approach considers the critical loads that have been agreed upon in international treaties or on other relevant scales.
- An “ecosystem” approach uses historical data to evaluate the coastal systems and their reaction to changing loads and identifies indicators, attempting to distinguish between natural and anthropogenic changes.
- A “regional management” approach consults local authorities, identifies criteria for indicators or critical loads, and incorporates socioeconomic factors along with scientific data.

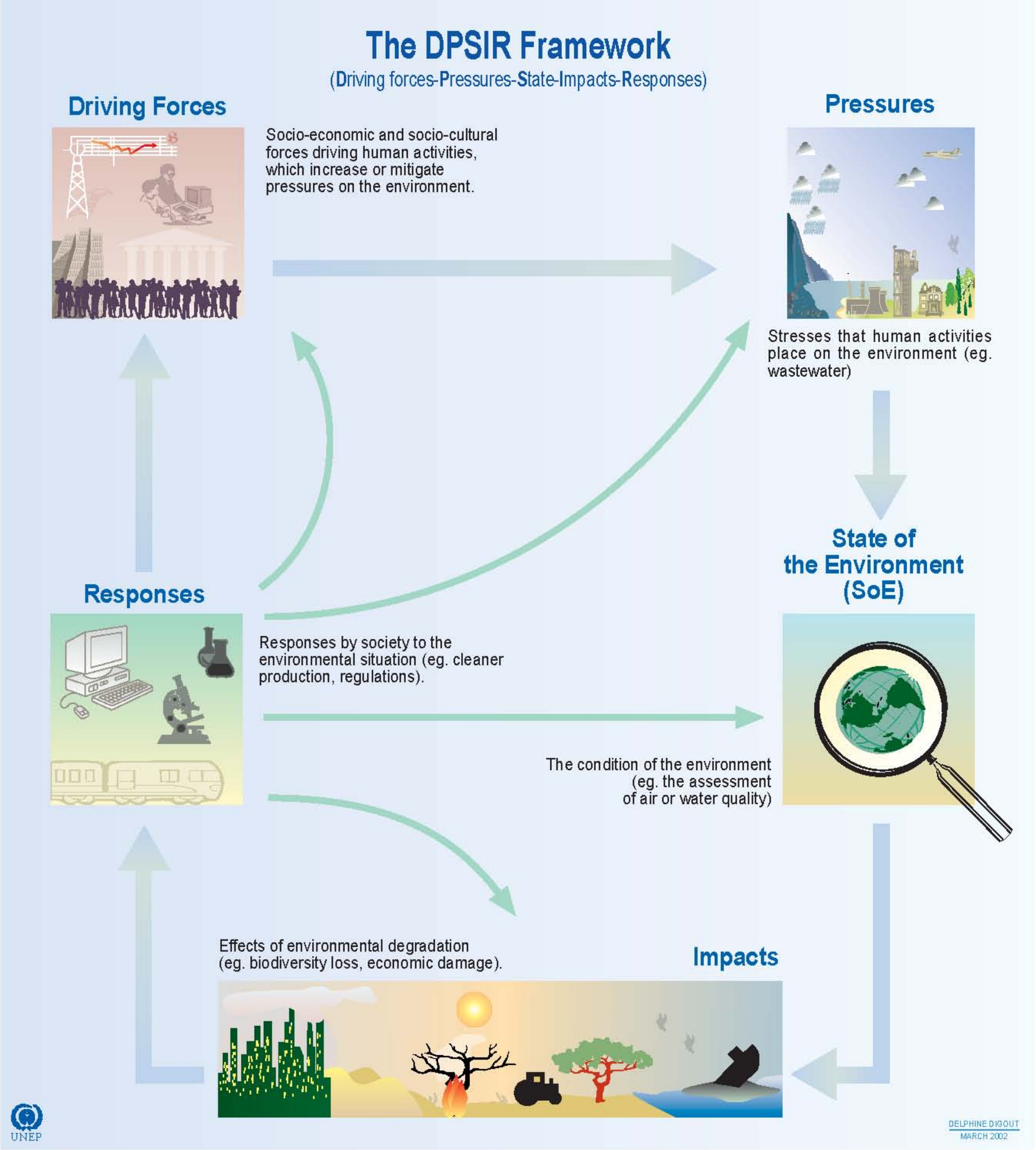
The indicators and targets are used to derive critical concentrations. This critical load or critical outflow of the catchments is a combination of inputs by socioeconomic activities and transformations in the river catchment and coastal system. When the links and transformation of the loads are established, it is possible to simulate scenarios for cost-benefit analysis and trade-offs, integrating natural and social scientists, and stakeholders from industry, government, non-governmental organizations, user groups and citizens. Hence, the LOICZ Basins approach has used the following aspects:

- Determine the time delay between changes in land-based material flows, the causes of the delays, and their impacts on the coastal system
- Generate better understanding of the complexities of coastal environments and from this derive critical loads
- Explore and consider the diversity of stakeholder’s interests affected by trans-boundary and water continuum issues.

5 Methodology of the Study Report

In order to consider the impact of changes that are taking place and/or likely to happen in the river catchments of South and South-East Asia and the downstream impacts on the coastal systems, LOICZ organized a workshop in Sri Lanka in 2005 to address these issues. The workshop was supported by UNEP-GPA and UNESCO-IOC and hosted by the LOICZ Regional Node South Asia at NSF, Colombo. This report highlights the outcome of various scientific findings by experts from South and South-East Asia, by identifying the biophysical sub-regions and the issues involved in the river catchment-coastal continuum of each of these sub-regions. The original workshop was complemented and supported by extensive desk studies to obtain the latest references and data over the last three years.

***Fig. 28**: The DPSIR framework* [5]



Source : Global International Water Assessment (GIWA), 2001; European Environment Agency (EEA), Copenhagen.

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III. CATCHMENT SCALE SYNTHESIS

1 Introduction

Chapter 1 provided essential background details about the rivers and the river basins that have been studied for this report. Chapter 2 outlined the DPSIR framework and the reasoning behind its use. This chapter details the DPSIR framework for each of the river basins. A critical load approach has been adopted for the catchments. It is a quantitative estimation of the ecosystem sensitivity in to a given impact compared with present state of ecosystems regarding a given parameter and/or pressure. Coastal impacts are characterized and ranked according to their degree of importance based on qualitative and quantitative evaluation with respect to the present distance to critical threshold of a pressure for system functioning. Thus the ranking provides an expert judgment based typology picture.

2 Bengal Basin

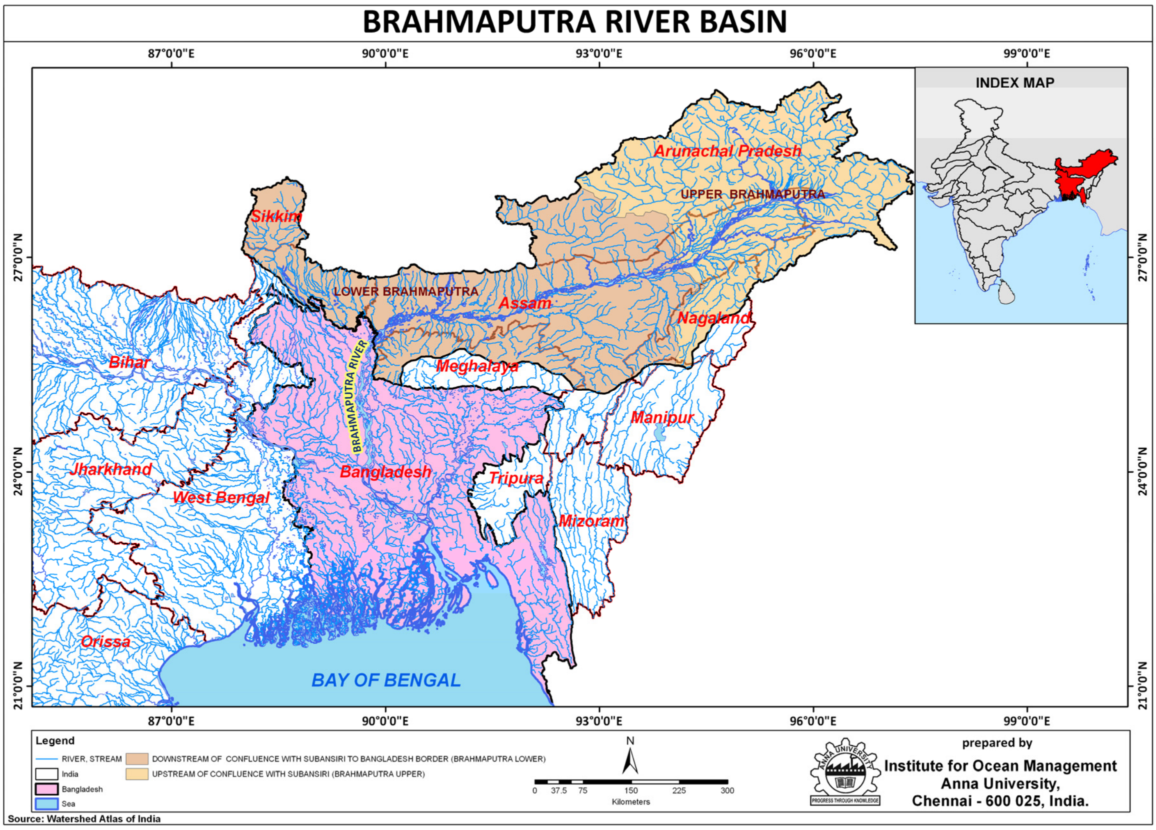
2.1 Brahmaputra

The Brahmaputra valley in Assam is home to more than 15 million people. Despite gigantic efforts and colossal expenditure (more than INR 15,000 million) in building 3647 km of embankments, 599 km of drainage channels and 431 km^2 area for soil conservation, the Brahmaputra continues to wreck havoc through uncontrollable floods year after year[1].

The catchments of the Subansiri, Jia Bharali and the Manas along with the Dihang (Siang) are estimated to have high denudation rates of 73-157 cm/yr in 24 years (1955 to 1979), which is normally the average for a 1000 year period. The sediment and water yields downstream indicate an increase in sediment yield by 240 % accompanied by an equally significant rise of nearly 120 % in water yield during the period 1971-1979 between Tsela D'Zong (China) and Ranaghat (India). High rates of denudation of the Himalayan catchment of the Brahmaputra are probably attributable to the rapid uplift of the mountain system, steep slopes, high susceptibility to erosion, an intensely powerful monsoon regime, recurring earthquakes and the adverse impact of anthropogenic factors.

Shifting cultivation is extensively practiced and this, along with deforestation, faulty land use, improper land tenure system and lack of awareness are important causes of floods in the region. The total area prone to floods in the basin is 31,740 km^2 while 3,609 km^2 experience floods every year[2]. A suspended sediment budget for the Ganges-Brahmaputra catchment shows that of the 794×10^6 t/yr transported in the rivers of the Ganges catchment, 80 ± 10 % comes from the High Himalaya, 20 ± 10 % from the Lesser Himalaya, and the proportions from the Tethyan Himalaya, Siwaliks, Plain, and Peninsular while unknown are each likely to be < 10 %. About 8 % of the river sediment is deposited on floodplains and delta-plains in Bangladesh. The remaining >45 % is deposited in the subaqueous delta and the Bengal Fan[3].

***Fig. 29**: Brahmaputra watershed* [4]



Source: Watershed Atlas of India

The Brahmaputra changes its course and pattern along with its current flow very frequently especially in its upper stretches and this has a strong bearing on its hydrobiology. The hydro-geological pattern of the Brahmaputra has resulted in a possible zonation of the river into five major types of fish habitat. Altogether 167 fish species have been recorded from the upper Brahmaputra of which about 30 % may be considered as ornamental varieties. Large-scale felling of trees in the catchment areas, construction of embankments along the river banks as well as dams in the connecting channels of the floodplain lakes have altered the riverine ecosystem drastically, as a result of which, the river has become heavily silted[5].

The basin area of Brahmaputra covers the states of Arunachal Pradesh, Assam, Nagaland, Meghalaya, Sikkim and West Bengal. The important urban centers in these States are Shillong (Meghalaya), Guwahati, Jorhat Dilbrugarh, Siliguri, Alipurduar, Dhubri, Nagaon, Tezpur, Tinsukia (Assam), Dimapur (Nagaland), Kohima (Sikkim), Darjeeling, Dabgram Jalpaiguri, Koch-Bihar (West Bengal). As of 31 July 2008, there were eight multi-purpose projects being planned by the Brahmaputra Board[6].

According to the Central Pollution Control Board (India), the water quality of River Brahmaputra is conforming to water quality criteria with respect to pH, conductivity and DO. The BOD value ranges from 0.1-3.4 mg/l[7]. According to Immerzeel[8], in the floodplains the main threat of climate change lies in the increase of extreme precipitation in the monsoon and the associated flooding. In combination with anticipated sea level rise the effects for Bangladesh will be devastating. Rapid accumulation of water in glacial lakes can lead to a sudden breaching of the unstable 'dam' behind which they have formed. The resultant discharges of huge amounts of water and debris often has catastrophic effects on people, both upstream and downstream. In the long-term it will change the timing and availability of water.

The changes occurring in the CNP pools of the Brahmaputra basin and the manner in which they may be influenced by climate change activities have been analyzed based on data on several anthropogenic factors such as population growth, deforestation, agricultural activities, urbanization, fertilizer and fossil fuel consumption and construction activities. The analysis showed how the changes that are potentially affected by climatic factors have affected the biogeochemistry of the region, particularly that of the Brahmaputra basin[9]. The authors also point out that imprints of climatic variability may have already become visible on the biogeochemical flux from the region. The Particulate Organic Carbon (POC) concentration varied from 0.64 % during non-monsoon to 1.93 % during monsoon (ranging from 0.5 mg C/l to 17 µg C/l). Thus, the average annual flux of particulate organic carbon (POC) through the Brahmaputra River in a downstream location at Pandu was computed as 6.24×10^6 tons/yr. Particulate nitrogen (PN) in the Brahmaputra varied from 0.2 % to 0.4 % (avg. 0.25 %) during pre-monsoon, and 0.08 % to 0.11 % (avg. 0.1 %) during monsoon with an increasing trend downstream during pre-monsoon. The flux of PN was estimated to be 8.5×10^5 tons/yr. The total phosphorus in suspended sediment particles varied between a minimum of 1,025 µg/g and a maximum of 1,290 µg/g (monsoon) and 945-1,160 µg/g (pre-monsoon) with an annual transport of the order of 3.4×10^4 tons P per year. This is greater than the particulate phosphorous load for the Amazon (2.8×10^4 tons/yr)[10]. Although the relative magnitudes of anthropogenic and natural impact are still unknown, it is apparent that carbon, nitrogen, phosphorous cycles are strongly influenced by sediment fluxes and consequently by climate variability in the region. However, the seasonal variations, high inter-annual unpredictability and rapid change on larger time scale of the monsoon over the basin would require to be understood with further research, to establish the climate link conclusively.

Early signs of climate change appear earlier in the most ecologically sensitive places. The Brahmaputra basin is a biogeochemical hot spot that is located at the transitional zones between different climatic regions and different distinct ecosystems, such as that of the cold dry climate of the Tibetan Plateau and the warm tropical climate of the Assam-Bangladesh plains. The temperature contrast is likely to occur here earlier than in other regions. The magnitude and direction of climate change impacts could be significant both in relative and absolute terms. The open sea connection to this high nutrient flux is of particular importance as time-series studies revealed sediment load fluctuations of an order of magnitude over two decades indicating one of the highest variability in the world. Distribution of C-N-P and DO in the deep Indian Ocean suggests that the sediment flux serves as a major nutrient source and oxygen sink[11]. Little however is known about the past changes in the fluvial sediment loads despite the recognition of significant variation under changing climatic regimes. The timing of immense discharge in the early Holocene strongly suggests its relation to a stronger than present southwest monsoon in South Asia. Similar patterns of high monsoon-related sediment discharge have been noted throughout the tropics and subtropics, suggesting a widespread fluvio-sedimentary response to climate change, the potential magnitude of which is already showcased by the Ganges-Brahmaputra system[12].

***Table 11**: Major coastal impacts and critical thresholds in coastal zones: Overview and qualitative ranking (Brahmaputra basin)*

(Value 1-3 no or minor importance; values 4-6 = medium importance, values 7-9 = major importance, value 10 = critical)

Coastal impact	Local site	Critical threshold (for system functioning)	Distance to critical threshold	Impact category	Refer-ence
		Environmental Impacts			
Suspended sediments	Estuary	1,050 mg/l during period of low river discharge; 1,700 mg/l during high discharge	Seasonal variation in sediment concentrations; currently accumulating trend	5	13
Erosion	Downstream/ delta	Analysis shows that the erosion rates in the Brahmaputra-Jamuna River were 160 m/yr between 1973 and 1992, indicating the severity of erosion hazard along the river	Bank erosion is high, and reportedly increasing due to sudden higher water flows in the river	7	14
Siltation	Midstream and downstream	Annual sediment load of Brahmaputra: 72×10^6 tons and average sediment concentration: 1.89 kg/m^{-3}	No distance can be calculated as the sediment load continues and there are no studies indicating the contrary	5	15
	Coast	Annual sediment yield 160 acre-feet mi^{-2}/yr	No distance can be calculated as the sediment load continues and there are no studies indicating the contrary	7	16
General water quality	Midstream	Possible impact due to pollution from refinery	Qualitative news reports indicate poor water quality	6	17
Metals	Midstream	The average trace metal concentrations in the samples were of the order Mn > Zn > Ni > Cr > Cu > Pb with the suspended load showing increased enrichment relative to the bed load	Could become critical if trend continues	6	18
Organic load	Entire river	D.O. 5.1-10 mg/l; B.O.D. 0.1-3.4 mg/l; C.O.D. 3.1-15.4 mg/l; total Coliform and Fecal Coliform 0-2.4 x 10^4MPN/100ml	The water quality seems to be improving in recent years	5	19
Salinity	Coast	Seasonal salinity variations depending on water flow in the river	Currently no problem of significance in the Brahmaputra due to the absence of large dams that reduce water flow	5	20
		Ecological Impacts			
Riparian vegetation	Midstream	Critical; three-quarters of the habitat in this eco-region has been cleared or degraded	The riparian areas along the Brahmaputra River that have been cleared are characterized by wet grasslands	10	21
Wetlands (bheels)	Midstream and downstream	Significant decline of wetland areas from 1990 to 1997, however, the decline rate is less from 1997 to 2002	"Bheel" area has decreased from 33.5% (1990) to 21.1% (1997) and to 19.4% (2002). e.g. Deepor Bheel	8	22
Wetlands (intertidal)	Coastal	Decline in wetlands due to conversion into rice paddies, settlements and for industries	Loss of habitat for a number of water birds	7	23
Mangroves	Coast	Decline in mangrove area in general due to conversion into shrimp farms	Loss of habitat for fish and other fauna, no recent data available	7	24
		Socioeconomic Impacts			
Agriculture	Coast	Increased conversion of accreted areas for agriculture and settlements	Frequent flooding results in crop losses or switch to low yielding varieties	7	25, 26
Aquaculture	Coast	Increased conversion of land into shrimp farms; intense fishing for fish fry and larvae; loss of livelihood for traditional fishers	Loss of mangrove habitat	7	27
Fisheries (inland)	Upstream	Annual catch: 505 tons (1989-90); 391 tons (1991-92)	Declining fish catch according to survey of fishermen as well as other sources	8	28
Flood: coastal (cyclone, storm surge)	Coast	Declining viability / loss of protective function of coastal ecosystems due to degradation, e.g., mangroves, wetlands	Highly vulnerable to coastal flooding due to storm surges	8	29
Flood: riverine	Midstream and delta	glacial snowmelt and localized deforestation resulting in increased flooding and flood related damages	Increased number and extent of flood related disasters	7	30

***Table 12**: DPSIR matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes impacting the coastal zone versus catchment size class (Brahmaputra basin)*

(p = progressive, d = discrete)

Driver	Pressure	State change	Impact on coastal ecosystem	Time scale
Agriculture	Changes in hydrological cycle; damming; water abstraction; control of freshwater discharge; increased rate of sedimentation; increase in anaerobic conditions due to release of deep impounded water	Minor - medium	Environmental: altered coastal geomorphology Economic: reduced flow during lean season results in river becoming not- navigable	p/d
	Deforestation: conversion into tea plantations	Medium	Environmental: increased sediment delivery at the coast	p
	Chemical inputs: fertilizers, pesticides	Medium	Environmental: eutrophication Ecological: changes in biodiversity	d
Industrialization/ petroleum exploration and refining	Industrial effluents; oil spills	Minor	Environmental: pollution by toxic organic and inorganic substances Ecological: loss of biodiversity	d
Urbanization/ population pressure	Changes in water quality (organic and inorganic loads); dumping of wastes including solid wastes into the river	Medium	Environmental: water quality does not meet standards; eutrophication due to excess nutrient loads Ecological: changes in species biodiversity	d
Global warming/ glacial snowmelt	Bank cutting and enhanced soil erosion due to glacial melt and precipitation – higher sediment load in river; water logging	Medium; to become major in future	Environmental: non-seasonal high water flows; flooding and water-logging Ecological: changes in sediment budget due to excess sediment delivery Socioeconomic: non-seasonal flood related problems – crop losses and forced migration	d/p

***Table 13**: Linking coastal issues/impacts and land based drivers in coastal zones – an overview, qualitative ranking and trend expectations on local or catchment scale (Brahmaputra basin)*

Coastal impact	Drivers	Local catchment	Impact category	Trend expectations	Reference
Siltation	Agriculture: shifting cultivation	Himalayan foothills to Bangladesh floodplains	7	⇑	
	Deforestation: timber production	Hilly catchment as well as plains	8	⇑	31
		Excess tree felling in some sub-basin pockets			
	Urbanization (SS and TDS in waste-water streams)	Major cities and towns, particularly those downstream (e.g., Dibrugarh to Dhubri and beyond)	6	⇑	
	Global warming: glacial snowmelt	Himalayan glaciers	7	⇑	
	Damming	Operational dams (e.g., Kopili, Umiam, Ranganadi), several more in planning	6	⇑	
	All drivers	River Brahmaputra	7	⇑	32
Impaired water quality: nutrients from agriculture	Agriculture	Himalaya foothills to Bangladesh floodplains	6	⇑	33
Impaired water quality: nutrients from municipal wastes	Municipal waste load	Major cities and towns, particularly those downstream (e.g., Dibrugarh to Dhubri and beyond)	7	⇑	
Impaired water quality: oil a.o. pollution (production and refining of petroleum)	Petrochemical industries	Oil fields of upper Assam and refineries, downstream industries spread over the state	7	⇑	
Impaired water quality: industrial wastes	Other industries		6	⇑	
	All drivers	Entire basin	7	⇑	

2.2 Ganges

The Ganges or Ganga basin is the biggest river basin in India covering slightly more than a quarter of the country's total area. The water quality monitoring of the Ganges River and its several tributaries are being done in the basin by the State Pollution Control Boards of Uttaranchal, Uttar Pradesh, Bihar, West Bengal, Haryana, Himachal Pradesh, Rajasthan, Madhya Pradesh and Central Pollution Control Board at 141 locations. The Ganges system is one of the most regulated river systems with dams and barrages on practically every tributary and extensive embankments throughout the river basin[34]. Because of this, the rivers have been rendered dry for many stretches, and there is accumulation of silt apart from the reduction of the floodplains and the carrying capacity of the rivers. The greatest problem for the river systems in this section is caused by the discharge of untreated or partly treated domestic and industrial effluents. The problem of pollution is further increased by the disposal of solid wastes, religious offerings, idols, dead bodies and carcasses and other in-stream activities. Soil erosion due to deforestation and land use changes at the river mouth and upstream have increased in recent years causing serious impact on natural resources and infrastructure. The entire basin is polluted with a variety of contaminants whereas the delta and hinterlands have already reached critical state where groundwater is contaminated with arsenic. Specifically, it can be concluded that:

- In general, water quality has deteriorated at most locations in the basin and many of the sub-basins.
- Temporal and spatial scale changes are seen in key water quality indicators such as Most Probable Counts for health-related bacterial species.
- About 800 km downstream of the Ganges, near Patna, where many large tributaries join the river, the dolphin population has declined.
- Due to poor enforcement, many toxic metals are reported to be above threshold concentration in water and sediments in many stretches of the river. Subramanian and Madhavan[35] reported high levels of mobile fraction of total Hg in sediments of the tributary Yamuna all along its 1200 km before it joins the Ganges at Allahabad.
- Preliminary scientific calculations suggest that the CO_2 consumption due to weathering in the Himalayan river basins is much higher than due to the loss of forest cover, considered generally to be the traditional CO_2 sink from the atmosphere. Thus processes in the river basin may have large scale global implications if climate change scenarios are considered.
- River linking and diversion in the Ganges river system have been considered seriously and two small basins within the sub-basin Yamuna are planned to be linked. The Ken-Betwa link, expected to be operational within this decade, may well set trend for future water sharing issues and problems in the Gangetic plains.
- The River Ganges is also transboundary in nature: one of the tributaries originates in Nepal while a section of the main Ganges River (River Padma) flows into Bangladesh. The other section of the main river flows through the Indian state of West Bengal as the River Hooghly.
- Any changes in sediment supply from the Ganges would affect the ecosystem either directly or indirectly through the disruption in the food web. Published data clearly indicate reduction of sediment supply from the Ganges river system to Bay of Bengal in the recent years, and therefore changes in natural habitats are also evident (e.g., the Sunderban).
- Water abstraction is a key issue in the river basin. Nearly 300 million people depend on the direct water supply from the river. Hence, both water withdrawal and discharge of waste water have implications with respect to both quality and quantity of water in the entire river basin.
- Given the conflict between supply and demand of water resources in the river basin, definition of sustainable development for the entire basin is required.

Sunderban is the largest mangrove ecosystem in the world located at Bengal delta in India and Bangladesh. Significant changes in habitats due to alteration in sediment input (reduction in supply), water quality degradation and shrinkage of mangroves have been observed due to discharge of urban and industrial wastes[36]. Shrinkage of mangrove areas is mainly due to felling of trees for coastal aquaculture, house construction, fuel production etc[37].

***Fig. 30**: The Ganges watershed* [38]

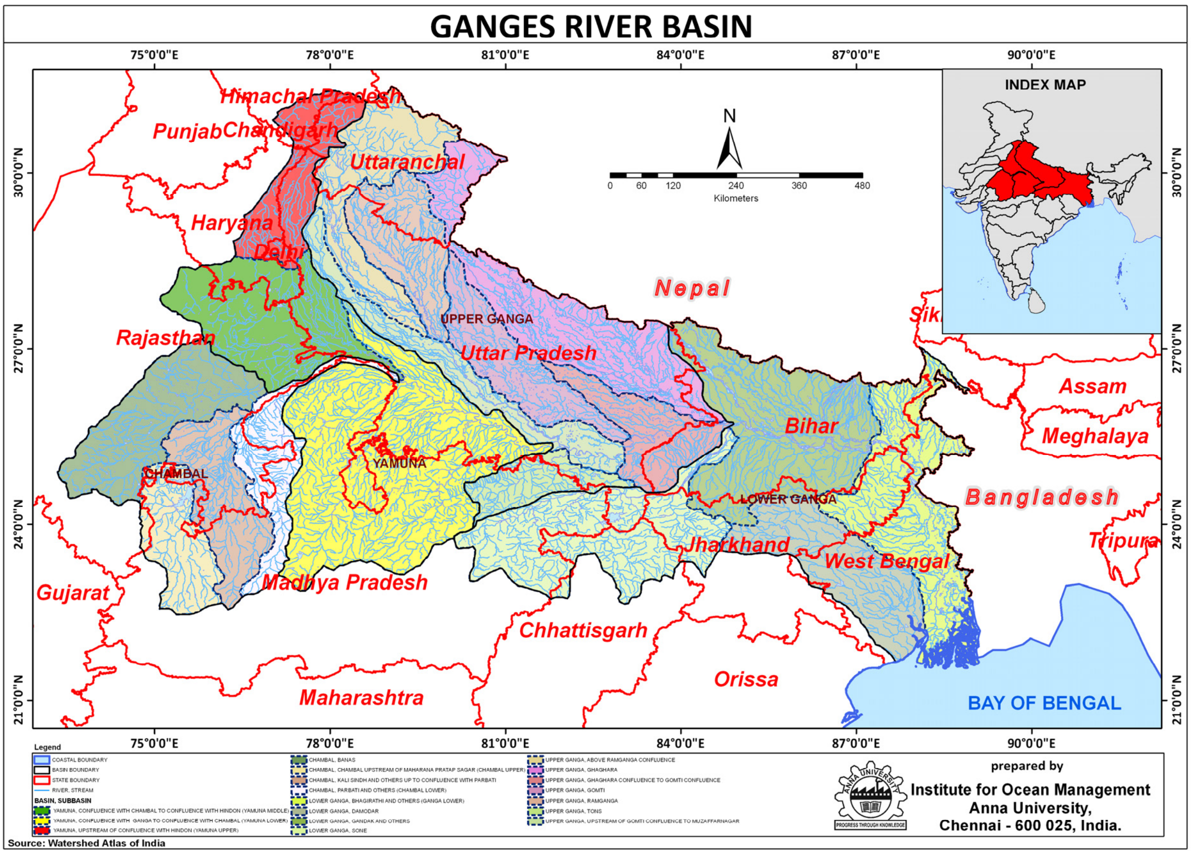


***Table 14**: Major coastal impacts and critical thresholds in coastal zones: Overview and qualitative ranking (Ganges basin)*

(Value 1-3 no or minor importance; values 4-6 = medium importance, values 7-9 = major importance, value 10 = critical)

Coastal impact	Local site	Critical threshold (for system functioning)	Distance to critical threshold	Impact category	Reference
Environmental Impacts					
Suspended sediments	Contribution from upstream and midstream areas	No standards available	Critical - deposition for Ganges-Brahmaputra basin has reduced from 554 MT/yr to ~ 40MT/yr	10	39
Erosion	River mouth and upstream Physical erosion at source	Reduced sediment supply 600 t km^{-2}/yr	Critical	7 (7-9)	40

Nutrient load	Entire river	Nitrate (NO_3^-): 0.1-3.8 mg/l Nitrite (NO_2^-): 0.01-3.3 mg/l Ammonical Nitrogen (NH_4-N): 0.0-1.5 mg/l		6	41
Organic load	Entire river	DO: 1.4 to 11.0 mg/l BOD: 0.0-14.4 mg/l Fecal Coliforms (FC): 0 to 7, 00,000 MPN per 100 ml Total Coliforms (TC): 0 to 31,00,000 MPN per 100 ml	Water quality indicates that pH, conductivity and DO are meeting the water quality criteria at most locations, but are high in others (indicate pollution due to discharge of untreated wastewater	8	42
Metal concentrations	Mirzapur region	Cadmium and cobalt were in the range 13.37-32.73 µg/land 10.50-26.77 µg/l respectively. Copper, iron and manganese were found in the range of 38.0-157.80 µg/l, 19.75-72.77 µg/l and 34.25-105.55 µg/l respectively. Nickel was recorded to be in the range 67.25-176.13 mg/l Lead and zinc were in the range of 34.25-185.75 µg/l and 94.25-423.75 µg/l.	Concentrations of heavy metals beyond limits	8	43
Salinity	In quaternary aquifer system of the marginal alluvial plain (Ganges Plain) in Bah Tahsil, Agra district, India	Analyses show drastic changes in the salinity levels of shallow, intermediate and deep aquifers. The deep aquifers are more saline compared to the shallow and intermediate aquifers. On the contrary, concentration of chemical constituents, such as Na+, K+, Cl− and F−, was more in the shallow aquifers compared to the deep aquifers.	Critical	7	44
Ecological Impacts					
Impaired water quality; lack of water; rocky shores; salinity	Upstream Coast	Decline in number of Gangetic dolphins (from 2000 to 152 in 1988-89)	Critical	9	45, 46, 47
Siltation, growth of macrophytes, embankment construction	Floodplain lakes	Loss of feeding and breeding habitat for fish; decline in fish catch from 961 kg/km in 1956-60 to 630 kg/km in 1981-87	Critical	8	48,49
Mangroves	Sunderban region of delta	Distortion in sediment input (reduction in supply) Water quality degradation	Not known	Not known	50, 51
Socioeconomic Impacts					
Agriculture	Entire basin	Land use	Passed	9	52
Aquaculture	Sunderban region Increased conversion of land into shrimp farms; intense fishing for fish fry and larvae;	From 0 to 1500 km^2 shrimp farms between 1977 and 2002	Passed	9	53
Fisheries (inland)	Allahabad, Buxar	Farakka barrage – decline in fish catch (Hilsa) from 19.3 tons to 1.04 tons at Allahabad and from 32 tons to 0.6 tons at Buxar	Passed critical threshold	9	54
Flood: coastal (cyclone/ storm surge)	Tidal reaches – flooding when high tide synchronizes with heavy flooding in river				
Flood: riverine	Widespread rain in catchment area				
Sea level rise	Coastal areas especially islands	Sea level rise is critical at 3.24mm/yr		9	55

Table 15*: DPSIR matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes impacting the coastal zone versus catchment size class (Ganges basin)*

(p = progressive, d = discrete)

Driver	Pressure	State change	Impact on coastal ecosystem	Time scale
Agriculture	Changes in hydrological cycle: damming, water abstraction, river linking	Medium	Environmental: reduction in sediment reaching coast; reduced freshwater availability at the coast	d/p
	Chemical inputs: fertilizers	Minor	Environmental: eutrophication due to higher nutrient loads	p
	Land use changes Soil degradation	Major	Socioeconomic: increased use of fertilizers and hence higher capital inputs	p
Industrialization	Manufacturing industries, e.g., leather industry	Major	Environmental: metal load; change in water quality Ecological: loss of biodiversity	p/d
Urbanization/ population pressure	Domestic wastes disposal	Medium	Environmental: changes in water quality (organic and inorganic loads); eutrophication due to higher nutrient loads Ecological: habitat loss/alteration	p

Table 16*: Linking coastal issues/impacts and land-based drivers in coastal zones – an overview, qualitative ranking and trend expectations on local or catchment scale (Ganges basin)*

Coastal impact	Drivers	Local catchment	Impact category	Trend expectations	Refer-ence
Siltation / erosion	Global warming, glacial snowmelt resulting in upstream erosion	Haridwar to Patna	8	⇑	56
	Agriculture, diversion/damming	Farakka, Agra Canal, Yamuna Canal	6	⇑	57
	Municipal waste load / urbanization	Along major cities of basin	7	⇑	58
	Sediment load modification	Entire Ganges basin	8	⇑	59
	All drivers	Whole Ganges basin	8	⇑	
Impaired water quality due to nutrients from agriculture (fertilizer excess)	Agriculture	Throughout the basin	8	⇑	60
	Agriculture	Sub basins of UP and Bihar Plains	7	⇑	61
Impaired water quality due to wastewater from industries	Industries	Kanpur and downstream	8	⇑	62
Impaired water quality due to wastewater disposal from municipal sources	Urbanization/population pressure	Major cities: Kolkata and downstream	8	⇑	63
Impaired water quality due to acid wastes from mining processes	Mining	Kolkata and hinterland	8	⇑	
Reduction in water levels	Groundwater over withdrawal	UP and WB part of basin	8	⇑	
	All drivers	Entire basin	8	⇑	

2.3 Karnafuli

Various activities in the catchment have led to erosion and input of pollutants into the estuaries and coastal waters. Eutrophication, pollution and erosion are severe in the lower reaches of Karnafuli River. It is observed that nearly 480 tons of solid waste and untreated sewage are being dumped into the Karnafuli River and estuary each year which enters the Bay of Bengal directly[64]. Major industrial contaminants include ammonia, chromium, mercury, phenols and DDT. The major waste producing industries include fertilizer and agrochemical industries, pulp and paper mills, dyeing, printing and packaging, textile mills, iron and still mills, sugar mills and breweries, jute industries, tanneries, cement industries, plastic and rubber industries, distilleries and refineries etc[65].

The nutrient load is likely to surpass the threshold if the current trend of nutrient loading continues[66]. Pollution is mainly due to the location of industries (nearly 27.8 %) particularly the ship breaking and dismantling industries in the coastal area of Bangladesh as well as untreated domestic and industrial effluents[67]. Increasing concentration of trace metals and pathogenic bacteria has been observed in the surface waters due to this[68].

Table 17*: Major coastal impacts and critical thresholds in coastal zones: Overview and qualitative ranking (Karnafuli basin)*

(Value 1-3 no or minor importance; values 4-6 = medium importance, values 7-9 = major importance, value 10 = critical)

Coastal impact	Local site	Critical threshold (for system functioning)	Distance to critical threshold	Impact category	Reference
Environmental Impacts					
Suspended sediments	Lower reaches of Karnafuli River and estuary	Increase in total solids (TS) Increased rate of sedimentation	Not known	Erosion 6 (4-6)	69
Nutrient load	Lower reaches of Karnafuli River and estuary	Increasing number of Dinoflagellates Declining trend of O_2 level	Toxicity levels may change due to change in Dinoflagellate population Nutrient load is likely to surpass threshold, if current trend of nutrient load continues culminating in eutrophication	Eutrophication 8 (7-9)	70
		Growth of Ulva sp.	Not known		
		Nitrate 66.1 mg/l, Ammonia 115 mg/l, Phosphate 0.55 mg/l			71
Chemical load		Industries directly discharge degradable and persistent organic and inorganic wastes as well as toxic metallic components COD 571 mg/l	Sub critical threshold	8	72
Organic load		BOD 118 mg/l Higher numbers of pathogenic bacteria	Sub critical threshold	8	73
Metal conc.	Karnafuli estuary	Concentrations of Pb, Cu, Fe, Ni higher and of Mn and Cd, lower than the recommended values		7	74
Salinity		0.56 g/l		4	75

***Table 18**: DPSIR matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes impacting the coastal zone versus catchment size class (Karnafuli basin)*

(p = progressive, d = discrete)

Driver	Pressure	State change	Impact on coastal ecosystem	Time scale
Agriculture	Changes in hydrological cycle: dam (Kaptai); water abstraction; control of freshwater discharge; increased rate of sedimentation	Major	Environmental: change of coastal morphology, particularly around the vicinity of Karnafuli River Ecological: change in floral and faunal habitat	p
	Chemical inputs: fertilizers; pesticides	Minor	Environmental: eutrophication Ecological: changes in biodiversity	d
Industrialization	Manufacturing industries, e.g., Urea factory	Major	Environmental: water quality does not meet standards Ecological: loss of coastal biodiversity	p
Urbanization/ population pressure	Changes in water quality (organic and inorganic loads)	Major	Environmental: Water quality below standards Ecological: changes in species biodiversity	p

***Table 19**: Linking coastal issues/impacts and land-based drivers in coastal zones – an overview, qualitative ranking and trend expectations on local or catchment scale (Karnafuli basin)*

Coastal impact	Drivers	Local catchment	Impact category	Trend expectations	Reference
Siltation	Damming	Catchment of Karnafuli and its allied streams covers 11,000 km^2	5	=>	76
Flooding	Damming	Hill cutting for dam in Kaptai	6	⇑	
		Hill cutting in Nasirabad and Fauzdarhat	7	⇑	
	Timber extraction	Catchment below dam	3	=>	77
Lower fish catch	Over fishing	Catchment below dam	5	=>	
Impaired water quality – wastewater from industries	Industrialization: oil spills; waste load	Catchment below dam	5	⇑	
			8		
	Industrialization: fertilizer industry; petrochemicals	Urban and estuarine section	6		78
			5		
Impaired water quality due to municipal / domestic wastewater disposal	Urbanization	Urban and estuarine section	7	⇑	79

2.4 Ayeyarwaddy

The Ayeyarwaddy River of Myanmar (formerly known as Irrawaddy), one of the muddiest rivers of the world, flows into the northern Andaman Sea and the Gulf of Martaban. It is the fifth largest river in the world in terms of suspended sediment discharge. Together with the Salween and Sittang Rivers, it deposits annually more than 350 million tons of sediment to the ocean. This area, like other areas in this region, is characterized by the seasonally reversing Asian monsoons. The freshwater and the sediment discharge are highly seasonal with more than 80 % of the annual discharge during SW monsoon. The suspended sediment concentrations and area covered by the highly turbid zone mainly in the Gulf of Martaban was found to strongly relate to spring-neap tidal cycles throughout the year[80].

As yet, pollution and contamination problems are not grave threats in Myanmar mainly because of the costs involved in fertilizer and pesticide usage. Deforestation is increasingly significant. Forests are cut for shifting cultivation and are also under pressure because of the increasing population. In the case of fisheries and aquaculture, traditional harvest methods are used and hence they are reportedly not under high pressure[81]. Arsenic contamination of drinking water sources is an emerging public health issue in Myanmar. This was identified based upon geographic similarities between Myanmar and Bangladesh after a project that facilitated construction of shallow tube wells (STW) for drinking water sources after the 1997 floods. Preliminary surveys showed that arsenic contamination was in excess of the proposed Myanmar national standard of 0.05 mg/l in 35 % of the 145 inspected STWs[82]. Lake Inle, the second largest lake in Myanmar and a major tourist attraction, like many other wetlands in the region, has shrunk because of siltation due to deforestation for cultivation. There are also problems reportedly due to invasive weeds apart from untreated wastes flowing into the lake.

Fig. 31: Houses in Lake Inle, Myanmar [83]

Fig. 32: Floating farm in Lake Inle, Myanmar [84]

***Table 20**: Major coastal impacts and critical thresholds in coastal zones: Overview and qualitative ranking (Ayeyarwaddy delta)*

(Value 1-3 no or minor importance; values 4-6 = medium importance, values 7-9 = major importance, value 10 = critical)

Coastal impact	Local site	Critical threshold (for system functioning)	Distance to critical threshold	Impact category	Reference
Environmental Impacts					
Suspended sediments		Annual load of about 265 x 10^6 metric tons of silty clay			85
Erosion	Delta	Accretion and Protruding delta	The sediment delivery due to damming could be reduced to such a level that coastal erosion becomes an important issue.	4	n.a.
General water quality	Delta	Increased oil and gas exploration		5	n.a.
Metals	Delta	Arsenic in ground water	Water samples containing arsenic levels in excess of 0.01 mg/l (WHO standard) were detected in 45% of the STWs examined. A total of 21% of the sample exceeded 0.05 mg/l, the proposed Myanmar standard	6	86
Organic load	Inle lake	Concentration of nutrients (PO_4-P, NO_2-N, and NO_3-N) and coliform bacteria		6	87
Salinity	Delta	Saline intrusion into paddy growing areas		7	88

Ecological Impacts					
Wetlands	Delta	Loss of wetlands to industries in some areas		7	
Mangroves	Delta	If the present rate of destruction is maintained, all the mangrove forest will disappear in 50 years; deforestation rate between 1975 and 1989 estimated at 220,000 ha per year		9	89, 90
Biodiversity/ endangered species		Crocodiles, Hawksbill turtle, terrapins severely threatened		9	91
Socioeconomic Impacts					
Agriculture		Traditional rice cropping methods		5	
Fisheries (inland)		Traditional methods are practiced		5	
Flood: coastal (cyclone/ storm surge)	Delta	Flooding due to cyclones/storm surge (e.g., cyclone Nargis) 1,300 km of major embankments in the delta, protecting over 600,000 ha of rice paddy		5	92
Navigation	Delta	Reduced navigability		5	n.a.

***Table 21**: DPSIR matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes impacting the coastal zone versus catchment size class (Ayeyarwaddy delta)*

(p = progressive, d = discrete)

Driver	Pressure	State change	Impact on coastal ecosystem	Time scale
Agriculture	Habitat loss and degradation due to conversion of wetlands and mangroves into rice fields; deforestation (soil erosion)	Major	Environmental: increase in nutrient levels in water Ecological: loss of biodiversity esp. wetland birds due to reclamation of wetlands, cutting nesting trees Socioeconomic: increase in rice production but loss of protection against floods	d/p
Industrialization	Manufacturing industries	Medium	Environmental: metal load; change in water quality Ecological: loss of biodiversity	d
Urbanization/ population pressure	Domestic waste disposal, e.g., Inle Lake	Major	Environmental: changes in water quality (organic and inorganic loads); eutrophication due to higher nutrient loads Ecological: habitat loss	d/p

***Table 22**: Linking coastal issues/impacts and land-based drivers in coastal zones – an overview, qualitative ranking and trend expectations on local or catchment scale (Ayeyarwaddy delta)*

Coastal impact	Drivers	Local catchment	Impact category	Trend expectations	Refer-ence
Siltation/erosion	Agriculture Deforestation/ damming	not available numerous	7	=>	
Impaired water quality due to excess nutrients	Agriculture Population pressure	not available	7		
Habitat loss	Agriculture (shifting cultivation) Population	frequent	6	=>	93

3 Peninsular Rivers of India and Sri Lanka

3.1 Mahanadi

In the Mahanadi delta basin, sedimentation is a big problem due to deforestation and land use changes. During monsoon or rainy season 5.1 x 10^{13} liters of water and 27 million tons of suspended materials are carried through the micro tidal Mahanadi river estuarine system into the Bay of Bengal. Land use pattern, mining and agriculture are major indicators to be studied to know the impact on the basin delta[94,95]. IRS-1C WiFS data has been used to study the suspended sediment concentration (SSC) from the surface waters of the Mahanadi estuary along with the Sea-truth data.

The Hirakud dam and Cuttack barrage were constructed on the Mahanadi River to meet the need of agriculture, industry and urban use. The dams have greatly affected the fisheries sector and the entire estuary system and have led to loss of biodiversity due to reduced freshwater flow in the coastal waters[96]. Monitoring, studying of fish production and biodiversity are main indicators for the changes taking place in the coastal habitats of the Mahanadi estuary. Pollution at the Paradip estuary region is a major concern, because the estuary is dominated by freshwater influx during the monsoon and discharges about $28x10^6$ tons of sediment annually into the sea. This freshwater influx is considered as a vital source of nutrients for the estuary[97]. Port activities as well as other industries located in that area contribute to the waste load into the Paradip estuary.

The Mahanadi River is by far the largest river basin in the state of Orissa. It is only a relatively small part of the basin that has an influence on the Chilika lagoon, but its tributaries Bhargavi, Daya and Nuna account for the major part (61 %) of the freshwater input and 75 % of the sediment input (nearly 280,000 tons) into the lagoon. These, together with certain climatic factors such as rainfall, evaporation and wind patterns, influence the two key factors that shape the geomorphology and determine the biological productivity and diversity of the lagoon: the salinity regime and sedimentation patterns. The coastal area consists mainly of sandy accreting beaches.

The sand bar separating the lagoon from sea is planted with *Casuarina equisetifollia*. This species, though not native to India, has been extensively planted as a bioshield along the coast by the forest department because of its hardy nature. The local fishermen who live along the outer channel of the lagoon fish in coastal waters using traditional craft and no deep sea fishing is practiced.

***Fig. 33**: A traditional fisherman in Chilika lagoon (Photo: D.K. Mythili)*

***Table 23**: Major coastal impacts and critical thresholds in coastal zones: Overview and qualitative ranking (Mahanadi basin)*

(Value 1-3 no or minor importance; values 4-6 = medium importance, values 7-9 = major importance, value 10 = critical)

Coastal impact	Local site	Critical threshold (for system functioning)	Distance to critical threshold	Impact category	Refer-ence
Environmental Impacts					
Siltation	Chilika lake	inflow of silt amounting approximately to 13 million tons per year			98
General water quality	River	pH ranges from 7.3-8.7, DO ranges from 6.2-8.9, BOD 1.2-3.6, Nitrate from 0.11-1.89 mg/l	Medium, pollution higher in the lower reaches	5-7	99
Metals	Estuary region (Paradip port)	Higher metal concentrations	Close to critical	9 (7-9)	100
	River basin	Pb, Zn, and Cr have been accumulating in recent years in the sediments. Si, Al, Fe, Ca, and Mg dominate the bed and suspended sediment composition. Metals show increasing concentrations in finer sediments			101
Nutrient load	Estuary region (Paradip port)	Eutrophication	Close to critical	9 (7-9)	102
Organic load		DO – 1.3 to 10.4 mg/l in 2002 and 6.2-8.9 mg/l in 2007.	During the five year period, DO levels appear to have varied extensively, but in general seem to be lower than should be	9	103
		BOD Values have ranged from 0.2-16 mg/l	Extensive variation in BOD values indicates river is under stress		
		Total coliforms range from 15-30000 MPN in 2002 has gone up to 27-35 x 10^3 in 2007	River highly polluted by domestic wastes		
Salinity		Varied from 0.11-11.01 ‰ in the Atharbanki creek and 0.44 -1.12 ‰ in the Mahanadi River and 22.44 ‰ in the coastal area Chilika lake: The average salinity near Satpada has increased to 14 ‰ in December 2000 as compared to the salinity of 3-4 ‰ recorded during the same period one decade ago.	Critical	7	104, 105
Ecological Impacts					
Loss of habitat	Entire estuary	Loss of biodiversity Fall in fish catch	Close to critical	8 (7-9)	106
	Chilika lake	Macrophyte growth	Subcritical	5	107
	Estuary	Mangrove area decreased from 234 km^2 to 199.19 km^2 from 1975 to 1993	Critical	7	108
Socioeconomic Impacts					
Agriculture	Coastal stations between Chilika and Kendrapara	Pesticide: trace amounts of endosulphan (0.013-0.02 mg/l) in 3 canals and dieldrin (0.003 mg/l) in one canal Nutrients: nitrate, phosphate, and potassium range between 0.37 and 8.4 mg/l, 0.09 and 0.4 mg/l, and 0.2 and 8.0 mg/l, respectively.	Of concern	6	109, 110
Aquaculture	Chilika lagoon and Mahanadi delta	Decline in shrimp production from 1241 to 281 tons between 1986-87 and 1996-97	Very Critical	9	111
Fisheries	Chilika lagoon	Fish production has declined from 6863 MT to 1352 MT between 1986-87 and 1996-97	Very Critical	9	112

***Table 24**: DPSIR matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes impacting the coastal zone versus catchment size class (Mahanadi basin)*

(p = progressive, d = discrete)

Driver	Pressure	State change	Impact on coastal ecosystem	Time scale
Agriculture	Changes in hydrological cycle: damming	Medium	Seasonal variation in quantum of freshwater reaching the estuary increased	d
	Chemical inputs: fertilizers; pesticides	Major	Environmental: change in water quality; eutrophication Ecological: spread of weeds; reduction in biodiversity	p
	Land use changes	Major	Ecological: Increase in the spread of low density scrub forests	p
Aquaculture	Destruction of mangroves; increased groundwater salinity	Major	Environmental: increased siltation of Chilika lake Ecological: change in area and density of mangroves; loss of important mangrove species Socioeconomic: increased poverty among fisherfolk due to reduced fish catch, salinization of land due to aquaculture	p
Industrialization	Manufacturing industries; mining	Major	Environment: shoreline changes due to deflection of longshore current; impact of construction activities Ecological: changes in number of nesting turtles; reduced biodiversity Socioeconomic: displacement of fishers and coastal communities	d
Urbanization/ population pressure	Domestic wastes disposal	Medium	Environment: impaired water quality Socioeconomic: reduced availability of potable water	

***Table 25**: Linking coastal issues/impacts and land-based drivers in coastal zones – an overview, qualitative ranking and trend expectations on local or catchment scale (Mahanadi basin)*

Coastal impact	Drivers	Local catchment	Impact category	Trend expectations	Reference
Erosion	Agriculture	Downstream of Hirakud dam	9	⇑	113
Siltation	Deforestation; mining	Catchment area below dam (42%)	9	⇑	114
Water pollution due to nutrients from agriculture: fertilizer excess	Agriculture	Downstream 42%	5	⇑	115, 116
Water pollution due to municipal wastes	Urbanization/ population pressure	Cuttack, Bhubaneshwar, Paradip	6	⇑	117, 118
Water pollution due to industrial wastes: mining	Industrialization	Below the dam: metal and nutrient enrichment	7	⇑	

3.2 Godavari

The wastewater generated from domestic (rural and urban) and the industrial sector is the main source of pollution in this river basin. Amongst the five states that the Godavari passes through, Orissa is least industrialized followed by Chhattisgarh and Karnataka, with Maharashtra having high urban industrial pockets. Most of the industrial activities are centered mainly at Aurangabad and Nashik in Maharashtra and at East and West Godavari districts in Andhra Pradesh. A large number of sugar and distillery units are located in Maharashtra followed by pharmaceuticals, leather, pulp and paper and pesticide units. In Andhra Pradesh, there are many sugar and distillery units followed by pulp and paper and fertilizer industries. These industries are massive water consumers and the deterioration in water quality in the river cannot be ruled out particularly from Nashik to Nanded in Maharashtra and at Bastar in Chhattisgarh and Burganpad in Andhra Pradesh[119].

The river Godavari from downstream of Nashik to Nanded including Nanded city limits in Maharashtra and upstream of Bhadrachalam at Mancheral and Ramgundam have been identified as the polluted river stretches. The major sources of wastes in the polluted stretches are from domestic and industrial wastewater generated from the Nashik and Nanded cities in Maharashtra and Mancheral, Ramgundam and Bhadrachalam cities in Andhra Pradesh. Depletion of dissolved oxygen has been reported due to addition of high organic load into the river besides bacteriological pollution[120].

Like most other rivers, municipal/domestic sources account for 82 % of total pollution, whereas industrial pollution accounts for about 18 %. Over half of the river basin (18.6 million ha) is categorized as cultivable land. Most of the river's water is drawn for irrigation purposes. Application of fertilizers is very high at 49.34 kg/ha, almost twice the country's average. Pesticides are also applied at the high rates of 146.47 kg km^{-2} of which 79 % are organochlorines. A lot of the industrial pollution originates from about 72 industries in the Patancheru Industrial area that have been dumping their effluents into the river. In the absence of treatment facilities, industrial effluents are let out into streams that collect in ponds. Industrial discharge from such industries has severely affected public health, surface and ground water and agriculture in twenty-two villages in this area. The river water is heavily used for agriculture, as it is the only available water source. However, the river's water has turned the fertile soil toxic with heavy metals. The soil contains metals such as iron, nickel, zinc, copper, cobalt and cadmium.

***Table 26**: Major coastal impacts and critical thresholds in coastal zones: Overview and qualitative ranking (Godavari basin)*

(Value 1-3 no or minor importance; values 4-6 = medium importance, values 7-9 = major importance, value 10 = critical)

Coastal impact	Local site	Critical threshold (for system functioning)	Distance to critical threshold	Impact category	Reference
Environmental Impacts					
Erosion	Godavari Delta	Decrease in sediment loads from an annual average of 145.26 million tons in 1971-79 to 56.76 million tons during 1990-98 Sustained erosion at the Godavari delta for the past two and a half decades claimed about 18.36 km^2 of coastal land	Severe reduction	9	121
Freshwater availability	Coringa Mangroves	Affect growth of less saline tolerant species	Severe	7-8	
Siltation	Kakinada Bay	Growth of sand spit due to deforestation till about late 1970s; erosion in the 1990s onwards due to lack of sediments reaching the bay	High	7-8	122
Environmental Impacts					
General water quality	Entire river	DO value ranges from 3.2-12 mg/l, BOD values ranges from 0.2-36 mg/l, Fecal Coliforms ranges from Nil-2200 MPN/100 ml	Polluted in stretches – correlated to human settlements	7	123
Metals	Entire river basin	Compared to the other tropical Indian rivers such as the Krishna, the Godavari appears to be a significant contributor of heavy metals to the Bay of Bengal.	Severe	8	124
Impaired water quality due to inorganic nutrients	Entire river	Nitrate values range from0.1 to 2.9 mg/l and ammonia nitrogen from 0 to 0.6 mg/l	High levels in sampling points near large human settlements	8	125
Ecological Impacts					
Wetlands	Kolleru Lake	1967 that the total lake boundary area was 180.38 km^2, in which 70.70 km^2 had water throughout the year and 100.97 km^2 had water during the rainy	Nearly 60% of lake has been encroached	8	125

		season. 2004 satellite data revealed that Kolleru was no longer a lake and the lake area of 62.65 km^2 (34.73%) only remained in a degraded state, extensively colonized by macrophytes			
Mangroves	Delta area – Coringa Wildlife sanctuary	Area occupied: 33,150 ha of which dense mangroves occupy only 16,406 ha; degraded mangroves occupy 3,355 ha; mudflats and water bodies cover the rest of the area; loss of mangroves facing the sea due to erosion	Restoration, natural regeneration has increased mangrove area, total change almost balanced	5	126
Socioeconomic Impacts					
Aquaculture	Delta	Increase in area under aquaculture from 2006 ha in 1989 to 19239 ha in 1999	Almost 80% of mangrove degradation attributed to shrimp farms	7	127

Table 27: *DPSIR matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes impacting the coastal zone versus catchment size class (Godavari basin)*

(p = progressive, d = discrete)

Driver	Pressure	State change	Impact on coastal ecosystems	Time scale
Agriculture	Changes in hydrological cycle: damming; water abstraction	Major	Environmental: reduction in sediment reaching coast, erosion; reduced freshwater availability at the coast Socioeconomic: high erosion levels requiring move of some shore villages such as Uppada further inland	d/p
	Chemical inputs: fertilizers; pesticides	Major	Environmental: eutrophication due to higher nutrient loads	p
	Land use changes: mangrove clearing	Major	Environmental: increased coastal erosion Ecological: loss of nursery grounds Socioeconomic: loss of access to timber and Non timber forest produce (NTFP); reduction in storm surge during cyclones	p
Aquaculture	Land use changes: mangrove clearing	Major	Environmental: increased siltation due to deforestation; increased salinization of land and groundwater Ecological: loss of nursery grounds Socioeconomic: loss of access to timber and NTFP, reduction in protection against storm surge during cyclones	d/p
Industrialization	Manufacturing industries	Major	Environmental: metal load; change in water quality Ecological: loss of biodiversity	d/p
Urbanization/ population pressure	Domestic wastes disposal	Major	Environmental: changes in water quality (organic and inorganic loads); eutrophication due to higher nutrient loads Ecological: habitat loss	

Table 28: *Linking coastal issues/impacts and land-based drivers in coastal zones – an overview, qualitative ranking and trend expectations on local or catchment scale (Godavari basin)*

Coastal impact	Drivers	Local catchment	Impact category	Trend expectations	Reference
Erosion	Agriculture: damming upstream, Aquaculture: clearing of mangroves on the coast Population pressure	Major	9	⇑	
Freshwater availability	Agriculture: damming upstream Natural change in river course	Major	8	⇑	
Siltation	Aquaculture: deforestation of mangroves	Major	8	⇑	
Salinity intrusion	Groundwater extraction Reduction in freshwater flow in river			⇑	128
	All drivers	Entire basin	7	⇑	

3.3 Krishna

Flowing through three states, the river Krishna receives wastewater from a large number of large cities, including Pune, Satara, Kolhapur, Hyderabad, Kurnool and Vijayawada, among others. More than 500 important industrial units operate from the Krishna basin, 200 of which are large-scale industrial units[129]. The stress on water resources in Krishna River is from multiple sources and the impact takes diverse forms. The growth of urban megalopolises, increased industrial activity and dependence of the agricultural sector on chemicals and fertilizers has led to the overriding of the carrying capacity of water bodies in this basin to assimilate and decompose wastes. The overall population density of the basin is about 250 per km^2. However, in the western part the population density is between 251 and 500 people per km^2. In the delta and the coastal region a major source of degradation is the expansion of aquaculture and agriculture. Between 1986 and 2004, the delta area experienced a major change in land use in the form of extensive development of prawn farms. The area of aquaculture farms in the Krishna wetland is nearly 20,000 ha. A large area of paddy fields around the Krishna mangroves was converted into aquaculture farms from 1992 onwards but mangroves were not cleared for this purpose. However, mangroves were exploited by local communities for firewood, fencing material, fodder and house construction. These impacts are exacerbated by impacts arising from developments upstream such as construction of dams and reservoirs and changes in land use[130]. The main effects of these activities and their coastal impacts are:

Reduction in freshwater flow: The total storage capacity from various irrigation projects in the Krishna Basin is 29,860 million m^3, of which 90 % of the stored water is entirely used for irrigation of agricultural crops. Furthermore, the decreased level of nutrients also negatively influences the coastal fishery and aquaculture potential. It is estimated that the downstream river fishery has gone down by over 60%. The yield of fish decreased from 19.2 to 3.5 ha^{-1} yr^{-1}. There are faunal shifts from river-adapted species to those more adapted to lentic environments. The formation of reservoirs in the Krishna River Catchment has negative impact on both inland and coastal fishery. The fishery resources of Andhra Pradesh are being depleted by over fishing, excessive use of pesticides, industrial pollution and construction of coastal structures. The loss of inshore fish nursery habitats by coastal development, and pollution from land-based activities cause significant change to ecosystems supporting fisheries. The case study on Kolleru Lake in Andhra Pradesh showed that an environment which has been steadily degrading due to conversion of land for agriculture, domestic, agricultural and industrial waste inflow, sedimentation and aquatic macrophyte infestation, is showing further signs of degradation due to introduction of carp culture during 1983-1989.

Reduced sediment discharges: The sediment load decreases sharply from 68 x 10^6 ton/yr from the upstream region (Morvakonda) to 4 x 10^6 ton/yr at the delta region (near Vijayawada). The depletion of sediment supply at the river mouth and lack of uniformity in sediment transport within the basin is mainly due to several human activities such as dams and change in land use. In Andhra Pradesh, tidal flats and mangroves have been found reducing in extent because of reclamation. Satellite imagery shows destruction of mangroves in Krishna and Guntur Districts of Andhra Pradesh for construction of shrimp farms. The spits at the Krishna delta and Kakinada are growing and the Pulicat Lake is shrinking. The river discharge data from the barrage at Vijayawada shows a reduction of about 400 m^3/s from 1964-65 to 2004-05. This has resulted in two visible changes in the mangroves: a) reduction in species diversity due to loss of saline-sensitive species resulting in declining fisheries productivity and b) formation of sand bar in the mouth region, which prevents free flow of tidal water in and out of the mangroves and restricts the flow of nutrients that could enrich the coastal waters.

Declining agriculture potential: The farming population dependant on the delta experience water scarcity for irrigation, ground water depletion, seawater intrusion into the ground water and decline in the soil fertility due to decreased sedimentation rates.

Water quality degradation: The intensive agriculture and industrial development together with high population density has resulted in extremely high levels of water pollution. The state of Maharashtra, through which the river flows, is ranked first in terms of industrial investment in the whole country. Within the state are major industrial facilities in the power, fertilizer, sugar and cement sectors. It is estimated that the high organic load (measured as BOD) entering the river system is well beyond the assimilation capacity of the river. Thus, the river system is polluted by many point and non-point sources. Domestic wastewater contributes mainly towards organic pollution, whereas industrial wastewater is responsible for both organic and inorganic pollution – and in certain cases, to toxic and hazardous pollution as well. In addition, agricultural run-off contributes to chemical pollution in terms of nutrients and pesticides.

Variability in water availability: The discharge in the river ranges from approximately 100 m^3/s to 4000 m^3/s at both upstream and downstream. The existing seasonal variation in rainfall during the dry (December - May) and wet (June - November) seasons suggests such a variation in the stream discharges. The stream hydrographs are characterized by high discharges from June to November, followed by a decline, until a low is reached in May, which is the end of the dry period.

Shoreline changes: The Krishna delta has undergone many changes starting from Sorlagondi in the east end to Nakshatranagar in the west end of the delta. Both erosion and accretion are noticed in the west and east coast of the delta, while considerable accretion has occurred in the southern part. The western part of the delta shows erosion of both land and mangrove vegetation. The sedimentation in this part mainly due to discharge from Uppurevu and its distributor canals has resulted in natural regeneration of mangrove vegetation. Sedimentation near Solragondi due to discharge from canal network in the delta has led to the formation of dynamic sand-spit and lagoon. The coastline and its mangrove vegetation have eroded completely due to wave action in the south facing delta portion of the Krishna River.

The Krishna basin case study demonstrates the linkages between upstream activities and downstream ecosystems and the need for reasonable distribution of benefits and costs of coastal and river basin development activities among various user groups through a linked management program. Construction of dams along the river has led to a drastic reduction in water flow reducing the agriculture and fisheries potential of the delta and the estuary. Economic activities and livelihoods in the delta and the estuary can be maintained in the long term only if the upstream development activities are regulated in a responsible manner. It shows that in the Krishna basin, future projects have to be designed in such a way that the economic and environmental viability of the delta and the estuary are not compromised with, and in a manner that promotes responsiveness among the user groups.

***Table 29**: Major coastal impacts and critical thresholds in coastal zones: Overview and qualitative ranking (Krishna basin)*

(Value 1-3 no or minor importance; values 4-6 = medium importance, values 7-9 = major importance, value 10 = critical)

Coastal impact	Local site	Critical threshold (for system functioning)	Distance to critical threshold	Impact category	Refer-ence
Environmental Impacts					
Suspended sediments	Entire basin	Decrease from 68 x 10^6 ton/yr (upstream region) to 4 x 10^6 ton/yr (delta region); sediment load estimates before dam construction could be used as an indicator of critical threshold	Decline in fishery resources Habitat degradation Increased erosion	8	131
Erosion/ siltation	Entire delta	Reduction in sediment quantity due to upstream dams	Gradual degradation	4 (4-6)	132, 133
Siltation	Coast	Formation of sandbar in the mouth region prevent free flow of tidal water	Severe	8	
Ground water recharge	Entire basin, especially upper delta	Decline in water table, increasing salinity of ground water	High	8	134
General water quality	Groundwater	Increasingly brackish because of lower recharge due to insufficient flow in canals and higher water abstraction	Severe	9	135
Environmental Impacts					
Metals, industrial wastes	Metal and pesticide pollution in Bhima and Tungabadra tributaries Tungabadra tributary contains industrial pollutants	Sewage, urban and industrial effluents dominate. Measurements of basic parameters such as BOD, COD, nutrients may be used as indicators to identify sources	Decline in river surface water quality; fish kills reported in Tungabadra; BOD in raw effluents released into the river were 1000 mg/l up to 40 km downstream	8	136, 137, 138
Organic load	Throughout the river, wastewater from large cities (Pune, Satara, Kohlapur, Hyderabad, Kurnool, Vijayawada); sewage from Pune pollutes the Mula and Mutha tributaries; Musi tributary has sewage pollution	DO does not meet water quality criteria at some stretches BOD ranges from 0.1-9.8 mg/l Fecal coliform ranges from 0-1600 MPN per 100 ml	Polluted in stretches, corresponding to human settlements dumping waste load into river directly	8	139
Nutrient load	Krishna River and delta	Increase in phytoplankton population and enhanced primary production Depletion of dissolved O_2 in the surface waters (< 3 mg/l); high nutrient load (particularly of NO_3, PO_4)	Entire delta of the Krishna River has been affected by eutrophication	6-7	
Salinity	Coast	landward intrusion of the saltwater/freshwater interface of the second aquifer (30 to 60 meters deep) by 10 to 20 km inland over the past two decades	Severe	8	140
Ecological Impacts					
Loss of mangroves	Coastal forests	Freshwater discharge. River discharge has been reduced by 400m^3/s from 1964-65 to 2004-05	Freshwater is required for mangrove survival	8	
Loss of fisheries	Whole river	Faunal shift towards lentic species	Density of fish decreased from 19.2 ha^{-1} yr^{-1} to 3.5 ha^{-1} yr^{-1}	8	
Reduced river discharge into ocean	Whole river	57 BCM (1960) to 10.8 BCM (2000) to almost nil in 2004	Threshold defining natural ecosystem is about 48.5 BCM per year	10	141
Socioeconomic impacts					
Agriculture	Coast	Conversion of coastal agricultural land into aquaculture farms, brackish water aquaculture resulting in salinization of adjacent agricultural lands	Severe	8	142
Fisheries	Whole river	Fish yield decreased from 19.2 ha^{-1} yr^{-1} to 3.5 ha^{-1} yr^{-1}	Severe	8	

***Table 30**: DPSIR matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes impacting the coastal zone versus catchment size class (Krishna basin)*

(p = progressive, d = discrete)

Driver	Pressure	State change	Impact on coastal ecosystem	Time scale
Agriculture	Changes in hydrological cycle: damming; water abstraction (surface, groundwater)	Major	Environmental: reduction in sediment reaching coast; reduced freshwater availability at the coast Ecological: reduction in mangrove extent and biodiversity Socioeconomic: reduction in water availability; farmers go for short duration, less profitable crop	d/p
	Chemical inputs: fertilizers	Major	Environmental: eutrophication due to higher nutrient loads; change in nutrient availability	d
Aquaculture	Land use change – conversion of agricultural lands into aquaculture farms	Major	Environmental: reduced soil fertility; increased salinity of water and land Ecological: loss of mangroves (grazing, use for timber, housing, fencing, fuel and other purposes) Socioeconomic: poverty related migration to cities/towns in search of jobs often ancillary to shrimp farming; brackish water aquaculture has increased salinization of adjacent agricultural lands and reduced production	p
Industrialization	Manufacturing industries		Environmental: metal load; change in water quality Ecological: loss of biodiversity	p/d
Urbanization/ population pressure	Domestic wastes disposal Withdrawal of ground water		Environmental: changes in water quality (organic and inorganic loads); eutrophication due to higher nutrient loads Ecological: habitat loss Socioeconomic: reduction in availability of potable water, drop in household well water levels	p

***Table 31**: Linking coastal issues/impacts and land-based drivers in coastal zones – an overview, qualitative ranking and trend expectations on local or catchment scale (Krishna basin)*

Coastal impact	Drivers	Local catchment	Impact category	Trend expectations	Reference
Siltation	Deforestation	Raichur, Bellary, Belgaum, Tumkur	7	⇑	143
	Damming	Ghatprabha, Tungabatra,Srisailam, Alamatti	8	⇒/(⇑)	144
Impaired water quality due to nutrients from agriculture	Agriculture	Krishna, Guntur, Kurnool, Prakasam, Kurnool, Cuddapah Canal, Bhima diversion	8	⇑	145
Impaired water quality due to municipal wastes	Urbanization	Pune, Solapur, Hyderabad	8	⇑	
Impaired water quality due to industrial wastes	Industrialization	Vijayawada	8	⇑	146

3.4 Cauvery

The major concern in the Cauvery River basin is related to preserving the quality and availability of fresh water. About 50 % of human population of this basin lives within 200 km of the coastline and many urban cities are located in these coastal zones. It is estimated that Cauvery River is the source of over 45 % of annual material discharge to the Bay of Bengal. The frequency of “no flow intervals”, total number of “no flow days” and “maximum no flow length” of this river has increased in recent decades. This change in stream flows caused by irrigation, hydropower and varying/reduced water supply has changed salinities in the mangroves and the Coleroon estuary and in turn the biodiversity and productivity. Land use changes, such as removal of mangroves for aquaculture, location of industries along the coast and intensive agriculture have increased the loads of sediment, nutrients, toxic chemicals and pesticides in this delta.

Discharges of sewage and industrial effluents have deteriorated the water quality and caused significant adverse impact to the coastal ecosystems, resources, and the livelihoods of the people. There are two major mangrove wetlands in the Cauvery delta: Pichavaram and Muthupet. The Pichavaram mangrove wetland receives freshwater from the Coleroon River, which is one of the distributaries of the Cauvery riverine system. The Coleroon River receives freshwater from the Cauvery through Lower Anicut (small dam), located 70 km west of the Pichavaram mangroves. A number of small distributaries of the Cauvery riverine system, namely Pamini, Korayar, Marakkakorayar and Kilaithangi, supply freshwater to the Muthupet mangrove wetlands.

Since 1924, a number of major and minor dams have been constructed on the Cauvery River as well as its tributaries and distributaries. Consequently the Anicut area has increased and large quantity of freshwater is being diverted for irrigation. This has resulted in the gradual decline of the quantity as well as the periodicity of freshwater discharged into the Pichavaram and Muthupet mangrove wetlands. The discharge data from lower Anicut to Coleroon River, from which the Pichavaram mangroves receive freshwater, collected from the Public Works Department of Tamil Nadu from 1934 to 1999 shows that in the 1930s 73 TMC[1] of water was let out into the Coleroon river, which reduced to 31 TMC in the 1980s and further to 3 to 5 TMC in the 1990s.

As a result of this, the amount and periodicity of freshwater discharged and sediment supplied along with it into the Pichavaram and Muthupet mangrove wetlands has reduced resulting in the development of high annual average salinity. This in turn resulted in the disappearance of a number of mangrove plant species, which are sensitive to increase in salinity.

***Table 32**: Major coastal impacts and critical thresholds in coastal zones: Overview and qualitative ranking (Cauvery basin)*

(Value 1-3 no or minor importance; values 4-6 = medium importance, values 7-9 = major importance, value 10 = critical)

Coastal impact	Local site	Critical threshold (for system functioning)	Distance to critical threshold	Impact category	Reference
Environmental Impacts					
Suspended sediments	Delta	Less than 20 µm fraction accounts for nearly 60% of the total sediment transported by the river; at dam sites, coarse sediments are selectively removed from the suspended load	Not known		147
Groundwater	Delta and coastal area	Increasingly brackish nature of groundwater	Near critical	7	148
Metals	Cauvery in Karnataka (8 test stations)	Heavy metal concentration in water was Cr >Cu _ Mn > Co > Ni > Pb > Zn	Not known		149
Organic load	River	DO in the range of 0-14, minimum standards observed; all parameters meet minimum requirements except at three locations			150
	Mettur	Dominance of rotifers over other organisms in the water	Critical	7	151
Salinity	Delta and adjoining inland region	Soil and water quality increasingly saline	Near critical; estuarine and mangrove water affected	9 (7-9)	152
Ecological Impacts					
Loss of biodiversity	Estuarine areas of Poompuhar, Pichavaram, and Muthupet	Lowered fresh water supply Increased salinity levels Excess nutrient supply (C, N and P)	Near critical	8 (7-9)	153

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[1] Abbreviation for "thousand million cubic feet", commonly used in water management in India. One TMC ft is equivalent to 28.317 million m^3 or 22 956.8 acre feet. One TMC ft/day is 11 574 cubic feet per second or 327.74 m^3 per second

Reduced mangroves	Ca. 30% reduction in the last 3 decades	Loss of mangrove species diversity	Near critical	8 (7-9)	154 - 157
Socioeconomic Impacts					
Aquaculture	Increase in spread of aquaculture farms	Soil and water quality deterioration	Near critical; estuarine and mangrove water affected	9 (7-9)	155 - 157
Fisheries	Reduction in fish catch	Loss of livelihood	Medium	5	156, 157
Natural disaster (tsunami)	Entire delta and up to about 7 km inland	Soil salinity changes Change in water flow Water quality changes (surface and sub-surface)	Study under progress	7 (7-9)	

***Table 33**: DPSIR matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes impacting the coastal zone versus catchment size class (Cauvery basin)*

(p = progressive, d = discrete)

Driver	Pressure	State change	Impact on coastal ecosystem	Time scale
Agriculture	Changes in hydrological cycle: damming; water abstraction (surface and ground)	Major	Environmental: reduction in sediment reaching coast; reduced freshwater availability at the coast Socioeconomic: droughts/floods resulting in crop losses; increased access problems to potable water	p
Aquaculture	Land use changes: soil degradation; salinization	Major	Environmental: salinization of soil and ground water; reduced soil fertility Ecological: loss of mangroves and biodiversity; reduction in fish catch Socioeconomic: loss of livelihood, increased poverty related migration; increased access problems for potable water	p
Industrialization	Manufacturing industries	Major	Environmental: change in water quality Ecological: loss of biodiversity	P
Urbanization/ population pressure	Domestic wastes disposal Sand mining		Environmental: changes in water quality (organic and inorganic loads); eutrophication due to higher nutrient loads Ecological: habitat loss	p

***Table 34**: Linking coastal issues/impacts and land-based drivers in coastal zones – an overview, qualitative ranking and trend expectations on local or catchment scale (Cauvery basin)*

Coastal impact	Drivers	Local catchment	Impact category	Trend expectations	Reference
Erosion/ siltation	Aquaculture	Estuarine region	8	⇒/(⇓)	158
	Damming	Delta and coast	9	⇑	
	Sand mining	River	8	⇑	
Reduced freshwater reaching coast	Damming	River	9	⇑	159 - 161
Impaired water quality: nutrients	Agriculture	Entire basin	5	⇑	160
	Urbanization/population pressure	Stretches of Bhavani, Amaravathi and lower reaches	9	⇑	161 - 164
Impaired water quality: metals, chemical load	Industrialization	Entire basin	7	⇑	162
Increased withdrawal of ground water	Aquaculture; agriculture; population pressure	Whole river basin particularly in the delta	7	⇑	
Loss of biodiversity	Reduced water flow Contaminated water flow due to damming and urbanization Tsunami	Entire river In the stretches of Bhavani, Amaravathi and lower reaches: 7 km inland the coastal stretches	9 8 8	⇑	163, 164

Walawe Basin (Sri Lanka)

The Walawe River basin covers an area of 2,442 km^2 starting from the central massif of Sri Lanka to the southern coast in Ranna/Hambantota area. Hundreds of small irrigation tanks constructed during the ancient times are scattered throughout the Walawe basin. The Walawe irrigation system in southern Sri Lanka draws water from the Uda Walawe reservoir on the Walawe Ganga. There are two main canals on the right and left banks respectively, which flow through several smaller tanks on tributaries of the Walawe, and which contribute to the system's water resources. The Walawe Irrigation Improvement Project area covers some 12,000 ha on the right bank. The rainfall in the upper reaches of the basin is over 100 inches per year on the average, while at Ambalantota near the river mouth it is below 40 inches per year. The river discharges 1,100,000 acre feet of water into the sea annually. The development area under the Walawe Basin Project includes two small areas, extending on the east up to the Malala Oya and on the west up to Urubokka Oya[165].

The major environmental and health issues include[166]:

- Coastal lagoon ecology changed by inflow of fresh water
- Human-elephant and cattle-elephant conflicts (Walawe Park and extension scheme)
- High fluoride and iron concentration in a majority of wells used for drinking water
- Erosion, forest fire, and landslides in the mountain area
- Solid waste pollution (Embilipitiya)
- Salinization of irrigated land (limited to some parts in the lower basin).

***Table 35**: Run-off statistics from major river basins in Sri Lanka* [167]

River	Area (10^2 km^2)	Discharge (km^3/yr)	Run-off (mm/yr)	TDS	N	P	Si
				Load * 10^6 t/yr			
Walawe	2.47	2.17	876	0.28	0.13	0.05	4
Mahaweli	10.44	11.02	1055	2.42	0.77	0.37	24
Malwathu Oya	3.28	0.56	171	0.24	0.10	0.03	3
Kala Oya	2.81	0.59	209	0.24	0.07	0.04	7
Mi Oya	1.52	0.34	223	0.20	0.03	0.02	2
Deduru Oya	2.65	1.61	607	0.68	0.43	0.10	7
Maha Oya	1.51	1.61	1065	0.30	0.38	0.09	8

***Table 36**: Major coastal impacts and critical thresholds in coastal zones: Overview and qualitative ranking (Walawe basin)*

(Value 1-3 no or minor importance; values 4-6 = medium importance, values 7-9 = major importance, value 10 = critical)

Coastal impact	Local site	Critical threshold (for system functioning)	Distance to critical threshold	Impact category	Reference
Erosion (coastal geomorphology)	Kachchigalara	Lagoon ecosystem affected due to irrigation drainage and sedimentation	Extent of lagoon reduced and reduction of diversity and quantity of fish (quantitative)	8	168
	Kalametiya – Lagoon silted due to sedimentation coming from Kachchigalara has caused shrinkage of area	Coastal stability impacted due to artificial drainage canal as otherwise it was a closed system	Impact of changes in the coastal ecosystem changes on the livelihood of the people	8	169
		Sand bar formation impacting on local communities	Paddy area affected and negative impact on people's daily activities (e.g. clearing of sand bar removal)	7	170
		Agricultural land affectted due to inundation		7	171
Water quality impairment due to high nutrient concentration	Kachchigalara	Nutrient load is at the threshold	Further increased nutrient load will change the system	5	172
Water quality impairment due to industries (point sources) and agriculture (non point sources)	Kachchigalara and Walawe River Mouth		Increasing trend (no information available)	Not known	
Water quality impairment due to organic (sewage) sources	Kachchigalara	Significant – local community perceptions	Kachchigalara Diffuse Pollution Project (ongoing)		173
Saline intrusion	Walawe River Mouth at Ambalantota	Salt water intrusion	Has reached the threshold in terms of previous ecosystem of a hyper-saline lagoon due to irrigated drainage water development in the basin	5	174
	Karagan Lagoon	Complete change in the lagoon ecosystem - more freshwater, change in organisms		8	175
	Walawe River Mouth	Significant		9	176

***Table 37**: DPSIR matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes impacting the coastal zone versus catchment size class (Walawe basin)*

(p = progressive, d = discrete)

Driver	Pressure	State change	Impact on coastal ecosystem	Time scale
Agriculture	Changes in hydrological cycle due to damming: water abstraction; increasing sediment transport; nutrient and sediment sequestration	Major	Environmental: siltation; erosion Socioeconomic: change in longstanding livelihood systems	p
	Chemical inputs: fertilizers	Major	Environmental: eutrophication due to higher nutrient loads	p
Deforestation	Sediment budget alteration	Major	Environmental: increased salinization Socioeconomic: change in long standing livelihood systems	p
Industrialization	Waste loads: seasonal discharges	Minor	Environmental: change in water quality	d

***Table 38**: Linking coastal issues/impacts and land-based drivers in coastal zones – an overview, qualitative ranking and trend expectations on local or catchment scale (Walawe basin)*

Coastal impact	Drivers	Local catchment	Impact category	Trend expectations	Reference
Soil erosion; sedimentation	Damming	Samanala Wewa	8	⇑	2
		Uda Walawe			
		Mau Ara Diversion (new)			
		Weli Oya Diversion (new)			
		Chandrika Wewa			
	Deforestation	Walawe Irrigation Left Bank Area (10,000ha)	9	⇑	Walawe Left Bank Extension Project
		Residual TSS production			
	New diversion	Weli Oya	8	⇑	Weli Oya project
		Mau Ara			Malala Oya project
Land use changes	Increasing agricultural productivity	Residual nutrient production increase due to cultivation of field crops (e.g., vegetables)	10	⇑	
Eutrophication; water pollution	Municipal waste	Local urbanized area	2	⇑	

4 Inflow of Small Rivers into the Arabian Sea

4.1 Pamba Basin

The Kerala region, comprising southern part of the Western Ghats mountain range hosts as many as 41 mountainous minor catchments draining in to the Arabian Sea with a total drainage area of 35,997 km^2. Total annual run off is estimated at 72,000 million m^3, and the annual sediment yield varies from 20 to 120 tons km^{-2} with spatial and temporal variations. On land, changes starting with large scale deforestation for agricultural and developmental schemes have their impact on the coast. Sediment supply to segments of the coast has been reduced, with attendant aggravation in sea erosion; nutrient supply stands terminated in certain segments. Considering the very high density of coastal population along the Kerala coast and its known high productivity rates, the social and economic fallout of these activities is likely to be very high. Lack of precise data on these aspects is a major lacuna in management practices.

A glaring example of how an upstream catchment pollution problem can influence the productivity and health regime in the downstream estuary is amplified through the DPSIR sheets on Pamba River in Kerala. The upstream shrine on Pamba catchment is frequented by millions of pilgrims in two seasons every year. Sewage and waste from the pilgrimage area finds its way into the river. Downstream municipalities and population centers also discharge their waste in to the river. Agricultural run-off is yet another source of pollution. The river water is polluted and the downstream estuary is under serious stage of eutrophication. Many water-borne diseases are known in coastal areas. A scientifically viable pollution abatement scheme and appropriate land use plans are essential for keeping the economic and environmental health of the coastal stretch of this basin. Alternatively, this example testifies to the fact that river catchment activities/uses should find a place, at least in select cases, in coastal management plans.

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[2] References for these were drawn from the presentation made at the LOICZ Workshop in Sri Lanka by the Sri Lankan participants. All the above data have been taken from different Sri Lankan Government departments as mentioned in Table 38

***Table 39**: Major coastal impacts and critical thresholds in coastal zones: Overview and qualitative ranking (Pamba basin)*

(Value 1-3 no or minor importance; values 4-6 = medium importance, values 7-9 = major importance, value 10 = critical)

Coastal impact	Local site	Critical threshold (for system functioning)	Distance to critical threshold	Impact category	Reference
		Environmental Impact			
Siltation	Pamba River to the Vembanad estuary on the Arabian sea coast	~100,000 tons of sediments per year are retained in the dams upstream and the bund in the estuary	Passed	5	177
Erosion	Sand mining in Pamba river	Off take must not exceed the annual sedimentation	Critical	7	178
	Channel degradation due to sand mining	River bed has been lowered during 1985-2000 (8cm/yr).	Critical	7	179
Water quality impairment due to inorganic nutrients	Vembanad estuary at the mouth of Pamba River	Occurrence of anoxia in pockets in the estuary	Passed	10	180
		Low productivity			
		Nutrient loads appear to have surpassed the threshold			
Water quality impairment due to organic load	Pamba River	Exceeds threshold due to nutrient and E-Coli inputs	Passed	10	181
		DO levels range from 3.7 to 7.6 mg/l, BOD from 0.3 to 1.5 mg/l; fecal coliforms from 900-1300 MPN per 100 ml	High values indicate pollution from domestic sources	~7	182
General water quality impairment	Pamba River near Sabarimala	Total coliforms count rising up to 94,000 per 100 ml of water (the allowable limit is 500 per 100 ml) during the festival season.	Critical	9	183
		Ecological Impact			
Habitat fragmentation	Vembanad lake	Bird species biodiversity – absence of migratory ducks due to heavy boat traffic	Tending to critical	8	184

***Table 40**: DPSIR matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes impacting the coastal zone versus catchment size class (Pamba basin)*

(p = progressive, d = discrete)

Driver	Pressure	State change	Impact on coastal ecosystem	Time scale
Agriculture	Changes in hydrological cycle: water abstraction; dams in upper catchment	Medium	Environmental: reduction in sediment reaching coast; reduced freshwater availability at the coast Socioeconomic: loss of crop productivity due to insufficient water	d/p
	Chemical inputs: fertilizers; pesticides	Major	Environmental: eutrophication due to higher nutrient loads; pesticide contamination in water	p
	Bunding[3] in the estuary	Major	Environmental: siltation; reduced sediment supply to coast; reduction in nutrient levels Socioeconomic: higher incomes due to higher agricultural production	p
Industrialization	Coir retting industry	Major	Environmental: change in water quality Ecological: loss of biodiversity	p
Urbanization / population pressure	Domestic wastes disposal Deforestation	Major	Environmental: changes in water quality (organic and inorganic loads); eutrophication due to higher nutrient loads; increased silt load during heavy rainfall Ecological: habitat loss	d
Tourism	Waste disposal	Major	Environmental: change in water quality especially nutrients and organic material; eutrophication due to higher nutrient loads Health: disease outbreaks especially those transmitted by water	p

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[3] Bunding, also called a bund wall, is the area within a structure designed to prevent inundation or breaches of various types

***Table 41**: Linking coastal issues/impacts and land-based drivers in coastal zones – an overview, qualitative ranking and trend expectations on local or catchment scale (Pamba basin)*

Coastal impact	Drivers	Local catchment	Impact category	Trend expectations	Reference
Erosion	Damming	Catchments involved-41	5	⇑	185
		Area: 35,997 km^2			
		Volume: 72,000 MCM			186
		Run-off reduction 20-25%			
	Deforestation	Area: 8,000 km^2 over last 30 yrs	9	⇑	187
		Residual TSS production: 10-60, rarely up to 100 mg/l			
	Diversion	20 irrigation projects, effect on water flow varies in catchments, average~10% reduction	5	⇒	188
	River sand mining	River bed has been lowered to about 1 1.23m in Pamba river during 1985-2000 (bed lowering = 8cm/yr).	7	⇑	189
	Entire Basin		7	⇑	
Water quality changes: higher nutrient load	Agriculture	Residual nutrient production increased	8	⇑	190
Water quality changes: higher nutrient load	Mariculture	Local residual nutrient production increased	3	⇑	191
Water quality changes: higher organic load	Municipal waste	Local urban centers discharge untreated waste into water bodies	9	⇑	
	Entire Basin		7	⇑	

4.2 Zuari and Mandovi Rivers

The Mandovi-Zuari river systems located in the state of Goa on the west coast of India are the two major tidal stream estuaries of the state. These river systems are considered the life lines as they satisfy the fresh water demands of the state. Being the main waterways of the region, developmental activities have been concentrated along the banks of the two river basins. Recognizing their importance, the Central Board for Prevention & Control of Water Pollution (CBPCWP) formulated a Master Plan for Pollution Control under which the water quality of these two rivers with respect to their physical, chemical and biological characteristics was assessed during 1977-79. The major issues of concern during this study were:

Mining activity along the banks of the rivers: Iron ore mining being the major revenue earning industry of the region, about two thirds of the total production of iron, manganese and ferromanganese ores were transported to the Marmagoa harbor, (situated at the mouth of the Zuari estuary) by barges through the waterways of these rivers. About 0.50 million tons of suspended solids were added to the sea every year from these rivers by way of mining rejects reaching the estuary through river run-off.

Domestic waste water discharge: The population of Goa was 0.86 million with 55 % dwelling along the banks of these rivers. The annual domestic waste water discharge was 9.9 x10^6 m^3. The sewage water treatment plant discharging waste water to the Mandovi River was with a designated capacity of 5.7 million liters per day'[192].

Discharge of Industrial effluents: There are 236 large to small industries situated along the banks of these rivers with a total annual effluent discharge of 5.2 x10^6 m^3. Suspended solids, oils and grease and phenolic compounds which originated from mining industry had somewhat higher concentrations than those prescribed in the Indian standards. Plants and animals were abundant and were not found to be affected by human activities. However, reduced dissolved O_2 concentration, high suspended solids and blanketing of bottom deposits by mining rejects, has resulted in more than 70 % reduction in clam production, near extinction of resident fauna and the appearance of low diversity bottom fauna comprising of tolerant but vagrant species in the Mandovi and Cumbarjua canal system for the 10 years period from 1972-1973 to 1982-1983. Fecal coliforms were observed. Mandovi and Zuari have tidal stream estuaries; the good flushing of these rivers twice a day up to a considerable distance upstream keeps them fairly clean.

Later during 2002-2003, the assessment of these two rivers was carried out under the Integrated Coastal and Marine Area Management (ICMAM) Project in order to identify the problems and issues, analyze them and suggest solutions for integrated management. The major issues of concern during this study were:

Impact of mining: Mining and processing of iron ore generate large quantities of rejects/wastes impacting environment to varying degrees. Production of iron ore in Goa in the vicinity of these river systems is 156 million tons and the waste generated is 360 million tons. A decline in foraminiferan fauna between 1972 and 1990 is postulated to be due to continuously increasing suspended load (2-4 mg/l in 1972, 4.5 – 8 mg/l in 1982 and 6.69 – 114.49 mg/l in 1990) in the estuary. This increased suspended load can be attributed to mining activities in the catchment area of the Mandovi River along with its tributaries. Extraction of one ton of iron ore generate about 1.5 to 4 tons of mining reject, and over the years more than 1 billion metric tons of mining reject is estimated to have accumulated in the mining belt of Goa[193].

Impact of expanding tourism: Tourism exerts positive as well as negative impacts on the coastal environment. The positive impact is better revenue to the commercial establishments, transporters, and restaurants and improved socioeconomic conditions of the local population. The negative impacts due to improperly managed tourism areas are loss of natural environment due to destruction of sand dunes, shortage of drinking water, beach pollution, pollution due to domestic sewage and decrease in aesthetics around the beaches.

Impact of developmental activities: Tourism related development activities and negligence towards agriculture has resulted in the conversion of agricultural lands to non agricultural use such as residential and commercial establishments, and beach resorts. Such developmental activities have resulted in loss of Khazan lands. The Khazan lands are now reduced from 112 km^2 in 1970 to 19 km^2 at present.

Impact on coastal fisheries: Mandovi-Zuari estuaries are now said to be saturated with mechanized trawlers. Premature fishing, fishing of small fish using nets below a specific mesh size and prepondment and violation of fishing ban period are some of the factors affecting the coastal fisheries in Goa. Though the effects of these ill practices are not seen immediately, they are expected to affect the fish catch in the next 10 to 15 years.

Water quality: The water quality of both Mandovi and Zuari estuaries showed low levels of nutrients during non-monsoon periods with increased levels in monsoon. Overall both the estuaries showed healthy water quality conditions. However, past studies reflected nutrient enrichment in the areas close to the mining ore rejects during peak southwest monsoon and normal levels beyond these zones, indicating that the impact is localized. The Mandovi-Zuari estuarine complex seems to be quite productive and healthy though a slight decrease in the benthic fauna is observed compared to the past data collected in this area.

The waters of the Mandovi and Zuari were found unfit for bathing going by the coliform count. During September 2002, the counts of TC exceeded 100 mg/l at many locations. This is primarily due to excessive land run-off containing raw sewage and fecal debris that support the proliferation of coliform bacteria examined. During the other observations too, there were hardly any samples that had counts of bacteria that would be considered safe[194].

Table 42: *Major coastal impacts and critical thresholds in coastal zones: Overview and qualitative ranking (Mandovi-Zuari Rivers)*

(Value 1-3 no or minor importance; values 4-6 = medium importance, values 7-9 = major importance, value 10 = critical)

Coastal impact	Local site	Critical threshold (for system functioning)	Distance to critical threshold	Impact category	Reference
Environmental Impacts					
Suspended sediments	Rivers: Mandovi, Zuari, Chapora, Tiracol, Sal, Talpona, Galgibag	100 mg/l	Awareness is being created and lately measures have been taken to reduce the suspended load to the coastal zone. There is every possibility that the critical threshold may not reach	5	195
General water quality	Rivers of Goa	Generally water quality meets desired criteria for DO, pH, conductivity			196
Water quality impairment: Industrial effluent load	Goa, West coast of India: Mandovi, Zuari	COD 1.6-40 mg/l in Zuari and 2-47.6 mg/l in Mandovi	Not alarming as pollution is localized	2	197
Water quality impairment: organic load		3 mg/l (BOD)	0.5 mg/l (BOD)	2	198
Water quality impairment: nutrient loads		Increased nutrients loading during monsoon	Suboxic to Anoxic conditions are encountered along the Goa coast	4	199
Oil pollution		Tar balls spread along the beach affecting beach aesthetics, mangroves affected	Oil spillage is accidental and affected areas recover to normal conditions after mitigation measures are taken	3	200
Ecological Impacts					
Wetlands (intertidal)	Goa, West coast of India (9 tidal rivers)	Affecting nursery grounds for fish species like shrimps affecting exotic weeds	Alarming	8	201, 202
Socioeconomic Impacts					
Beach aesthetics	Goa, West coast of India (9 tidal rivers)	Not known	Beach aesthetics is affected, impact on drinking water availability	5	203

Table 43: *DPSIR matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes impacting the coastal zone versus catchment size class (Mandovi-Zuari Rivers)*

(p = progressive, d = discrete)

Driver	Pressure	State change	Impact on coastal ecosystem	Time scale
Agriculture	Changes in hydrological cycle: damming; water abstraction; river linking		Environmental: reduction in sediment reaching coast; reduced freshwater availability at the coast	
	Chemical inputs: fertilizers; pesticides		Environmental: eutrophication due to higher nutrient loads	p
	Land use changes; soil degradation			p

Tourism	Change in land use, increased waste loads	Major	Environmental: water quality changes; changes in beach area	p
Aquaculture	Soil acidification; damage to agricultural lands; seepage of saline water; increasing soil infertility	Minor	Not known	d
Industrialization	Mining; suspended load; turbidity	Major	Environmental: metal load; change in water quality Ecological: loss of biodiversity (benthic fauna) Socioeconomic: loss of agricultural land, lowered productivity, lowered incomes	d
Urbanization/ population pressure	Domestic wastes disposal	Minor	Environmental: changes in water quality (organic, inorganic loads); eutrophication due to higher nutrient loads Ecological: habitat loss	d

***Table 44**: Linking coastal issues/impacts and land-based drivers in coastal zones – an overview, qualitative ranking and trend expectations on local or catchment scale (Mandovi-Zuari Rivers)*

Coastal impact	Drivers	Local catchment	Impact category	Trend expectations	Reference
Land use change, loss of beach area	Tourism	Mandovi	7	⇒	204
Impaired water quality due to industrial effluents	Industrialization	Mandovi	2	⇒	205
Salinization of agricultural land	Aquaculture	Mandovi	2	⇒	206
Land use change, loss of beach area	Tourism	Zuari	7	⇒	207
Impaired water quality due to industrial effluents	Industrialization	Zuari	3	⇒	208
Salinization of agricultural land	Aquaculture	Zuari	3	⇒	209

5 Gujarat Sub-Region

No data were made available at the LOICZ workshops and hence the DPSIR framework could not be prepared.

6 Indus Delta

The Indus basin irrigation system is the world's largest contiguous irrigation system. The irrigation system in Pakistan is comprised of three major storage reservoirs, 19 barrages or head works, and 43 main canals with a conveyance length of 57,000 km and 89,000 km water courses with a running length of more than 1.65 million km. The Tarbela dam and Chashma reservoirs have resulted in the siphoning of 74% of Indus waters before it reaches Kotri barrage[210]. The flow distribution at Kotri barrage provides valuable information about flow conditions in the downstream delta areas. A low flow analysis was carried out, covering the period from 1940, before construction of Kotri barrage (1955) and commencement of major irrigation diversions (1960). Rabi , i.e. spring harvest, also known as the "winter crop" in India and Pakistan, flows downstream of the barrage averaged 13.5 billion m^3 from 1940-61 and reduced markedly to an average of 3.6 billion m^3 following diversions of water from Kotri barrage. They reduced further to 1.4 billion m^3 in the period post-Mangla (1967-75). Average rabi season flows increased to 3.1 billion m^3 in the post-Tarbela period (1975-98). Within these years there was significant variability. From 1980-85, for example, the seasonal mean was 1.2 billion m^3 whereas from 1990-95 it was 5.9 billion m^3 [211]. 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, following the construction of dams and barrages on the Indus River[212] 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.

***Table 45**: Main dam structures on the Indus River* [213]

- Mangala Dam, completed in 1968
- Tarbela Dam, completed in 1976, is the largest dam on the Indus River and exerts significant control over flows in the upper catchment.
- Kotri Barrage, constructed in 1955 near Hyderabad, Pakistan, is at the upstream end of the lower Indus floodplain and the delta area and has a significant effect on the amount of water reaching the delta.

***Table 46**: Changes in freshwater flow in the lower Indus River source*

Date	Comment	Flow Rate (10^6 m^3/yr)
1892	From historic maps and data	185000
1932	Following the constitutions of the Sukkur Barrage	105000
1960	Construction of the Kotri Barrage in 1956	79581
1970	Developments following Indus Water Treaty	43000
1990s	Following the agreements of the Indus Water Accord	12300

Historically, the abundant freshwater discharges and nutrient-rich sediment load supported a highly productive coastal ecosystem, including mangrove forests and fisheries, on which local communities depended for their livelihood. The decline in freshwater flow because of upstream dams has led to a general reduction in the health of the floodplain and delta ecosystems. From a biodiversity perspective the delta is also important, with ten species of mammals, 143 species of birds, 22 species of reptiles, over 200 species of fishes, many invertebrate species, including 15 species of shrimp. The Indus River is also home to one of the few species of freshwater dolphin, *Platanista minor* and to the fishing cat. Because the lives of local people are closely linked to the natural resources of the delta ecosystems, each environmental impact has a social impact. Local communities are dependent on natural resources for their livelihood, including floodplain forests, mangrove forests and fisheries[214].

Freshwater releases to the lower Indus have been proposed, but it conflicts with increasing demand for irrigation upstream. Further, providing sufficient flow to the lower Indus and its delta is dependent on cooperation between authorities responsible for the operation of dams and barrages throughout the Indus system. This is a challenging task since the Indus basin encompasses parts of the four autonomous regions of Pakistan (Sindh, Punjab, Balochistan, North West

Frontier Provinces). Recent national legislation and provincial conservation strategies that address freshwater issues indicate that there is growing awareness at national and provincial levels of the need to conserve and protect freshwater ecosystems. However, there is currently a lack of coordination between authorities and stakeholders.

Best scientific evidence suggests that the minimum level of freshwater flows to the delta area set by the Indus River Accord (12.3 billion m^3/yr) is inadequate to maintain effective ecosystem functions of the wetlands of the Indus delta. The Indus River is currently contributing hardly any sediment now; consequently, there has been intrusion of sea water upstream of the delta – at places extending up to 80 km inland in the coastal areas of Thatta, Hyderabad and Badin districts. As a result, a significant deterioration in the natural resources of the delta has been observed[215].

Table 47*: Environmental impacts of reduced flow in the lower Indus River* [213, 214]

Component	Observed Impact
Mangrove forest	Reduction in size of forest. Decrease in biodiversity (loss of 5 species in the last 20 years). Desertification due to loss of forests.
Fisheries	Decrease in reproductive success of fish and shrimp due to loss of mangrove habitat Change in seasonal water availability and modified water quality.
Water quality	Reduction in water quality following the use of pesticides and fertilizers from the irrigation plots. Effects are exacerbated as flows are reduced, since the concentration of pollutants increases. Chemicals found in the water include NO_3^-, PO_4^-, Hg, Fe, Mn, H_2S, Lindane and DDT. Accumulation of agricultural chemicals in the soil. Growth of filamentous algae on the mudflats as a result of increased nutrient and organic enrichment. Saline-tolerant algae restrict the growth of mangrove seedlings. Increased salinization of the lower Indus has resulted in the decline of fish species sensitive to changes in temperature and salinity.
Sea encroachment	Reduction in freshwater inflow has led to severe encroachment of the sea into the delta area. Saline water has intruded inland and 1.2 million acres of farmland have thus been lost.

Karachi, the port city, has more than half the country's industrial units. Poor planning and untreated industrial wastes as well as domestic wastes are dumped into the watercourses and find their way to the coast. It is estimated that about 37,000 tons of industrial waste is being dumped yearly in coastal environment of Karachi whereas, 20,000 tons of oil finds its way to beaches, harbors of Karachi and fishing grounds annually. Further, municipal sewers generate about 110 million gallons per day. In addition to these wastes killing mangroves, clearing of land for setting up industries as well as ports has resulted in the depletion of the mangrove cover especially in the northern part of the delta[216]. The Indus delta is subjected to the highest average wave energy of any major delta in the world[217]. This is mainly due to the intense monsoonal winds which produce high energy levels. 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. The sharp drop in the quanta of water and sediment reaching the coast via the Indus basin due to human interventions, viz., the reduction in flow due to abstraction by upstream reservoirs is of great concern. If this continues, it is expected that the delta will evolve into a more wave dominated form characterized by extensive beach, beach ridges, and dune formation, probably accompanied by substantial coastal retreat[218].

Table 48: *Major coastal impacts and critical thresholds in coastal zones: Overview and qualitative ranking (Indus basin)*

(Value 1-3 no or minor importance; values 4-6 = medium importance, values 7-9 = major importance, value 10 = critical)

Coastal impact	Local site	Critical threshold (for system functioning)	Distance to critical threshold	Impact category	Reference
		Environmental Impacts			
Erosion/ accretion	River Indus delta	For coastal stability - Sustained delivery of sediments 13-15 million tons per year	Erosion affects 11 million ha and ca. 45 million tons of soil are eroded annually	9	219, 220
Water flow	Kotri Barrage	Fresh water flow to the sea should be minimum 10-15 MAF			221
General water quality	Khobar Creek and man-made drainage system			7	222
Suspended solids	Layyah	High values after monsoon (June - August); steady increase in suspended solids concentration via runoff from catchment area; currently observed range 150-245 mg/l, maximum permissible for fish diversity is 400 mg/l		3	223
Organic load		Occurrence of anoxia or low oxygen in estuaries		3	224
Salinity	Up to 80 km from river mouth				225
		Ecological Impacts			
Delta area	Indus Delta below Kotri barrage	Delta area reduced from 6180km^2 to 1192 km^2			226
Riverine forests	Indus flood plains	Loss of 100,000 acres of forests			227
Mangroves	Creek system of Indus deltaic region (Indus river draining into the Arabian sea through the Khobar Creek)	Mangrove forest shows sign of deterioration shortage of fresh water from Indus and reduced sediments input	Extensive program for mangrove plantation in the Indus can reduce the damage	3	228
		Socioeconomic Impacts			
Flood: riverine		Probable maximum flood for the Jhelum River varies between 48,000-70,000 m³/s at the gauge station; 52 of the 2420 lakes are potential for glacial lake outburst flood			229

Table 49: *DPSIR matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes impacting the coastal zone versus catchment size class (Indus basin)*

(p = progressive, d = discrete)

Driver	Pressure	State change	Impact on coastal ecosystem	Time scale
Agriculture	Changes in hydrological cycle: damming; water abstraction	Major	Environmental: reduction in sediment reaching coast; reduced freshwater availability at the coast	d/p
	Chemical inputs: fertilizers; pesticides	Major	Environmental: eutrophication due to higher nutrient loads	d
Urbanization/ population pressure	Domestic wastes disposal		Environmental: changes in water quality (organic, inorganic loads); eutrophication due to higher nutrient loads Ecological: habitat loss	
Climate change	Glacial snowmelt		Environmental: river floods Socioeconomic: loss of lives, property, infrastructure, crops	
	Deforestation	Medium	Environmental: erosion leading to higher sediment load in rivers	p

***Table 50**: Linking coastal issues/impacts and land-based drivers in coastal zones – an overview, qualitative ranking and trend expectations on local or catchment scale (Indus basin)*

Coastal impact	Drivers	Local catchment	Impact category	Trend expectations	Refer-ence
Impairment of water quality (nutrients)	Agriculture, Population pressure/ urbanization	Local urban areas, agriculture	8	⇑	230
Reduction in fresh-water reaching the Arabian Sea	Upstream dams	146 MAF per year to less than 10 MAF per year	9	⇑	231
Erosion	Deforestation	Loss of 100,000 acres of forests	8	⇑	232
	Damming: Kotri barrage	Loss of 1.5 feet of land every day	8	⇑	233
Reduction in spread of mangroves	Population pressures – waste disposal, grazing of animals, seawater intrusion, upstream dams	the mangroves spread was 0.26 million hectares in 1983 but this area reduced to only 73,000 hectares in 2002	8	⇑	234
Reduction in man-grove biodiversity	Deforestation, increasing salinity	From 8 species in 1950, currently 3 species of mangrove exist in the delta area	8	⇑	235
	All drivers	Entire basin	8	⇑	

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IV. SUMMARY ACROSS SUBREGIONS

1 Introduction

In the earlier sections, coastal issues from individual river basins were discussed in detail. Here, we provide a sub-regional synthesis to understand the issues pertaining to the river catchment-coast continuum in a quantitative and synthesized manner. Subsequently, we identify “hot spots”, which serve as a first overview of issues to be addressed in future research. Finally, a summary of the responses to the perceived issues from various approaches is being provided.

2 Sub-regional Synthesis

The catchment-based synthesis helped in understanding the important impacts in each sub-region. The most important include the environmental, ecological and socioeconomic effects of various drivers and pressures. The important coastal impacts and the drivers across the various sub-regions are now synthesized across the sub-regions in the following tables.

***Table 51**: Linking coastal issues/impacts and land-based drivers in coastal zones – overview, qualitative ranking and trend expectations for the sub-region 1 (Bengal basin)*

Coastal impact	Drivers	Sub-region	Impact category	Trend expectation
Siltation	Rainfall; episodic natural events; climate change	Ganges	9	⇒
		Brahmaputra	5	⇒
		Karnafuli	?	?
		Ayeyarwaddy	5	⇒
	Land-use change: agriculture; deforestation	Ganges	8	⇑
		Brahmaputra	7	⇑
		Karnafuli	5	⇑
		Ayeyarwaddy	7	=>
Siltation		All basins	6	=>
Habitat change: mangrove loss	Land-use change incl. agriculture	Ganges, Ayeyarwaddy	8	⇑
	Sediment load	Brahmaputra	7	⇑
	Waste disposal: nutrients	Karnafuli	7	⇑
	Urbanization: sewage disposal	All basins	7	⇑
	Upstream erosion	Ganges, Brahmaputra	8	⇑
		Karnafuli	5	⇑
	Climate change	All basins	7	⇑
Habitat change: mangrove loss total per driver	Land-use change incl. agriculture	All basins	7	⇑
	Water quality impairment: sediment and nutrients load	All basins	7	⇑
	Urbanization (sewage)	All basins	7	⇑
	Upstream erosion	All basins	7	⇑
Habitat change: mangrove loss		All basins	7	⇑
Water quality impairment: nutrient enrichment/ contaminants	Agricultural run-off	All basins	6	⇑
	Mining and industry	All basins	7	⇑
Water quality impairment: arsenic	Petrochemical industry	All basins	6	⇑

contamination, in sub-surface water	Over-abstraction of ground water	All basins	9	⇑
Water quality impairment: organic load	Municipal waste	All basins	7	⇑
Water quality Impairment: all drivers		All basins	8	⇑
Soil salinization (seasonal)	Canal links	Ganges, Brahmaputra, Meghna delta	7 (locally higher	⇑

***Table 52**: Linking coastal issues/impacts and land-based drivers in coastal zones – overview, qualitative ranking and trend expectations for the sub-region 2 (Peninsular rivers of India and Sri Lanka)*

Coastal impact	Drivers	Sub-region	Impact category	Trend expectation
Habitat modification (mangroves, lagoons and coral reefs)	Natural			
	Cyclone, flooding		6	⇑
	Episodic events (tsunami, earthquake)	All basins	9	?
	Climate change	All basins	7	?
	Damming/diversion (reduced river flow)	Cauvery	(8 up to 10)	⇑
		Godavari, Krishna		⇑
		Mahanadi	5	=>
	Land-use change	All basins	3-4	⇑
	Agriculture (reduced flow, sediment load, nutrient load)		7	⇑
	Urbanization (sewage disposal)	All basins	7	⇑
Habitat modification (total per driver)	Natural	All basins		⇑
	Cyclone/flooding		9	
	Natural hazards (tsunami, earthquake)		7	
	Climate change		3	
	Anthropogenic			
	Damming, diversion		7	
	Urbanization		6	
	Land-use change		7	
Habitat modification	All basin drivers		7	⇑
Water quality impairment: nutrient enrichment, organic load	Agriculture	All basins	8	⇑
	Aquaculture	India	7	⇒/ ⇓
		Sri Lanka	5-6	⇒/ ⇑
Water quality impairment: contaminants	Industry and mining	Cauvery	7	⇑
		Godavari, Krishna	7	⇑
		Mahanadi	9	⇑
		All basins	3-4	⇒
Water quality impairment: organic load from municipal sources	Urbanization	All basins	8	⇑
	Tourism	All basins	5-6	⇑
Water quality change (total per driver)	Agriculture	All basins	8	⇑
	Aquaculture		7	⇒
	Industry and mining		7	⇑
	Urbanization		8	⇑
	Tourism		5	⇑
Water quality change	All drivers		(7)-8	⇑
Soil salinization	Natural hazards (cyclones, tsunami)	All basins	9	?
	Irrigated agriculture	Cauvery	8	⇑
		Godavari, Krishna	7	⇒/ ⇓
		Mahanadi	6	⇑
		Sri Lanka (Kala Oya, Walawe)	2	⇒
	Aquaculture	Cauvery	9	⇒/ ⇓

		Godavari, Krishna	6	⇒/ ⇓
		Mahanadi	5	⇒/ ⇓
		Sri Lanka (Kala Oya, Walawe)	5	⇒/ ⇑
Soil salinization (total per land-based driver)	Agriculture (irrigation)		6	⇒/ ⇑
	Aquaculture		7	⇒
Soil salinization	All drivers		7	⇒/ ⇑
Water salinity (due to salt water intrusion into aquifers)	Natural: cyclones, tsunami		7	⇑
	Anthropogenic: general water demand (groundwater overexploitation, reduced river flow)	Cauvery	9	⇑
		Godavari, Krishna	8	⇑
		Mahanadi	5	⇑
		All basins	9	?
Water salinity	General water demand		8	⇑

***Table 53**: Linking coastal issues/impacts and land-based drivers in coastal zones – overview, qualitative ranking and trend expectations for the sub-region 3 (inflow of small rivers into the Arabian Sea)*

Coastal impact	Drivers	Sub-region	Impact category	Trend expectation
Accretion/siltation	Agriculture (upstream dams)	Pamba	5	⇑
		Mandovi-Zuari		
Accretion	All drivers	All Basins	5	⇑
Erosion	Population pressure (sand mining)	Pamba	7	⇑
		Mandovi-Zuari	7	⇑
Erosion	All drivers	All Basins		
Water quality impairment: inorganic load	Agriculture	Pamba	8	⇑
		Mandovi-Zuari		
Water quality impairment: organic load	Population pressure, tourism	Pamba	9	⇑
		Mandovi-Zuari		
Water quality impairment	All drivers	All basins	8	⇑
Salinization of agricultural land	Aquaculture	Pamba		
		Mandovi-Zuari	3	⇒
Habitat modification: intertidal wetlands	Agriculture, aquaculture, tourism	Pamba	9	⇑
		Mandovi-Zuari	8	⇑
Loss of beach (change in land use)	Tourism	Pamba		
		Mandovi-Zuari	7	⇒
Habitat modification	All drivers	All basins	8	⇑

***Table 54**: Linking coastal issues/impacts and land-based drivers in coastal zones – overview, qualitative ranking and trend expectations for the sub-region 5 (Indus delta)*

Coastal impact	Drivers	Sub-region	Impact category	Trend expectation
Soil erosion and sedimentation	Agriculture (damming)	Indus	10	⇑
	Deforestation	Indus	8	⇒
Erosion	All drivers	Indus	7 (4-10)	⇑
Water quality impairment due to nutrient load	Agriculture, residual nutrient production	Indus	9	⇑
	Mariculture, local residual nutrient production	Indus: local	5	⇑
	Municipal waste, local urban areas	Indus: urban	10	⇑
Eutrophication	All drivers	Indus	8 (5-10)	⇑

3 Hot-Spot Identification

Clearly, there is a reduction in the quantity of sediments reaching the coast in most river basins (except in the Brahmaputra) due to the number of upstream dams and reservoirs that have been constructed across the rivers (either the main rivers or their tributaries). This has an impact on the quantity of sediments reaching the coast and has led to erosion and shrinking of deltas. Water abstraction for irrigation has also resulted in hydrological drought downstream, closer to the coast. For areas with mangroves this reduction of freshwater flow resulted in the disappearance of some species and only those tolerant to higher levels of salt are extending their range. The reduction in water reaching the coast as well as higher ground water abstraction has resulted in saltwater intrusion in coastal aquifers. The third serious problem observed is the impairment of water quality due to release of untreated wastes originating from settlements, industries and agriculture.

***Table 55**: Hot spots in the catchments based on key coastal impacts*

Impact	Driver	Pressure	Sub-region	Catchment Hotspot
Erosion (insufficient sediments reaching the coast)	Agriculture	Water abstraction, dams	1	Ganges
			2	Godavari
				Krishna
				Cauvery
			5	Indus
	Urbanization/ population pressure	Sand mining	3	Pamba
Siltation (high sediment load reaching coast)	Global warming/ glacial snowmelt	Deforestation	1	Brahmaputra
	Urbanization			Ayeyarwaddy
	Agriculture		2	Mahanadi (Chilika Lagoon)
			3	Pamba (Vembanad Lake)
Impaired water quality (nutrients, organic load)	Urbanization/ population	Disposal of wastewater	1	Ganges
			2	Krishna
			3	Pamba
Impaired water quality - chemical and metal concentrations)	Industrialization	Disposal of partially treated/ untreated wastewater	1	Ganges
			2	Godavari
				Krishna
Saltwater intrusion	Aquaculture (shrimp)	Groundwater abstraction	1	Ganges
			2	Godavari
				Krishna
				Cauvery
Coastal flooding	Sea level rise	Erosion	1	Ganges
			5	Indus
Habitat loss (mangroves)	Agriculture	Deforestation	1	Ganges
	Aquaculture			Ayeyarwaddy
	Urbanization/ population pressure		2	Godavari
				Krishna
			5	Indus
Socioeconomic impacts	Agriculture	Change in land use	1	Ganges
	Aquaculture	Increased conversion of land into shrimp farms; intense fishing for fish fry and larvae	1	Sunderban region
			2	Chilika Lake
				Godavari

Impact	Driver	Pressure	Sub-region	Catchment Hotspot
Erosion (insufficient sediments reaching the coast)	Agriculture	Water abstraction, dams	1	Ganges
			2	Godavari
				Krishna
				Cauvery
			5	Indus
	Urbanization/ population pressure	Sand mining	3	Pamba
Siltation (high sediment load reaching coast)	Global warming/ glacial snowmelt	Deforestation	1	Brahmaputra
	Urbanization			Ayeyarwaddy
	Agriculture		2	Mahanadi (Chilika Lagoon)
			3	Pamba (Vembanad Lake)
Impaired water quality (nutrients, organic load)	Urbanization/ population	Disposal of wastewater	1	Ganges
			2	Krishna
			3	Pamba
Impaired water quality - chemical and metal concentrations)	Industrialization	Disposal of partially treated/ untreated wastewater	1	Ganges
			2	Godavari
				Krishna
Saltwater intrusion	Aquaculture (shrimp)	Groundwater abstraction	1	Ganges
			2	Godavari
				Krishna
				Cauvery
Coastal flooding	Sea level rise	Erosion	1	Ganges
			5	Indus
				Krishna
				Cauvery
	Fisheries	Damming - Farakka barrage - decline in fish catch	1	Ganges (Allahabad, Buxar)
	Flooding	Storm surges	1	Brahmaputra - coastal regions
				Ganges - tidal reaches
			2	Mahanadi delta region
				Godavari
				Krishna
		Damming and timber extraction	1	Karnafuli - catchment below dam

Based on these observations, the next step has been to identify 'hot spots' on a sub regional as well as regional scale to help provide a first overview of issues to be addressed in future research. Insufficient freshwater and sediments reaching the coast due to water abstraction upstream, especially for irrigation, are common features across all catchments. Others include the impairment of water quality due to disposal of untreated or partially treated wastes from urbanization, industries, and agriculture. In some areas, deforestation and land use changes have led to higher silt loads being dumped into coastal water bodies such as the Chilika Lagoon and the Vembanad Lake. Socioeconomic impacts include loss of livelihoods due to flooding as a result of glacial snowmelts and natural hazards such as storm surges while availability of quality potable water is on the decline because of increased saltwater intrusion in many coastal areas due to over extraction of groundwater.

4. Responses

The last component of the DPSIR assessment framework applied here is to take stock the set of responses for each driver, pressure or impact. Responses are reactions of society and comprise the institutional dimensions aiming to deal with the impacts and changes observed. Responses as such are based on existing governance systems, which are the enabling (or not) platform on which society can respond and management can occur. They can be:

- scientific
- political
- management oriented
- legal (including the establishment of new rules and institutions)

Scientific responses include studies carried out at various spatial and temporal scales. They are aimed to identify or address problems at the catchment, sub-regional or regional level; based on which recommendations have been/can be made. These are often translated into management and policy responses. In some cases, where the problem is of sufficient magnitude, legislative response can be observed (see for example the European Water Framework Directive addressing issues along the water continuum as far out as one nautical mile to the sea). Some scientific responses are quite localized as in studies about biodiversity, while many others such as those on water quality status are more generalized. Many policy responses are generalized as well, applying a single policy to the entire country. Examples include those for agriculture, tourism, and environment. Similarly, in the case of legislative responses, the broad framework is usually for the entire country. For example, all countries have Acts for Environmental Protection and Forests. Particularly legislation addressing the catchment-coast or water continuum may face considerable constraints as far as transboundary issues are concerned.

Management responses are based on issues that have been identified on a catchment or sub-regional basis. Responses here include the setting up of special boards and commissions to administer requisite responses. These include the

- Brahmaputra Board
- National Biodiversity Authority
- Cauvery Tribunal in India
- Disaster Management Bureau in Bangladesh, to name a few.

In the case of transboundary sharing of waters, the Indus water treaty between India and Pakistan is a response to the need to share waters of the Indus and its tributaries. Responses are often complicated by issues arising from institutional dimensions. This evolves from the fact that different departments/ministries maybe involved in management of different aspects and scales of the same river basin. In India, for example, while the Ministry of Water Resources decides about dams, irrigation and water abstraction, the water quality comes under the Ministry of Environment and Forests. In India, most of rivers pass through multiple states and each state is individually responsible for the management of waters flowing through it. In some cases, the response may be tuned to the impact, while it may address a driver or pressure in other cases. Here we face a frequent dilemma of curing symptoms rather than root causes, an issue addressed in various Global Environment Facility (GEF) International Waters projects on global scale. Thus, it is a complex affair and requires extensive research to understand the ramifications.

The tables 56-59 illustrate the summary of the responses for the various drivers, pressures and impacts on a catchment, sub-regional and regional scale. It must be emphasized here that it does not claim to be exhaustive, but hopefully conveys some of the actions that have been taken to respond to the various Drivers, Pressures and Impacts affecting the coastal areas and may even be located in the wider contributing catchment.

***Table 56**: Summary of the Scientific Responses for the Various Drivers, Pressures and Impacts on a Catchment, Sub-regional and Regional Scale*

Country	Catchment	Driver	Pressure	Impact	Scientific Response (Scientific judgments and recommendations)		
					Catchment	Sub-regional Scale	Regional Scale
INDIA & BANGLADESH	**BRAHMAPUTRA**	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment /freshwater reaching the coast	Analysis of changing land use and water management within the catchment using GIS-India	Integrated water resources management; International agreements with riparian countries on joint management and data sharing	
					Prevention of land degradation (advise on proper tilling practices)		
INDIA	**GANGES**	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment /freshwater reaching the coast	Integrated assessment framework of the entire delta plain		
				Reduction in sediments and freshwater reaching coast		Land Use/Catchment Management, use the natural delta processes and maintain delta plain sedimentation	
		FISHERIES	Use of fishing nets which entangled dolphins	Reduction in species numbers		WWF Survey of Gangetic river dolphins - Pilot dolphin conservation initiative in 2001 and later in 2005	
			Unsustainable harvest of dolphins for their blubber				
	MAHANADI	**FISHERIES**	shift in bar mouth because of littoral drift, choking of river mouth	Siltation	ZSI study (1985-87); hydrobiological monitoring of lagoon by CDA-WISA, 1999-		
		AGRICULTURE	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment /freshwater reaching the coast	An Action Research Programme was initiated in Mahanadi Delta Irrigation Project		
		MULTIPLE DRIVERS	Deforestation - Mangroves		Task Force, constituted for rapid assessment of the status of mangroves in the State of Orissa after the 1999 super-cyclone, has recommended the establishment of a Mangrove Genetic Resource Centre (MGRC) in Bhitarkanika and identified Devi and Subarnarekha delta in Orissa for mangrove afforestation		

***Table 56**: (continued): Summary of the Scientific Responses for the Various Drivers, Pressures and Impacts on a Catchment, Sub-regional and Regional Scale*

Country	Catchment	Driver	Pressure	Impact	Scientific Response (Scientific judgments and recommendations)		
					Catchment	Sub-regional Scale	Regional Scale
INDIA	**GODAVARI**	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment /freshwater reaching the coast	Improved irrigation systems		
		AQUACULTURE	Land use changes, deforestation	Water quality impairment			
			Deforestation	loss of wetlands/ mangrove areas	Coastal Wetlands: Mangrove Conservation and Management-Project in 1997 by MS Swaminathan Foundation		
	KRISHNA	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment /freshwater reaching the coast	Land, Water and Ecoystems Management of Krishna River Basin and Delta with focus on decision support in water allocation, improved water productivity in agriculture, and combating (deltaic) environmental degradation.		
		AQUACULTURE	Land use changes	Loss of wetlands/ mangrove areas	Integrated multi-trophic aquaculture (IMTA)		
	CAUVERY	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment /freshwater reaching the coast			
		AQUACULTURE	Land use changes	Soil salinization			
				Water quality impairment			

***Table 56**: (continued): Summary of the Scientific Responses for the Various Drivers, Pressures and Impacts on a Catchment, Sub-regional and Regional Scale*

Country	Catchment	Driver	Pressure	Impact	Scientific Response (Scientific judgments and recommendations)		
					Catchment	Sub-regional Scale	Regional Scale
SRI LANKA	**WALAWE BASIN**	**AGRICULTURE**	Dams and water abstraction for agriculture	water quality impairment of lagoon ecosystem	International Water Management Institute (IWMI) study reports		
INDIA	**PAMBA**	**TOURISM**	Waste Disposal	Water quality impairment	CESS: Workshop - create a Pamba River Board		
	MANDOVI - ZUARI	**TOURISM**	Land use change, construction activities	Water Quality impairment	Goa State Council for Science & Technology (GSCST) functioning under the auspices of the Department of Science, Technology & Environment (DST&E), Govt. of Goa, has been actively involved in the promotion of appropriate Science & Technology Projects		
			Disposal of wastes				
		FISHERIES	Overfishing		Studies and reports from National Institute of Oceanography, Goa		
PAKISTAN	**INDUS**	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment /freshwater reaching the coast	National Institute of Oceanography, Karachi, Pakistan, has carried out studies about stresses on the Indus deltaic region and has called for ICZM practices for the delta region; Case studies on economic costs of reduction in wetland water supply in the Indus Delta by IUCN	After initial assessment of the problem during the APN Sediment Flux program a collaborative research program between WHOI and NIO is documenting the quantum of sediment flux since last couple of hundred years	APN and IGCP Mega Delta Programmes are helping by directly involving the coastal scientists of Pakistan in a regional platform to share their experience with international experts.
		VARIOUS DRIVERS	Land use changes	Water quality impairment			
		FISHERIES & AQUACULTURE		Eutrophication			
		VARIOUS DRIVERS	Forests and biodiversity	Soil erosion and sedimentation			

Table 57: Summary of the Policy Responses for the Various Drivers, Pressures and Impacts on a Catchment, Sub-regional and Regional Scale

Country	Catchment	Driver	Pressure	Impact	Policy Response (a deliberate plan of action to guide decisions and achieve rational outcome(s)		
					Catchment	Sub-regional Scale	Regional Scale
INDIA & BANGLADESH	**BRAHMAPUTRA**	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment/ freshwater reaching the coast	Functions of Brahmaputra Board (preparation of master plan for flood management, irrigation, hydropower etc)	MINAS water quality standards, India	
					National Environmental Policy, India	National Environmental Policy, India National Water Policy, Bangladesh	
						Bangladesh National Water Management Plan, 1980	
	GANGES	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment/ freshwater reaching the coast	Regulate discharge at Farakka Barrage		International Ganges River Commission, 1972
		FISHERIES	Use of fishing nets which entangled dolphins	Reduction in species numbers	Wildlife Conservation Strategy 2002		Activities of IUCN, WWF etc
			Unsustainable harvest of dolphins for their blubber				
INDIA	**MAHANADI**	**FISHERIES**	shift in bar mouth because of littoral drift, choking of river mouth	Siltation			
		AGRICULTURE	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment/ freshwater reaching the coast	State Water Policy on the line of National Water Policy, 1987	Transfer of water from Godavari to Krishna under the National River Linking Project	
		MULTIPLE DRIVERS	Deforestation - Mangroves				

Table 57: (continued) Summary of the Policy Responses for the Various Drivers, Pressures and Impacts on a Catchment, Sub-regional and Regional Scale

Country	Catchment	Driver	Pressure	Impact	Policy Response (a deliberate plan of action to guide decisions and achieve rational outcome(s)		
					Catchment	Sub-regional Scale	Regional Scale
INDIA continued	**GODAVARI**	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment/ freshwater reaching the coast		National Water Policy,1987	
		AQUACULTURE	Land use changes, deforestation	Water quality impairment	Aquaculture Authority has the maintenance of ecology as its prime guiding factor (Government of India, 1998)		
			Deforestation	loss of wetlands/ mangrove areas			
	KRISHNA	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment/ freshwater reaching the coast	Policy of low water charges		
					National Water Policy, 2002		
						National Environment Policy (NEP), 2006 for conservation of mangroves in Krishna delta	
					"Polluter Pays" Principle, water quality norms and standards, and market-based regulatory mechanisms.		
		AQUACULTURE	Land use changes	Loss of wetlands/ mangrove areas			
	CAUVERY	**AGRICULTURE**	Dams and water abstraction for agriculture	Water quality impairment	Cauvery Tribunal		
		AQUACULTURE	Land use changes	Soil salinization			
				Water quality impairment			

Table 57: (continued) Summary of the Policy Responses for the Various Drivers, Pressures and Impacts on a Catchment, Sub-regional and Regional Scale

Country	Catchment	Driver	Pressure	Impact	Policy Response (a deliberate plan of action to guide decisions and achieve rational outcome(s)		
					Catchment	Sub-regional Scale	Regional Scale
SRI LANKA	**WALAWE BASIN**	**AGRICULTURE**	Dams and water abstraction for agriculture	Water quality impairment of lagoon ecosystem	A new Water Act and Water Policy is under consideration by the parliament. The Act emphasizes basin management (and organizations) and the definition of water rights for bulk users.		
INDIA	**PAMBA**	**TOURISM**	Waste Disposal	Water quality impairment	Government of Kerala ordering Pamba Action Plan		Included in the National River Conservation Plan (NRCP)
	MANDOVI - ZUARI	**TOURISM**	Land use change, construction activities	Water Quality impairment			
			Disposal of wastes				
		FISHERIES	Overfishing				
PAKISTAN	**INDUS**	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment/ freshwater reaching the coast			
		VARIOUS DRIVERS	Land use changes	Water quality impairment			
		FISHERIES & AQUACULTURE		Eutrophication		National policy and strategy for fisheries and aquaculture development in Pakistan, 2007	
		VARIOUS DRIVERS	Forests and biodiversity	Soil erosion and sedimentation			

***Table 58**: Summary of the Management Responses for the Various Drivers, Pressures and Impacts on a Catchment, Sub-regional and Regional Scale*

Country	Catchment	Driver	Pressure	Impact	Management response (creation of boards/action plans)		
					Catchment	Sub-regional scale	Regional scale
INDIA & BANGLADESH	**BRAHMAPUTRA**	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment/ freshwater reaching the coast	Guidelines and Master Plan provided/ developed by the Brahmaputra Board		
					Setting up of Effluent Treatment Plant (STP)		
INDIA	**GANGES**	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment/ freshwater reaching the coast	Ganga Action Plan	Enhance joint research on environmental risk management in large river basins	
				Reduction in sediments and freshwater reaching coast	Setting up of ETP, STP and methods of safe disposal of wastes	Establish relevant boundary conditions for deltaic dynamics at management scales	
		FISHERIES	Use of fishing nets which entangled dolphins	Reduction in species numbers	Vikramshila Dolphin Sanctuary, Jharkhand	Public awareness campaign for Clean Ganga Plan	
			Unsustainable harvest of dolphins for their blubber		Promote the development of community-based fishing cooperatives (Choudary, 2006)		
	MAHANADI	**FISHERIES**	Shift in bar mouth because of littoral drift, choking of river mouth	Siltation	Chilika Development Authority (1992)		
		AGRICULTURE	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment/ freshwater reaching the coast	Government of Orissa has prepared Delta Development Plan of Mahanadi Delta Command Area in October, 1989 which also includes Drainage Development Plan of Mahanadi Delta Area; Hirakud Command Area Development Authority		

***Table 58**: (continued) Summary of the Management Responses for the Various Drivers, Pressures and Impacts on a Catchment, Sub-regional and Regional Scale*

Country	Catchment	Driver	Pressure	Impact	Management response (creation of boards/action plans)		
					Catchment	Sub-regional scale	Regional scale
INDIA	**MAHANADI (continued)**	**MULTIPLE DRIVERS**	Deforestation - Mangroves		Joint Forest Management	Under Global Environment Facility (GEF) program, a project on conservation and sustainable use of globally significant threatened wetland of India has been approved during the year; Establishment of "Crocodile Sanctuary" in the Mahanadi delta	Management Action Plans for Sundarbans mangroves in West Bengal, Mahanadi delta and Bhitarkanika Sanctuary in Orissa, Pichavaram and Muthupet in Tamil Nadu, Goa and Achra-Ratnagiri in Maharashtra were recommended by the National Committee on Mangroves and Coral Reefs
	GODAVARI	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment/ freshwater reaching the coast	Participatory Irrigation Management: Government of Andhra Pradesh transfers management of all irrigation systems to Farmers organizations in 1996		Transfer water from Godavari to Krishna under the National River Linking Project
		AQUACULTURE	Land use changes, deforestation	Impairment of water quality	Aquaculture Authority was established and a regulatory and institutional framework for the shrimp aquaculture sector has been set up		
			Deforestation	loss of wetlands/ mangrove areas	Participatory activities community-based organizations formed the Eco-Development Committee (EDC) and the Vana Samrakshana Samithi (VSS).		
					A subcommittee called Mangrove Restoration and Management Committee was created to ensure local's participation in the restoration project		

***Table 58**: (continued) Summary of the Management Responses for the Various Drivers, Pressures and Impacts on a Catchment, Sub-regional and Regional Scale*

Country	Catchment	Driver	Pressure	Impact	Management response (creation of boards/action plans)		
					Catchment	Sub-regional scale	Regional scale
INDIA (continued)	**KRISHNA**	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment/ freshwater reaching the coast	Watershed-Based Approach to Resource Management; Central government river authority of India 1996; Integrated aquatic ecosystem management at Catchment level; River Basin Management at regional scale Allocative water management; Andhra Pradesh Irrigation Project	Telugu Ganga Project, 1983 to provide drinking water to Chennai city in Tamil Nadu; Management Information System for allocative water management	
		AQUACULTURE	Land use changes	Loss of wetlands/ mangrove areas	Aquaculture Authority		
	CAUVERY	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment/ freshwater reaching the coast	Cauvery River Authority established in 2001		Central Government River Authority of India 1996
		AQUACULTURE	Land use changes	Soil salinization	Aquaculture Authority of India		
				Water quality impairment	Tamil Nadu Pollution Control Board		
SRI LANKA	**WALAWE BASIN**	**AGRICULTURE**	Dams and water abstraction for agriculture	Water quality impairment of lagoon ecosystem	The Uda Walawe Scheme is managed by the Mahawelli Authority of Sri Lanka; medium schemes by the Irrigation Department; minor tanks and anicuts[1] by Agrarian Services and farmers. The Uda Walawe Scheme is managed by the Mahawelli Authority of Sri Lanka; medium schemes by the Irrigation Department; minor tanks and anicuts by Agrarian Services and farmers. There is no basin level organization at the moment.		

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[1] In Tamil, an anicut is a dam or mole made in the course of a stream for the purpose of regulating the flow of a system of irrigation

***Table 58**: (continued) Summary of the Management Responses for the Various Drivers, Pressures and Impacts on a Catchment, Sub-regional and Regional Scale*

Country	Catchment	Driver	Pressure	Impact	Management response (creation of boards/action plans)		
					Catchment	Sub-regional scale	Regional scale
INDIA	**PAMBA**	**TOURISM**	Waste Disposal	Water quality impairment	Kerala Water Authority to implement Pamba Action Plan		
	MANDOVI - ZUARI	**TOURISM**	Land use change, construction activities	Water Quality impairment	The Goa State Coastal Zone Management Authority (GSCZMA)		
			Disposal of wastes		Monitoring by the State Pollution Control Board		
		FISHERIES	Overfishing				
PAKISTAN & INDIA	**INDUS**	**AGRICULTURE**	Dams and water abstraction for agriculture	Erosion/ Siltation due to change in sediment/ freshwater reaching the coast	GoP is trying to regulate the Indus water discharge downstream Kotri Barrage in manner that the habitants of the lower deltaic area can have sustainable supply of water for domestic and agricultural use and also to avoid loss of fresh water to the sea.	GoP has established an independent commission comprising of experts who are trying to determine the realistic amount of sediment and water flux required for sustaining the delta and consequently its ecology.	Indus Basin Project to implement provisions of the Indus Water Treaty
		VARIOUS DRIVERS	Land use changes	Water quality impairment		ESCAP, 1996. Coastal Environmental Management Plan for Pakistan, Report No. ST/ESCAP/1360, United Nations Economic and Social Commission for Asia and the Pacific, Thailand, Bangkok	
		FISHERIES & AQUACULTURE		Eutrophication			
		VARIOUS DRIVERS	Forests and biodiversity	Soil erosion and sedimentation			

***Table 59**: Summary of the Legislative Responses for the Various Drivers, Pressures and Impacts on a Catchment, Sub-regional and Regional Scale*

Country	Catchment	Driver	Pressure	Impact	Legislation / International Instruments (All acts)			Ministry/ Agency involved	Reference/ Weblink
					Catchment	Sub-regional Scale	Regional Scale		
INDIA & BANGLADESH	**BRAHMAPUTRA**	**AGRICULTURE**	Dams / water abstraction for agriculture	Erosion/ Siltation due to change in sediment /freshwater reaching the coast	Brahmaputra Board, Act, 1980 (46 of 1980)		Agenda 21 of chapter 18 of Rio conference (1992) on environment and Development emphasized the need for IWRM	Ministry of Water Resources, Brahmaputra Board	http://brahmaputraboard.gov.in/
				Impairment of water quality		Environment Protection Act, 1986; Prevention and Control of Water Pollution Act, 1974		Department of Environment, Government of Assam, Assam State Pollution Control Board; Ministry of Environment and Forests, Central Pollution Control Board	www.cpcb.nic.in
					Embankment Act, Bangladesh			Central Water Commission	http://wrmin.nic.in, http://cwc.gov.in/
	GANGES	**AGRICULTURE**	Dams / water abstraction for agriculture	Erosion/ Siltation due to change in sediment /freshwater reaching the coast	Farakka Act 1974; Ganga Cleaning Act 1985			Ministry of Water Resources	www.cpcb.nic.in
				Reduction in sediments and freshwater reaching coast	Between the government of the Republic of India and the government of the People's Republic of Bangladesh on Sharing of the Ganga/Ganges Waters at Farakka" signed on December 12, 1996				
		FISHERIES	Use of fishing nets which entangled dolphins	Reduction in species numbers	Patna High Court Directive to government to protect endangered species. Promote the development of community-based fishing cooperatives; West Bengal Marine Fishing Regulation Act 1993	Indian Wildlife Protection Act 1972	Convention on International Trade in Endangered Species of Wild Fauna & Flora 1973		Shiv Charan Singh, The Telegraph, 28.02.2005: http://www.telegraphindia.com/1050228/asp/jharkhand/story_4432586.asp
			Unsustainable harvest of dolphins for their blubber						Choudhary et al., 2006 Fauna and Flora International

***Table 59**: (continued) Summary of the Legislative Responses for the Various Drivers, Pressures and Impacts on a Catchment, Sub-regional and Regional Scale*

Country	Catchment	Driver	Pressure	Impact	Legislation / International Instruments (All acts)			Ministry/ Agency involved	Reference/ Weblink
					Catchment	Sub-regional Scale	Regional Scale		
INDIA	**MAHANADI**	**FISHERIES**	shift in bar mouth because of littoral drift, choking of river mouth	Siltation	Fishing in Chilika (Regulation) Bill 2002 Orissa Marine Fishing Regulation Act 1983		Chilika declared Ramsar site in 1981; Wildlife protection Act 1972	Ministry of Environment and Forests	Sinha, R.K (2004): Bait and Watch: Popularization of alternatives to dolphin oil among fishermen for the conservation of the Ganges River Dolphin in Bihar. Wildlife Trust of India, New Delhi.
		AGRICULTURE	Dams / water abstraction for agriculture	Erosion/ Siltation due to change in sediment /freshwater reaching the coast	National Waterway (Talcher-Dhamra Stretch of Rivers, Geonkhali-Charbatia Stretch of East Coast Canal, Charbatia-Dhamra Stretch of Matai River & Mahanadi Delta Rivers) Act 2008			Ministry of Environment and Forests, Coastal Aquaculture Authority	http://planningcommission.nic.in/reports/sereport/ser/irmed/irm_ch2.pdf; http://sambalpur.nic.in/cada.htm
		AQUACULTURE	Land use change, deforestation of mangroves	Water quality impairment, loss of biodiversity		Coastal Aquaculture Authority Act 2005; Coastal Regulation Zone Notification 1991		Ministry of Environment and Forests, Coastal Aquaculture Authority	www.envfor.nic.in; http://aquaculture.tn.nic.in
		MULTIPLE DRIVERS	Deforestation - Mangroves				Indian Forests Act 1927, Biodiversity Act 2002	Ministry of Environment and Forests	http://144.16.72.182/vigyan/annual/envforest.html
	GODAVARI	**AGRICULTURE**	Dams / water abstraction for agriculture	Erosion/ Siltation due to change in sediment /freshwater reaching the coast		AP Farmer's Management of Irrigation Systems Act 1997			
		AQUACULTURE	Land use changes, deforestation	Water quality impairment		Coastal Aquaculture Authority Act 2005; Coastal Regulation Zone Notification 1991		Ministry of Environment and Forests, Coastal Aquaculture Authority	www.envfor.nic.in; http://aquaculture.tn.nic.in
			Deforestation	loss of wetlands/ mangrove areas			Indian Forests Act 1927, Biodiversity Act 2002		

***Table 59**: (continued) Summary of the Legislative Responses for the Various Drivers, Pressures and Impacts on a Catchment, Sub-regional and Regional Scale*

Country	Catchment	Driver	Pressure	Impact	Legislation / International Instruments (All acts)			Ministry/ Agency involved	Reference/ Weblink
					Catchment	Sub-regional Scale	Regional Scale		
INDIA (continued)	**KRISHNA**	**AGRICULTURE**	Dams / water abstraction for agriculture	Erosion/ Siltation due to change in sediment /freshwater reaching the coast				Ministry of Water Resources	http://library.wur.nl/way/bestanden/clc/1891405.pdf
									Rajinikanth, R. and Ramachandra, TV. (2000). Effective wetland management using GIS. In: Proceedings of Geoinformatis 2000, Nov 17-18, 2000, PSG College of Technology, Coimbatore, pp 262-275.
		AQUACULTURE	Land use changes	Loss of wetlands/ mangrove areas			Coastal Aquaculture Authority Act 2005; Coastal Regulation Zone Notification 1991, Biodiversity Act 2002	Ministry of Environment and Forests, Coastal Aquaculture Authority	
	CAUVERY	**AGRICULTURE**	Dams / water abstraction for agriculture	Erosion/ Siltation due to change in sediment /freshwater reaching the coast				Ministry of Water Resources	
		AQUACULTURE	Land use changes	Soil salinization		CRZ Notification 1991; Aquaculture Act	Coastal Aquaculture Authority Act 2005; Coastal Regulation Zone Notification 1991	Ministry of Environment and Forests, Coastal Aquaculture Authority	
				Water quality impairment		EPA 1986 + The Water Prevention and Control of Pollution Act 1974	Environment Protection Act 1986; Prevention and Control of Water Pollution Act 1974	Ministry of Environment and Forests, Central Pollution Control Board, Tamil Nadu State Pollution Control Board	

***Table 59**: (continued) Summary of the Legislative Responses for the Various Drivers, Pressures and Impacts on a Catchment, Sub-regional and Regional Scale*

Country	Catchment	Driver	Pressure	Impact	Legislation / International Instruments (All acts)			Ministry/ Agency involved	Reference/ Weblink
					Catchment	Sub-regional Scale	Regional Scale		
INDIA (continued)	**PAMBA**	**TOURISM**	Waste Disposal	Water quality impairment			Environment Protection Act 1986; Prevention and Control of Water Pollution Act 1974	Kerala State Pollution Control Board	http://www.savepampa.org/pps/Pampa_Action_Plan.htm; German experts moot Pamba River Board, The Hindu 28 April, 2004; http://www.thehindu.com/2004/04/28/stories/2004042813490300.htm
	MANDOVI - ZUARI	**TOURISM**	Land use change, construction activities	Water Quality impairment			Coastal Regulation Zone Notification, 1991	Goa State Pollution Control Board, Central Pollution Control Board, Ministry of Environment and Forests	
			Disposal of wastes				Environment Protection Act 1986; Prevention and Control of Water Pollution Act 1974		
		FISHERIES	Overfishing		Goa, Daman and Diu Marine Fishing Regulation Act, 1980; Goa, Daman and Diu Marine Fishing Regulation Rules, 1982			Ministry of Agriculture	Ansari, Z.A, Achuthan-kutty, C.T. & Dalai, S.G.: Overexploitation of fishery resources with particular reference to Goa. http://drs.nio.org/drs/bitstream/2264/201/1/MD_GEChange_2006_285.pdf

***Table 59**: (continued) Summary of the Legislative Responses for the Various Drivers, Pressures and Impacts on a Catchment, Sub-regional and Regional Scale*

Country	Catchment	Driver	Pressure	Impact	Legislation / International Instruments (All acts)			Ministry/ Agency involved	Reference/ Weblink
					Catchment	Sub-regional Scale	Regional Scale		
PAKISTAN & INDIA	**INDUS**	**AGRICULTURE**	Dams / water abstraction for agriculture	Erosion/ Siltation due to change in sediment /freshwater reaching the coast	Irrigation and Drainage Management Transfer Agreement between the Canal Area Water Board and the Sindh Irrigation and Drainage Authority Pakistan (Sindh) Sindh Irrigation and Drainage Authority Act 1997; North-West Frontier Province Irrigation and Drainage Authority Act (Act No. 5 of 1997); Punjab Irrigation and Drainage Authority Act 1997 (No. XI of 1997); Pakistan Water and Power Development Authority Act 1958 (No. XXXI of 1958). Sindh Irrigation and Drainage Authority Rules (Notification No. 20 of 2000)		Indus Water Treaty 1960	Ministry of Water Resources, Government of India	www.wrrmin.nic.in

***Table 59**: (continued) Summary of the Legislative Responses for the Various Drivers, Pressures and Impacts on a Catchment, Sub-regional and Regional Scale*

Country	Catchment	Driver	Pressure	Impact	Legislation / International Instruments (All acts)			Ministry/ Agency involved	Reference/ Weblink
					Catchment	Sub-regional Scale	Regional Scale		
continued	**INDUS**	**VARIOUS DRIVERS**	Land use changes	Water quality impairment	Punjab Land Utilization Authority Ordinance, 1981; Land Reforms Act, 1977. ;	Pakistan Environmental Protection Act, 1997		Ministry of Environment, Forestry and Wildlife	
		FISHERIES & AQUACULTURE		Eutrophication	West Pakistan Fisheries Ordinance, 1961.; Baluchistan Sea Fisheries Ordinance, 1971 (IX of 1971).; Exclusive Fishery Zone (Regulation of Fishing) Act, 1975.; Northern Areas Fisheries Act, 1975.; Sind Fisheries Ordinance, 1980 (Sind Ordinance No. III of 1980)Part I.; Exclusive Fishery Zone (Regulation of Fishing)(Amendment)Ordinance, 1983(Ordinance No. XXIX of 1983)	Fisheries Act (No. 4 of 1897)		Ministry of Food, Agriculture and Livestock, Government of Pakistan, Islamabad	http://www.pakboi.gov.pk/pdf/Fisheries_Policy.pdf
		VARIOUS DRIVERS	Forests and biodiversity	Soil erosion and sedimentation	Forest Act 1927; North-West Frontier Province Management of Protected Forest Rules 1975; North-West Frontier Province Wildlife (Protection, Preservation, Conservation and Management) Act 1975; Punjab Wildlife (Protection, Preservation, Conservation and Management) Act 1974.				

V. CONCLUSIONS

1 Assessment of Impacts by Land-based Drivers

Water flows from the mountains to valleys through rivers over land and groundwater into the sea. However, the water flow depends on the meteorology, climate, geography, geology, economics and politics of each country. The status of each country is intrinsically tied to its history, development and progression of governments over the last several hundred years. Within the context of biogeochemical fluxes from the land to the sea, each country has made decisions about how the lands are managed. The consequence of these decisions has left some countries wealthy and prosperous and others in poverty. Biogeochemical fluxes reflect these decisions to some extent and are of particular interest to LOICZ. Although they flow from land to sea, there are a number of cases where the transport direction is reversed. Factors that can affect the movement of organic and inorganic nutrients into the coastal zone and their subsequent fates are listed in Table 60.

***Table 60**: Fluxes from land to sea and from sea to land*

Factors	Land to Sea	Sea to Land
Natural	• River discharge • Groundwater outflow • Riverine Sediment transport • Nutrient discharge • Humic and organic substances • Storm debris • Earthquake debris • Volcanic material	• Energy and material from hurricanes • Cold water and nutrients from upwelling • Wave actions • Salt and salt aerosols • Saline water intrusion e.g., tsunami, tidal bore, tidal waves
Anthropogenic	• Sediment (increase from land use and decrease from dams) • Nutrients and organic matter from agriculture and sewage • Coliform bacteria and pathogens • Herbicides and pesticides • Metals • Oil and chemicals	• Oil and chemical spills • Chronic input of oil and chemicals • Sewage from ships • Ballast water with alien species • Debris from ships • Brackish infiltrations of groundwater reservoirs by water extraction

Perhaps the most important feature of the tropical landscape in coastal ecosystems is how interdependent the different components are in particular, but not exclusively in a downstream direction. Food production and ecosystem-based management have been described as a series of nature-integrated systems that are managed to provide sequential filtration of sediment and nutrients from the land to the sea in order to maintain clear water for the coral reefs.

Boto & Robertson [1] have concluded that mangrove forests would generally benefit from increase in inorganic nutrients and sediments that have a high capacity to denitrify since one hectare of forest could process sustained inputs of 30 kg of N and 30 kg of P annually. In South Asia, mangroves are the first coastal systems to be impacted by natural and anthropogenic factors. The sea-grasses spread in the lower tidal and shallow sub-tidal zones are also vulnerable to eutrophication. The deterioration of sea-grasses allows the nutrients to flow into the coral reefs and help in the algal growth that smother the coral reefs. Large expanses of coral reefs in South Asia are damaged due to the nutrient input and mining for extraction of calcium carbonate (limestone). Major drivers/pressures of degradation of these coastal ecosystems are growing population, discharges of urban sewage and industrial wastes, and over-extraction of natural resources. A sustainable management approach to the coastal resources, i.e., mainly mangroves, sea-grasses and coral reefs, in the South Asia region is required. Based on an understanding of different land-based activities responsible for causing pollution of coastal waters, the priority issues to be addressed in South Asia can be broadly listed as follows:

- Discharge of untreated sewage (water quality impairment due to organic constituents)
- Agricultural run-off (nutrient and pesticide residues)
- Wastewater from coastal aquaculture (organic loading, nutrients and antibiotic residues)
- Occasional discharge of industrial wastewater (metals, toxic compounds)
- Salt water intrusion into coastal aquifers.

The socioeconomic driving forces influencing most of the priority issues seem to be rapid urbanization of coastal areas, industrial development in these areas due to easy access to port facilities, increase in tourism activities in some pockets and related construction/development activities, port activities and coastal aquaculture. Intrusion of saline water is also a major issue in some of the South Asian countries as increasing exploitation of groundwater in these areas is causing salt water ingress.

2 Human Impacts on the Marine Environment in South Asia

The anthropogenic activities in the coastal areas affect the quality of coastal waters and subsequently the health of the coastal ecosystem. The importance of the coastal regions for South Asia can be gauged from the fact that in this region more than 250 million people live within a distance of 50 km from the coast. Hence the coastal zone as a life supporting social-ecological system supports almost one Fourth of the population. According to the Central Pollution Control Board India [2], 120 class I cities and class II towns are located around the Indian coast. These cities are characterized by high and dense populations (>100,000 in class I, >50,000 in class II). Three of India's metropolitan cities are on the coast: Chennai, Mumbai and Kolkata. In South Asia, the anthropogenic pressure on the coastal waters is mainly due to the following activities:

- Rapidly growing population in coastal areas – unresponsive demographic and settlement policies leading to unregulated and ill-planned urbanization – causing problems of sanitation, wastewater discharge and solid waste disposal
- Rapid rate of economic development leading to development of industries, tourism activities, off shore oil exploration and other developmental activities in coastal areas
- Lack of integration of environmental concerns in development and spatial planning
- Unsustainable agricultural activities using harmful chemicals indiscreetly leading to harmful run-off
- Unsustainable aquaculture practices leading to discharge of untreated wastewater
- Poor management of rivers and their conservation programs

- Large volumes of petroleum products being transported through the coastal zone representing high potential risks for marine contamination.

Originally, many coastal towns have emerged favoring trade, communication and availability of coastal/marine resources. Major industries have been established in the coastal areas because of water availability, international trading facilities, and for power plants and chemical industries.

In the present pattern of global urbanization, the saliency of Asia is conspicuous by its huge urban population and the largest number of mega-cities. Of the world's 28 largest cities by 2000, 16 were located in Asia. Of these 16 Asian cities, all except four are located on the coast[3]. Asia's coastal cities are faced with a variety of environmental risks. Coastal pollution is widespread in all its sub-regions. Sewage treatment is an exception rather than the rule. All of Bangladesh's sewage finds its way into the sea, and the situation is only marginally better in India and Pakistan. Mumbai, for instance, discharges yearly 365 million tons of untreated sewage and municipal wastes into the sea. Nearly all near-shore waters along the urbanized coastline in South Asia are polluted with high bacteria counts, making seafood caught unfit for human consumption[4].

A survey by UNEP in India has revealed that the concentration of population along the coasts was about 230 per km and is much higher than in the hinterland. Growth of small fishing hamlets into large towns is the primary reason for this increase in coastal population. This led to the reclamation of low lying coastal areas for construction of factories, housing complexes, offices etc[5]. Around 10-15 % of the coastal population of India depends on fisheries for livelihood. The major threats to the Indian coastline are development of industries in the guise of development of backward areas where employment is limited to only traditional activities such as agriculture, aquaculture or locally available resources. These developments have created a multitude of problems ranging from increased urbanization and greater pressure on available resources like freshwater and fisheries to pollution from sewage and industrial effluents[6].

The tremendous population growth in South Asia in general and also in its coastal cities has degraded the water quality and worsening more and more with time. The increase in population has undermined rational coastal management. The numerous disasters impacting coastal areas in the last two or three decades are clearly indicative of the need for coastal management. Governments, international and national non-governmental organizations, universities and environmentalists have realized the need for the sustainable development of the environment by preserving what is remaining and repairing what is damaged.

3 Final Remarks

Worldwide, coastal zones and their recourses are under pressure. Caused by both natural and anthropogenic factors, South Asia is a key example. Various coastal environmental regulations exist that have been strengthened locally, nationally and globally. Yet, the problems that originate more distant from the coast within river catchment basins have not been adequately addressed. This doesn't only apply to South Asia but reflects a rather global phenomenon. There is still a lack of joined-up thinking in the responsible bodies dealing with processes, land use decisions and water management along the catchment by including a view on potential effects on the coastal parts of this water continuum. The LOICZ Basins approach, which was initiated in Latin America in 2001, has developed a global evaluation of coastal change issues in reviewing the coastal systems as the receiving body of land-based changes of material fluxes and resulting pressures and state changes. It has adopted the DPSIR framework to integrate the results of natural and social sciences with feedback to and from policy and management.

This report has dealt with the impact of human society on the material transport to the coast, including water, sediments, nutrients, heavy metals and man-made chemicals. The DPSIR matrices have been prepared with the help of expert information that derived from workshop presentations and discussions focusing on different drivers, pressures, state changes and impacts on the rivers down to the coasts. The overview of each river basin was evaluated in order to provide a regional and local scale analysis on which to base a full regional and sub-continental up-scaling assessment. Coastal issues and associated drivers were reviewed at different scales, beginning from the upper catchment to the sub-regional and regional levels, and ranked according to the category based on present situation of the impacts and existing data.

Within this standardized LOICZ basins study, fifteen catchment systems have been analyzed for the South Asia region and the individual assessments were scaled to coherent sub-continent levels. Fig. 34 visualizes the key findings and expert ranking plus trend expectations as expressed in the various workshop sessions and distilled from the huge literature reviewed prior and subsequent to the conference. One conclusion is that the immediate influence from land-based drivers and resulting flows is more often observed in small to medium catchments with high levels of socioeconomic activity, limited dilution capacity, flushing run-off and at short distances to the coast. In these smaller systems, changes in land cover and use need much shorter time-frames to reflect in coastal change and many of them exhibit more visible impacts than in large catchments where the buffering capacity against land-based change is higher simply as a function of catchment size. Thus, this assessment likewise with the first global synthesis published by LOICZ in 2005 reiterates that the investigation of small and medium catchments needs to be a priority not just for LOICZ as a scientific project but also to inform improved management.

5 References

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***Fig. 34a**: South Asia Sub-regional Synthesis and Expert Typology of River- Catchment-Coast (Sub-regions 1 and 2)*

SUBREGION 1: BENGAL BASIN OF INDIA AND BANGLADESH

Coastal Impact	Driver	Pressure	Pressure Status	Trend Expectation
Erosion	Agriculture	Water abstraction for irrigation; Dams	8	⇑
Water Quality Impairment	Urbanization/ Population pressure	Disposal of wastes	8	⇑
	Agriculture			
	Industrialization			
Siltation	Land use changes	Upstream erosion	7	⇑
	Episodic natural events	Disposal of wastes		
Loss of biodiversity/ habitat	Agriculture	Land use changes (clearing mangroves, encroachment of wetlands)	7	⇑
	Aquaculture			

SUB REGION 2: PENINSULAR RIVERS OF INDIA AND SRI LANKA

Coastal Impact	Driver	Pressure	Pressure Status	Trend Expectation
Water quality impairment	Urbanization / population pressure	Waste disposal	8	⇑
	Industrialization	Use of fertilizers and pesticides		
	Agriculture			
	Aquaculture			
Saline intrusion into groundwater	Agriculture	Withdrawal of groundwater	8	⇑
	Urbanization / Population pressure			
	Industrialization			
Loss of biodiversity/habitat	Urbanization/ population pressure	Land use changes	7	⇑
	Aquaculture	Waste disposal		
	Agriculture (water abstraction for irrigation, dams)	Insufficient freshwater reaching coast		

Fig. 34b: South Asia Sub-regional Synthesis and Expert Typology of River-Catchment-Coast (Sub-regions 5 and 3/4)

SUB REGION 5: INDUS DELTA OF PAKISTAN

Coastal Impact	Driver	Pressure	Pressure Status	Trend Expectation
Loss of habitat / biodiversity	Agriculture (water abstraction for irrigation, dams)	Insufficient water and sediments reaching coast	8	⇑
Erosion	Agriculture	Water abstraction for irrigation; Dams	7	⇑
Salinity intrusion	Agriculture: water abstraction for agriculture	Insufficient water reaching coast	4	⇑
Reduction in fish catch	Fishing	Overfishing Loss of mangrove habitat	4	⇑

SUB REGION 3 & 4: INFLOW OF SMALL RIVERS INTO THE ARABIAN SEA

Coastal Impact	Driver	Pressure	Pressure Status	Trend Expectation
Loss of habitat / biodiversity	Tourism Agriculture Aquaculture	Land use changes	8	⇑
Erosion	Agriculture (water abstraction for irrigation)	Insufficient water and sediments reaching coast	7	⇑
	Sand mining	Urbanization / Population pressure (building requirements)		
Water quality impairment	Tourism	Disposal of wastes	4	⇑
Decline in fishery	Fishing	Overfishing Water quality impairment Habitat loss	3	⇑