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NUTRIENT LOADING AND EUTROPHICATION OF COASTAL WATERS OF THE SOUTH ASIAN SEAS – A SCOPING STUDY

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Foreword

Land-based nutrients such as nitrogen and phosphorus inputs to coastal systems in South Asia have markedly increased in recent times due to increasing demand for food and energy production to support the growing population of over one billion people. The resulting nutrient enrichment has contributed to coastal eutrophication, degradation of water quality and coastal habitats, and increases in hypoxic waters, which in turn has undermined the services and livelihoods supported by the biologically rich marine and coastal ecosystems.

There is a critical need to understand the quantitative links between anthropogenic activities in watersheds, nutrient inputs to coastal systems, and coastal ecosystem effects. The challenge faced by South Asia is to optimize the use of nutrients to realize food security while minimizing negative impacts on the environment and human health. As a first step in addressing this challenging issue, a project titled “Controlling Nutrient Loading and Eutrophication of Coastal Waters of the South Asian Seas Region” was initiated by SACEP/SASP in collaboration with the GEF-funded Bay of Bengal Large Marine Ecosystem Project of FAO, with technical support from UNEP-GPA. The main outcome of the project was the initiation of a process in developing regional level policy dialogue to address the presently unsustainable nutrient management practices to reduce environmental impacts. This activity was presented at the 5th Inter-Ministerial Meeting of the South Asian Seas Programme (SASP) held in Islamabad, Pakistan on 5th December 2013 and received approval.

A scoping study was undertaken by the Indian Nitrogen Group on the nutrient pollution of the coastal and marine systems in the five maritime countries of South Asia: Bangladesh, India, Maldives, Pakistan and Sri Lanka. A two-day regional workshop was organized in May 2014 to validate the scoping study as well as to share experiences and lessons learned in addressing the issue. The Report highlights that agricultural nutrient loading to coastal waters is primarily during rains/floods, whereas sewage is the single main source of pollution of coastal waters from the land. The most crucial factors of governance that contribute to nutrient pollution across the region are inadequate emphasis on nutrient use efficiencies and environmental standards in agriculture, poor sewage management and inadequate recognition that some pollutants are nutrients essential for food production.

The situation merits strong national and regional interventions for thorough assessment to understand the extent and scale of the problem as well as to define remedial actions that could be pursued at various levels. I am confident that SACEP/SASP together with our partner organizations will be able to take the correct remedial measures to address the key issues highlighted.

Mr. S.M.D.P.A. Jayatilake

Director General, SACEP

Executive summary

Executive Summary and recommendations

The South Asia Cooperative Environment Programme (SACEP) together with the United Nations Environment Programme –Global Programme of Action (UNEP-GPA) and the Bay of Bengal Large Marine Ecosystem (BOBLME) Project developed the project concept “Controlling Nutrient Loading and eutrophication of Coastal Waters of the South Asian Seas Region” with the main objective of reducing and controlling nutrient loading into the coastal waters of the South Asian Seas Region through development of a regional action plan and policy forum/framework.

A first step in this activity was to understand the spatial and temporal complexity of nutrient loading and coastal eutrophication / hypoxia, including the functioning of ecosystems and socioeconomic systems. In 2013, BOBLME commissioned, through SACEP, the Indian Nitrogen Group (ING), a network of nitrogen researchers and experts, to carry out this scoping study. The desk review seeks to highlight important trends in eutrophication, sources of nutrients and current policy and legislation in various South Asian countries. The study covers the maritime countries of Bangladesh, India, Maldives, Pakistan and Sri Lanka and has been submitted to validation by a range of technical experts from the countries at a validation workshop held in Colombo, Sri Lanka in May 2014

The five South Asian maritime countries namely, Bangladesh, India, Maldives, Pakistan and Sri Lanka are home to about 22% of the global population, with only 4.8% of the world’s land mass, 14% of the global arable land, 2.73% of the world forest area and 4% of the world’s coastline. For this region like many other regions of the world, availability and use of nutrients is the key to ensure food security, hence it cannot afford to lose precious nutrients required for food production as pollutants to the environment. Notwithstanding the above, the coastal habitats of South Asia are at a high risk of eutrophication from nutrient enrichment due to leakages from agriculture, aquaculture, sewage, industrial effluents, marine trade and transport.

This desk study examined the problem of eutrophication of coastal waters for the maritime countries of South Asia with two seas separated by the Indian landmass.[1] With over 94% of arable land already under cultivation, food production in both rain-fed agriculture and irrigated areas depends on the use of fertilizers and nutrients, at a varying scale, such as compounds of reactive nitrogen (N) and phosphorus (P), which often leak into the environment from cropping, aquaculture and livestock systems. Sediment transport through river systems and sediment upwelling from the ocean surface also results in the release of nutrients into the ocean waters. Nutrients are also lost through sewage in densely populated areas along the major watercourses, where sewage treatment is mostly unavailable and/or inadequate, except in a few large cities and towns. Increasing contribution of reactive nitrogen compounds from the burning of fossil fuels in power generation and transport are also of concern. Together, they adversely affect the soil, water and air quality, health, biodiversity, ecosystem services including aquatic, estuarine, coastal and marine ecosystems and also contribute to processes leading to climate change.

Bangladesh, with a coastline of 734 km generates 600 tons of waste per day from its shrimp culture alone with mean levels of nutrients at 108.78 mg/l for $CaCO_3$, 0.526 mg/l for NH_4^+ -N, 3.075 wt% for organic carbon, 7.00 mg/l for PO_4-P and 5.57 mg/l for NO_3-N. In addition, a huge amount of pollutants released from its 8,542 industrial units contains 11-22 μg/kg dissolved or dispersed hydrocarbons or particulate petroleum residues in the surface water and 14-23 μg/kg in subsurface

[1] South Asia is also oceanographically significant, with two seas of opposite circulation physically separated by the Indian peninsula. The Bay of Bengal maintains a clockwise circulation of major currents during both the northeast and southwest monsoons while in the Arabian Sea it reverses with surface water masses circulating counter clockwise in the northeast monsoon and clockwise during the southwest monsoon.

water. India, with the longest coastline of 5,423 km contributes around 50 billion litres of industrial effluents, 30 billion litres of sewage, 5 million tons of fertilizer residues, 3,500 tons of petroleum hydrocarbons and 0.2 million tons of mining rejects, dredged spoils and sand extractions. In Maldives with 26 coral atolls, contamination from direct disposal of sewage wastes from tourist trade constitutes the major source of pollution, coupled with the global traffic of petroleum transport along the sea routes. Pakistan, with about 990 km long coastline contributes to coastal pollution mostly through direct discharge of industrial effluents and domestic sewage in the ratio of 60:40. In the Karachi coast alone, an estimated BOD load of >1,500 tons/day is added into sea by these industries in addition to inorganic pollutants. Discharges of 130,000 tons of solid nitrogen, 160,000 tons of organic matter, 800 tons of nitrogen compounds, 90 tons of phosphate compounds and 12,000 tons of suspended solid every year, is encountered in Manora Channel in the Karachi coast. Further, being on the gateway of Persian Gulf, transport of crude oil constitutes other major source of coastal pollution in Pakistan. Sri Lanka, an island nation with 1,625 km coastline with agriculture and aquaculture as the cornerstones of the country’s economy, pollution of coastal waters from agrochemicals contributes the major share with nitrate-N reaching 0.11-5.7 mg/l and phosphate at 0.11-0.78 mg/l in coastal aquifers. Shrimp farms also release effluents with high levels of suspended solids (200-600 mg/l) and high BOD levels (60-180 mg/l).

Signs of degradation of aquatic, estuarine, coastal and marine ecosystems due to nutrient loading are evident at various locations in South Asia, with several reports on eutrophic zones due to excessive growth of algae and fish kills due to hypoxia. Estuarine and coastal systems in South Asia are N-limited and N loading through upwelling, sediment transport and sediment release can trigger algal blooms and eutrophication. Some of the estuaries, especially along the Indian east coast, are phosphorus limited and are adversely affected by P loading. The Western side of the Indian peninsula is already prone to seasonal development of natural hypoxic zones, whereas the East coast is relatively less prone to hypoxia. Additionally the hydro-dynamics of the region (see footnote 1) often makes the situation complex and at times even invisible. Agricultural nutrient loading to coastal waters is primarily during rains/floods, whereas sewage is the single main source of pollution of coastal waters from the land. Nutrient leakage from sediment transport and upwelling, fisheries, aquaculture and livestock farming is also high, especially in areas of intensive aqua-farming.

Thus, while the sources of nutrient pollution and their degree of loading as well as the data quality and availability vary at different locations, there are clear overall indications of the effects of nutrient pollution throughout South Asia and a few of them could be of transboundary in nature. All the coastal countries of the region are signatories to various international treaties and are in agreement on implementing the international standards of coastal water management. They have institutional mechanisms for pollution control at multiple levels (central/state/local) but their success is limited by the level of enforcement. However, the most crucial factors of governance that contribute to nutrient pollution across the region are inadequate emphasis on nutrient use efficiencies and environmental standards in agriculture, poor sewage management and inadequate recognition that some pollutants are nutrients essential for food production.

The situation merits strong national and regional interventions for thorough assessment to understand the extent and scale of the problem as well as to define remedial actions that could be pursued at various levels. Some key recommendations are proposed below, based on an analysis of primary and secondary literatures as well as gray materials available to the study team and previous policy recommendations made by interregional committees.

1.1 Policy options

Effective responses to tackle the problem of nutrient pollution requires framing specific policies/programs designed to recover and recycle nutrients as well as enhance nutrient use efficiencies,. Such targets need simultaneous consideration of social, economic and environmental concerns, the bedrock of sustainable development. The following policy options could be considered to combat nutrient pollution of aquatic, coastal and marine environment:

1. Strict adherence to laws and policies related to coastal ecology.
2. Effective river conservation program ensuring direct linkage to coastal habitat conservation.
3. Develop quality standards for coastal waters including introduction of uniform standard for primary water quality criteria for the coastal waters.
4. Managing pollution sources on land including capture and recycling of the nutrients emanating from agriculture, aquaculture, poultry and livestock farming etc. to minimize nutrient leakages throughout the food chain. They should be enforced and monitored periodically through a joint task force comprising relevant scientific, administrative and civil society stakeholders.
5. Develop national and sub-regional policies for conservation, protection and sustainable policies for conservation, protection and sustainable development of oceanic and marine resources through a South Asian level intergovernmental working group/task force with governmental and civil society representatives. This may work within, or in consonance with the existing intergovernmental processes, including the UNEP-GPA, SAARC, and SACEP and other ongoing initiatives such as the BOBLME project etc. and build on them for stronger regional cooperation on nutrient management.

1.2 Recommendations

1. Nutrients such as Nitrogen and Phosphorus that are necessary for food production should be retained or recycled as they become pollutants if lost to the environment. The existing policies and practices of agriculture/aquaculture, sanitation, industry and environment do not sufficiently emphasize nutrient efficiencies and sustainable nutrient management to prevent nutrient pollution and eutrophication of aquatic and coastal ecosystems
2. The available quantitative information on nutrient losses from various human activities and their accumulation in the coastal zones of South Asia is very limited. This calls for detailed studies with actual long term measurements and simulation of nutrient pollution from source to sink (land to sea) for informed decision-making
3. Systematic studies to quantify the sources, flows, fate and extent of current industrial, agricultural and municipal effluents and the nutrients they contribute to water bodies and their impacts on aquatic life, fishing as well as human health.
4. Installation of information technology based effective mechanisms for exchange and sharing of data on the nutrient pollution status in different coastal regions of South Asia between various stakeholders including governments and non-governmental and interregional agencies.
5. Capacity building for sustainable fishing and aquaculture with integrated resource management to protect them from environmental degradation including bottom trawling and dredging and encroachment on the livelihood rights of fishermen.

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Acronyms used

ADB	Asian Development Bank
APN	Asia Pacific Network
BBS	Bangladesh Bureau of Statistics
BOBLME	Bay of Bengal Large Marine Ecosystem
BOD	Biological Oxygen Demand
CCD	Coast Conservation Department (Sri Lanka)
CNP	Carbon Nitrogen Phosphorus
CNRS	Center for Natural Resources Studies
COD	Chemical Oxygen Demand
COMAPS	Coastal Ocean Monitoring and Prediction Systems
CPCB	Central Pollution Control Board (India)
DAP	Di-ammonium Phosphate
DFID	Department for International Development
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorus
DOA	Departments of Agriculture
DOE	Departments of Environment
DOF	Departments of Forestry
DOF	Departments of Fisheries
DOF	Department of Fisheries
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Product
GEF	Global Environmental Fund
GOB	Government of Bangladesh
ICZM	Integrated Coastal Zone Management
ICZMP	Integrated Coastal Zone Management Program
ING	Indian Nitrogen Group
IUCN	International Union for Conservation of Nature
JICA	Japan International Cooperation Agency
LMT	lakh metric tonnes
LOICZ	Land Ocean Interaction in the Coastal Zone
MGD	million gallons per day
MLD	million liters per day
MOE	Ministry of Environment
NEWS	Nutrient Export from Watersheds
NGO	Non-Governmental Organisation
NUE	Nutrient Use Efficiency

PCB	Polychlorinated Biphenyls
PDO-ICZM	Programme Development Office for Integrated Coastal Zone Management Program
POP	Persistent organic pollutants
PTS	Persistent Toxic Substances
SAARC	South Asian Association for Regional Cooperation
SACEP	South Asia Cooperative Environment Programme
SAS	South Asian Seas
SASAP	South Asian Seas Action Plan
SASP	South Asian Seas Programme
SITE	Sindh Industrial Trading Estate
TDA	Transboundary Diagnostic Analysis
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development
WBC	Western Bay of Bengal Current
WHO	World Health Organization
WWF	World Wildlife Fund

1. Introduction

Majority of the anthropogenic activities are conducted in the coastal zones or within the river catchments that releases pollutants to coastal zones. The consequence of these activities – agriculture or industrial activity, transport and commerce, power generation or urban development results in an inevitable release of pollutants (**Figure 1**). These pollutants include nutrients, sediments, organic chemicals and xenobiotics, metals etc. that ultimately end up in the seas. Over the years, there have been efforts to reverse the historical approach of dumping wastes, including nutrients into the seas and adversely affect the quality of coastal and ocean waters and ecosystems. Mostly driven by human health concerns or agenda for preservation and protection of the environment, such pollution reduction efforts have come of age.

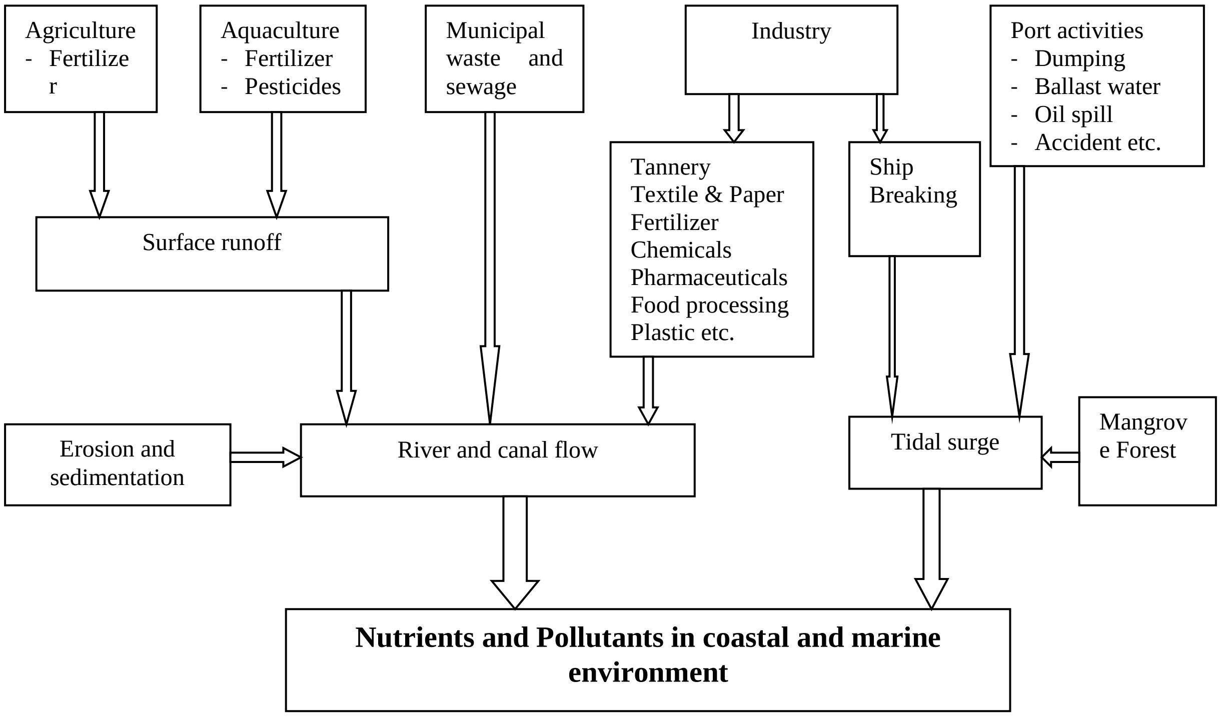

Figure 1: Pathways of entering nutrients and pollutants in coastal and marine environment

It was estimated that globally 10 billion gallons of sewage, 3.25 million metric tons of oil, 10 billion tons of ballast water and millions of tons of solid waste are discharged into the marine environment per annum (Ruiz-Villarreal, et al., 2006; UNEP, 2006a). Furthermore, industrial untreated wastes are contributing to the coastal dead zone (i.e. insufficient oxygen level to support marine life) extension and heavy metal contamination to the sea food constantly. Almost 70% industrial discharges and 85% of waste water are discharged untreated from developing countries. For instance, annually more than 600,000 tons of nitrogen is delivered into the Indian Ocean, while 17 tons of mercury and nearly 150 tons of cadmium are discharged into the Caspian Sea (Hossain, 2006; UNEP, 2006b).

The major issues of interest for coastal pollution and infringement on water quality are:

1. Sewage-borne pathogens and organic load

2. Solid waste/marine litter
3. Increasing nutrient inputs
4. Oil pollution
5. Persistent organic pollutants (POPs) and persistent toxic substances (PTSs)
6. Sedimentation
7. Heavy metals
8. Toxic algal (dinoflagellate) blooms

A few of these issues are also of transboundary in nature like discharge of untreated/partially treated sewage being a common problem, sewage and organic discharges from the Ganges-Brahmaputra-Meghna River are likely to be transboundary (BOBLME, 2012). Moreover, High nutrient discharges from rivers could intensify large-scale hypoxia, and a few hypoxic zones are already identified in the south Asian seas.

1.1. What is nutrient pollution and how is it affecting coastal and marine ecosystems?

Several nutrients, especially reactive nitrogen and phosphorus are essential to growth and development of all life forms, both terrestrial and marine, beginning with the primary producers including the free-living phytoplankton up to the consumers. Reports of excessive growth of algae, degradation of aquatic ecosystems and depleted oxygen levels in water causing mass fish kills have been traced to the loading of excess of nutrients in the coastal waters due to anthropogenic activities in the hinterland. While nutrients are chemicals essential for the growth of organisms, nutrient pollution refers to the contamination by excess inputs of nitrogen and phosphorus into aquatic systems (Sutton *et al*., 2013). This nutrient enrichment, eutrophication, initially stimulate growth of phytoplankton, microalgae and macroalgae, which in turn can lead to other impacts such as:

- Loss of subaquatic vegetation as excessive phytoplankton, microalgae, and macroalgae growth reduce light penetration.
- Change in species composition and biomass of the benthic (bottom-dwelling) aquatic community, eventually leading to reduced species diversity and the dominance of gelatinous organisms such as jellyfish.
- Coral reef damage as increased nutrient levels favour algae growth over coral larvae. Coral growth is inhibited because the algae outcompetes coral larvae for available surfaces to grow.
- A shift in phytoplankton species composition, creating favourable conditions for the development of nuisance, toxic, or otherwise harmful algal blooms.
- Low dissolved oxygen and formation of hypoxic or “dead” zones (oxygen-depleted waters), which in turn can lead to ecosystem collapse due to mass fish kills.

Over the last few decades since the era of intensive agriculture, the dependence on fertilizer N and P to enhance agricultural productivity has led to massive increase in the production and application of fertilizers to farm land (**Figure 2**). The often inefficient use of this fertilizer has led to substantial run-off and release of nutrients to the waterways ultimately reaching the oceans. The link between intensive agriculture and reactive N pollution is well-established with impacts on drinking water (Powlson *et al*., 2008; Galloway *et al*., 2008) and the eutrophication of aquatic ecosystems.

1.2. Why addressing nutrient pollution is important in south Asian Seas context.

The southern region of the Asian continent is known as South Asia and is bordered by West Asia, Central Asia, East Asia and South-East Asia. South Asia is bordered in the south by the Indian Ocean, in the South-east by Bay of Bengal and in the South-west 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 called biomes, which demonstrate the biodiversity and vegetation patterns of the region as determined by climate, water, geology, soil and diverse topography. South Asia's topography consists of an amazing variety of mountains, plateaus, dry regions, intervening structural basins, beaches, etc. South Asia consists of Afghanistan, Bangladesh, Bhutan, India, the Maldives, Nepal, Pakistan and Sri Lanka. However, given that the focus of this report being the coastal region, the five South Asian maritime countries *viz.*, Bangladesh, India, the Maldives, Pakistan and Sri Lanka (**Figure 3**) are considered here.

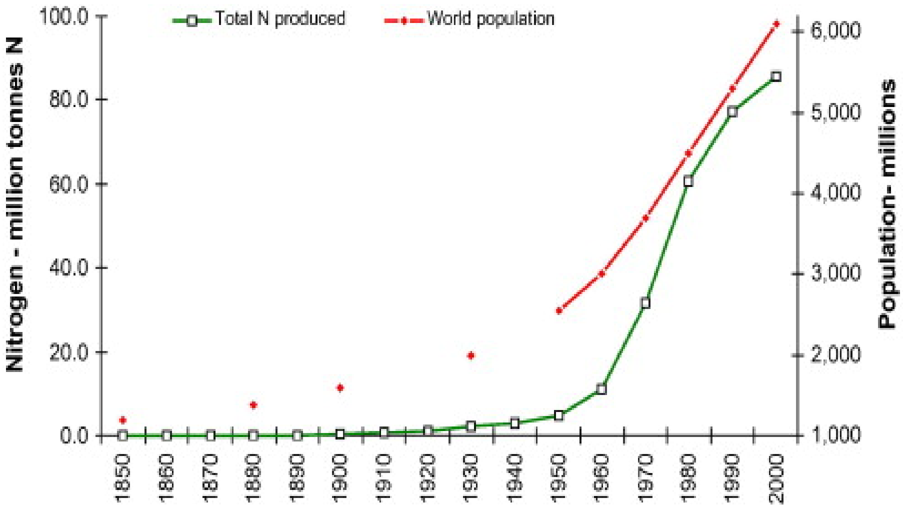

Figure 2: Production of N-fertilizer in relation to world population (Dawson and Hilton, 2011)

The five South Asian maritime countries are home to about 22% of the global population, with only 4.8% of the world's land mass, 14% of the global arable land, 2.73% of the world forest area and 4% of the world's coastline. The coastal areas of this region are characterized by the location of some of the largest population concentrations in the world including Karachi, Mumbai, Chennai, Kolkata and Dhaka. The entire population of the Maldives can be considered as coastal while in Sri Lanka more than 32% of population is found in the coastal belt. Agriculture is the major vocation of the population and also large contributor to the domestic economy of almost all the counties, followed by aquaculture.

Nutrients used far inland in agriculture are often in excess and leach out of agricultural lands. Once released to the environment, nutrients build-up in soils, groundwater and small aquatic bodies such as ponds and lakes which then become strongly eutrophic. Significant transport by rivers to the coast occurs mainly during the wet season. In many tropical countries, the concentration of nutrients in estuaries is generally not considered very high. However, point-source wastewater flows can sometimes be the major source of nitrogen to an estuary when the watershed is heavily populated and small relative to the size of the estuary itself. Even in some estuaries fed by runoff from larger watersheds, sewage wastewater can be the largest source of nitrogen if the watershed is heavily populated, which is the case in many places in South Asian countries. This becomes important considering that 90% of wastewater in developing countries is estimated to be discharged untreated into waterways and coastal areas.

Seitzinger *et al*. (2010) used an integrated modeling approach to connect socioeconomic factors and nutrient management to river export of nitrogen, phosphorus, silica and carbon based on an updated Global NEWS model. Past trends (1970–2000) and four future scenarios were analyzed. Modelling results showed that South Asia alone accounted for over half of the global increase in DIN and DIP river export between 1970 and 2000 and in the subsequent 30 years under the Global Orchestration scenario (globally connected with reactive approach to environmental problems); DIN river export decreased in the Adapting Mosaic (globally connected with proactive approach) scenario by 2030, although DIP continued to increase.

Figure 3: Map of South Asia

Nitrogen limits productivity in much of the ocean including the Indian Ocean (Kone and Aumont, 2009) and many tropical waters, but reports indicate that increased nutrient input through anthropogenic sources have resulted in alteration of the relative availability of nutrients driving phytoplankton productivity and accompanied by increasing incidence of noxious phytoplankton blooms and bottom water hypoxia (Beman *et al.,* 2005). It is also projected that by the year 2050, 27–59 per cent of all nitrogen fertilizer will be applied in developing regions located upstream of nitrogen-deficient marine ecosystems and hence adjacent coastal areas are at high risk to nutrient pollution.

Thus, rapidly growing coastal population (as well as livestock) in these countries as well as growing fertilizer use is of concern. Increasing reports on the number and frequency of algal blooms along the coast and concerns of development of hypoxic zones makes it imperative for efficient nutrient management in these countries especially because more than 90 per cent of fisheries depend in one way or another on estuarine and near-shore habitats which are increasingly being impacted by nutrient over-enrichment of coastal waters. In addition, tourism in the coastal areas that has emerged as one of the important industry also contributes to the nutrient pollution through release of sewage and other related anthropogenic activities.

1.3. Objectives and methodologies for the study

At the sub-region level, one of the important Environmental Agreement concerning the conservation of marine and coastal biological diversity is the South Asian Seas Action Plan (SASAP), developed under the umbrella of UNEP –Regional Seas Programme. Adopted in 1995 by the five maritime countries of South Asia. The objective of the SASAP is to protect and manage the marine environment and related coastal ecosystems of the region through the promotion of sustainable development of the resources. The protection of the marine environment from land based activities has been identified as one of the four priority areas to be address under the SAS Action Plan and therefore has been an activity, actively perused by SAS countries with the assistance of UNEP-GPA office. Six priority issues including agricultural chemicals have been identified for implementing GPA activities within the region.

SACEP[i] together with UNEP-GPA and BOBLME[ii] project developed the project concept "Controlling Nutrient Loading and eutrophication of Coastal Waters of the South Asian Seas Region" with the main objective of reducing and controlling nutrient loading into the coastal waters of the South Asian Seas Region through development of a regional action plan and policy forum/framework. The activities proposed under this initiative include:

- An inventory of point/non- point sources of nutrients that end up in the coastal waters
- Estimating the impact of nutrient enrichment on coastal waters.
- Develop and undertake actions to reduce nutrient inputs to agriculture as well as remedial masseurs to over eutrophication/hypoxia conditions in identified sites.
- Development of a regional action plan and establishment of a regional policy forum to be pursued by member countries.

The first step in this activity was to understand the spatial and temporal complexity of nutrient loading and coastal eutrophication/ hypoxia, including the functioning of ecosystems and socioeconomic systems. A desk review has been undertaken for this purpose. The desk review seeks to highlight important trends in eutrophication, sources of nutrients and current policy and legislation in various South Asian countries. The study will cover the maritime countries of Bangladesh, India, Maldives, Pakistan and Sri Lanka and consist of a review of the following areas of concern:

- Practices leading to nutrient over-enrichment, water pollution and degradation of coastal and marine environment.
- Fertilizer use and use efficiency and their contribution to excess nutrient fluxes.
- Contribution of livestock (animal husbandry) and other sources of excess nutrient export to coastal and marine environment.
- Various pathways, through which the excess nutrients enter the coastal and marine environment.
- Legal and policy frameworks that have direct and/or indirect impact on the current nutrient use efficiency and what policies are being considered to improve NUE and their merits.
- Legal and policy framework, existing water quality objectives, standards and criteria with regard to nutrients load into coastal waters and how they are monitored.
- Present status of nutrient enrichment, freshwater and coastal/marine water quality (with regard to nutrients): any information regarding identified eutrophication hotspots, coastal hypoxic zones and harmful algal blooms (with country specific data and maps).
- National (as well as participation in regional and international/global) programs or activities to monitor, regulate and report; and institutional mechanisms or arrangements for enforcement of legislations and policies that are in place.
- Existing challenges, constraints, gaps and issues (regarding information, policies, implementation and enforcement).

[i] South Asia Co-operative Environment Program
[ii] Bay of Bengal Large Marine Ecosystem

This report is prepared based on information collected from documents, papers, books and reports published in electronics and print media. Information were collected from the reports of the institutions that are actively involved with coastal and marine ecosystem management and development of national and international levels in different countries of South Asia. The institutions include Departments of Environment (DOE), Agriculture (DOA), Fisheries (DOF), and Forestry (DOF) of the South Asian countries. Further, reports of World Bank (WB), Asian Development Bank (ADB), Department for International Development (DFID), United States Agency for International Development (USAID), Center for Natural Resources Studies (CNRS) and the World Conservation Union (IUCN) were also consulted. The information was collected and evaluated for nutrient load and quality of coastal waters. The collected data comprised of physical, chemical and biological analysis of water samples, bio-assessment protocols and observations of environmental conditions in coastal waters.

2. Status and trends in South Asian Seas Region

The region of South Asian Seas (SAS) is physio-graphically diverse and ecologically rich, with rich natural and crop-related biodiversity. Although the present population of the region is principally rural, South Asia has seven of the 25 largest cities in the world. Agriculture is the main industry in several countries in this region. Exploitation of natural resources, associated with rapid urbanization, industrialization and economic development, has led to increasing air and water pollution, land degradation and other environmental problems in the focus countries. Climate change represents a further stress. South Asia’s climate varies considerably among its different areas, ranging from a tropical monsoonal climate in the south to a temperate climate in the north. This variation is influenced by altitude, as well as by factors such as proximity to the coast and the monsoons.

Much of the climate of South Asia is driven by monsoons and is characterized by wet summers and dry winters. The south-west monsoons (late May to October) bring the maximum rainfall, followed by the north-east monsoons. The precipitation and climate vary significantly from place to place in different countries within the region due to the variations in the landforms. The climate varies from a semi-arid climate in Pakistan, to tropical monsoon, hot-dry and humid-dry climates in the rest of the region (SACEP, 2012). Much of South Asia is a subcontinent that rests on the Indian Plate. It was formerly a small continent, which collided with the Eurasian Plate approximately 50-55 million years ago, giving rise to the Himalayan Range and the Tibetan Plateau.

South Asia is blessed with several major rivers, which are critical for the economy of the region. Further, there are many services provided by these rivers, especially in communication, transportation and agriculture. Dams built across rivers are also be used to produce hydro-electricity. However, some of the developmental projects in the river valleys have their own negative impacts, especially on the biodiversity and on its ecosystem services. Despite their various benefits, rivers can also destroy properties and cause loss of human life through flooding. They are therefore, critical in climate change adaptation and its effects in the region. Some of the world’s largest river systems are in South Asia. The Indus River (3,200 km long and with 20 tributaries), originates in Tibet and flows through India and Pakistan, out to the Arabian Sea. The Ganges (2,525 km in length) originates in the western Himalaya, in the Indian state of Uttarakhand, and flows into Bangladesh through north India. Finally, it flows into the Bay of Bengal. The Brahmaputra River (2,900 km long) begins in south-western Tibet (where he is known as the Yarlung Tsangpo River). It flows through Arunachal Pradesh and the Assam Valley (known in these areas as the Dihang and Brahmaputra, respectively) in India and then through Bangladesh (known there as the Jamuna – not to be confused with the Yamuna of India), where it merges with the Padma, the main distributary of the Ganges, and the Meghna, before meeting the Bay of Bengal (SACEP, 2012).

The focus countries have relatively small economies, with the exception of India, which ranks 12th in the world in terms of GDP, but have shown rapid growth over the past two decades, particularly in the industry and service sectors to reach 3rd position among Asian economies. This has led to increasing levels of industrial development in the coastal zones. All of the South Asian economies are decreasing their reliance on the agriculture sector, with the exception of India. Of the focus countries under discussion, Sri Lanka has the highest GDP per capita in the region, while India is the largest economy in the region (US$1.7 trillion) and makes up almost 82 percent of the South Asian economy. Pakistan has the next largest economy and the fifth highest GDP per capita in the region, followed by Bangladesh.

The South Asian Seas region is physically divided by the Indian landmass into the Arabian Sea and the Bay of Bengal. Oceanographically, the Bay of Bengal differs from the Arabian Sea in maintaining a clockwise circulation of major currents during both the northeast and southwest monsoons (Gangadhara Rao and Shree Ram, 2005 and Stramma *et al*., 2002). The circulation in the Arabian Sea reverses, with surface water masses circulating counter clockwise in the northeast monsoon (November–April, when the North Equatorial Current flows west) and clockwise in the southwest monsoon (May–October when the surface current flows eastward and splits to form clockwise currents in the Arabian Sea and the Bay of Bengal) (Shenoi *et al*., 1999; Schott and Fischer, 2000; Schott and McCreary, 2001). There is also a major difference in salinity (World Ocean Atlas, 2001, available at www.nodc.noaa.gov.oc5/WOA01/WOA01dat.html). In the Arabian Sea, evaporation exceeds precipitation and runoff, leading to the formation of high salinity water masses that flow south (Murty *et al*., 1991; Suryanarayana *et al*., 1993).The Bay of Bengal has comparatively low salinity due to high runoff and precipitation; in the southwest monsoon, maximum salinity is found at depths of about 500 meters, as high salinity water moves into the Bay from the Indian Ocean (Pernetta, 1993). Tropical storms also have a major impact; of the 12–13 that occur each year in the Bay of Bengal, three or four of cyclonic strength affect India, Bangladesh and Myanmar. The northern part of the Bay of Bengal is prone to impact from storms because it concentrates energy from storm centers (Dube *et a*l., 2009; Debsarma, 2009).

2.1. Eutrophication in coastal waters of South Asian Seas

Over the last 20 years, considerable data and expertise in understanding and addressing the various sectoral drivers, pressures, sources, impacts and response to nutrient enrichment and consequential eutrophication have been gathered. The key sectors include agriculture, aquaculture, waste-water management and fertilizer production. Model studies indicate that globally, roughly equal amounts of reactive N reach the oceans from fertilizer, manure and atmospheric deposition with smaller fractions from sewage (Setzinger *et al*., 2010). Analysis at the regional levels shows somewhat different proportions with sewage being less important in south Asia. But with increased urbanization, this scenario might be changing. This suggests the need to apply nutrient reduction strategies that best fit the nutrient profile of a given region or sub-region or basin. For the countries of the south Asian Seas region, agriculture remains the major vocation with fertilizer input being the most important contributor to nutrient pollution although marginal differences may be observed in the context of specific country.

2.1.1. Bangladesh

Bangladesh has a convoluted coastline with many rivers and distributaries and complex ecology, which is affected by natural hazards like cyclone, coastal flooding, tidal surges, salinity and other phenomenon. The coastline is of 734 km involving communities of about 50 million people, nearly one-third of the total population of the country (Miyan, 2009; Rahman, 2006). The Ganges, Brahmaputra and Meghna estuaries in the south and the Karnaphuli, Halda and Sangu rivers and Arakan ranges shoreline in the southeast are giving a distinct feature to the whole coastal zones. A network of 230 rivers with their tributaries and distributaries crisscross the country and, therefore, the country is virtually a conglomerate of islands (**Figure 4**). While annual floods devastate large areas, coastal flooding and storm surges caused by heavy rainfall due to cyclones impact the coast almost every year. Depending on the geo-morphological features, the coastal areas of Bangladesh can broadly be divided into three distinct regions *viz*. the eastern region, the central region and the western region. The PDO–ICZMP (2003) classified the coastal areas of Bangladesh under two broad categories *viz*. interior coast and exterior coast. A total of 47201 sq km is coastal area in Bangladesh of which 23935 sq km exposed and 23266 sq km interior categories.

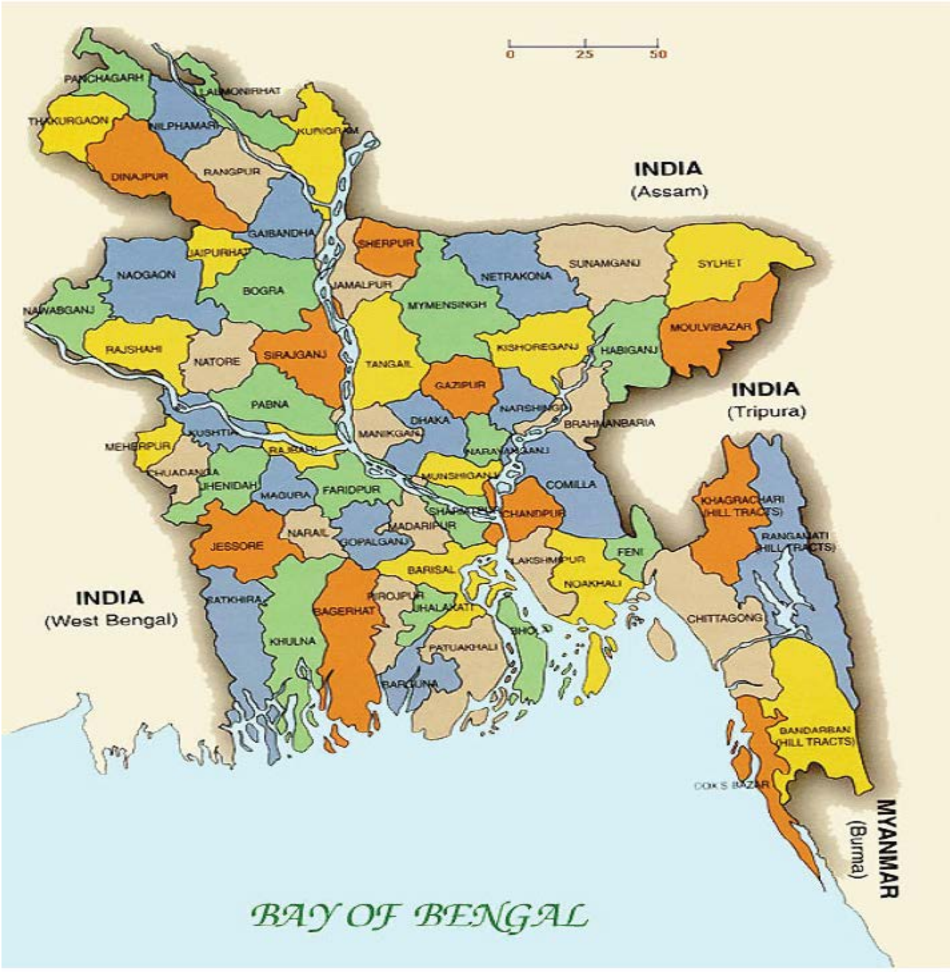

Figure 4: Map of Bangladesh and the major river systems (Source: BOBLME-Bangladesh)

Land use in the coastal zone, like most countries, is diverse and often conflicting. About 60 per cent of the land is used for agriculture. The use of high yielding varieties and construction of a series of embankments and dykes (polders) to keep out seawater initially increased agricultural production but poor water management practices resulted in internal drainage congestion and external siltation. Subsequently shrimp farm (especially brackish water varieties) expansions in the polder areas resulted in the encroachment into agricultural lands. Fisheries contributed to 4.57 per cent of GDP in 2009, provide 63 per cent of animal protein and employment to 9 per cent of the population. The Sunderban mangroves dominate the life and livelihood of the local communities engaged in a variety of activities ranging from timber and non-timber forest produce collection to fishery and collection of shrimp larvae. The Sunderbans act as a buffer protecting the hinterland from the impact of cyclones and storm surges.

Nutrient pollution has largely been measured from rivers associated with large population centres. Concentrations of nitrate, phosphate and silicate vary from 0.16 to 8.98 µg-at/1, 0.08 to 2.33 µg at/1 and 0.67 to 63.31 µg-at/1 reported at Karnapphuli river to St Martin Island(Holmgren, 1994). Chlorophyll-content varied from 0.19 to 12.62 µg/1. Higher values of inorganic nitrogen (~ 0.03 to ~ 0.10 mg. g^{-1}) have been observed in the bottom sediments in the Bay of Bengal drainage basin and in and around Sunderbans. At St Martin's Island, values of nutrients recorded were: Nitrogen (NO_3-N):

between 1.90 mg/l and 0.18 mg/l (monsoon and post-monsoon) and Phosphate Phosphorus (PO_4-P): 0.498 mg/l and 0.021 mg/l (monsoon and postmonsoon) (Hossain et al., 2009). Mortality incidents in shrimp farms are believed to be because of harmful algae. Fish kills have been associated with the appearance of (harmful) algal blooms but there are no detailed studies (BOBLME, 2011).Nutrient budget for the lower Meghna River system and the Karnaphuli were prepared using one layer single box DIP and DIN budgets. An increase in fluxes was noticeable during the monsoon season followed in time and magnitude by the postmonsoon season. Model results indicate that in both cases the estuaries are mainly heterotrophic denitrifying systems (Mahmood *et al*., 2004; Chowdhury *et al*., 2004).

Table 1: Seasonal variation of Total Phosphorus (TP) and Total Nitrogen (TN) in three river systems of Bangladesh river systems between September 2010 and February 2011 ( ) (Adapted from Bazlur Rahaman et al., 2013)

River	Season	TP mg/l	TN mg/l
Rupsha-Passur River	post monsoon	0.326~0.409	2.52~3.50
	Winter	0.091~0.371	3.43~5.25
	post monsoon	0.475~0.144	2.31~3.61
Arpangashia-Malancha River	Winter	0.060~0.113	3.22~5.95
Baleswar-Bhola River	Rainy	0.106~0.364	2.59~3.57
	Dry	0.053~0.075	2.87~5.60

2.1.2. India

India, the seventh largest country by geographical area and the second most populous country (with over 1.2 billion people) is bounded by the Indian Ocean in the south, the Arabian Sea in the south-west and the Bay of Bengal in the south-east. Of India's 7,517 km long coast, 5,423 km belongs to peninsular India and 2,094 km to the Andaman, Nicobar and Lakshadweep Islands. According to the Indian naval hydrographic charts, the mainland coast consists of the following: 43 percent, sandy beaches; 11 percent, rocky coast including cliffs; and 46 percent, mudflats or marshy coast (http://www.cse.iitb.ac.in/~smit/cs296.html).

Many towns and cities are located on the east coast. Major cities include Kolkata in West Bengal, Visakhapatnam in Andhra Pradesh and Chennai in Tamil Nadu. Similarly, the megacity of Mumbai along with other major cities like Panaji (Goa), Cochi and Thiruanantapuram are situated on the west coast. Major cities along the coast can be seen from **Figure 5**.

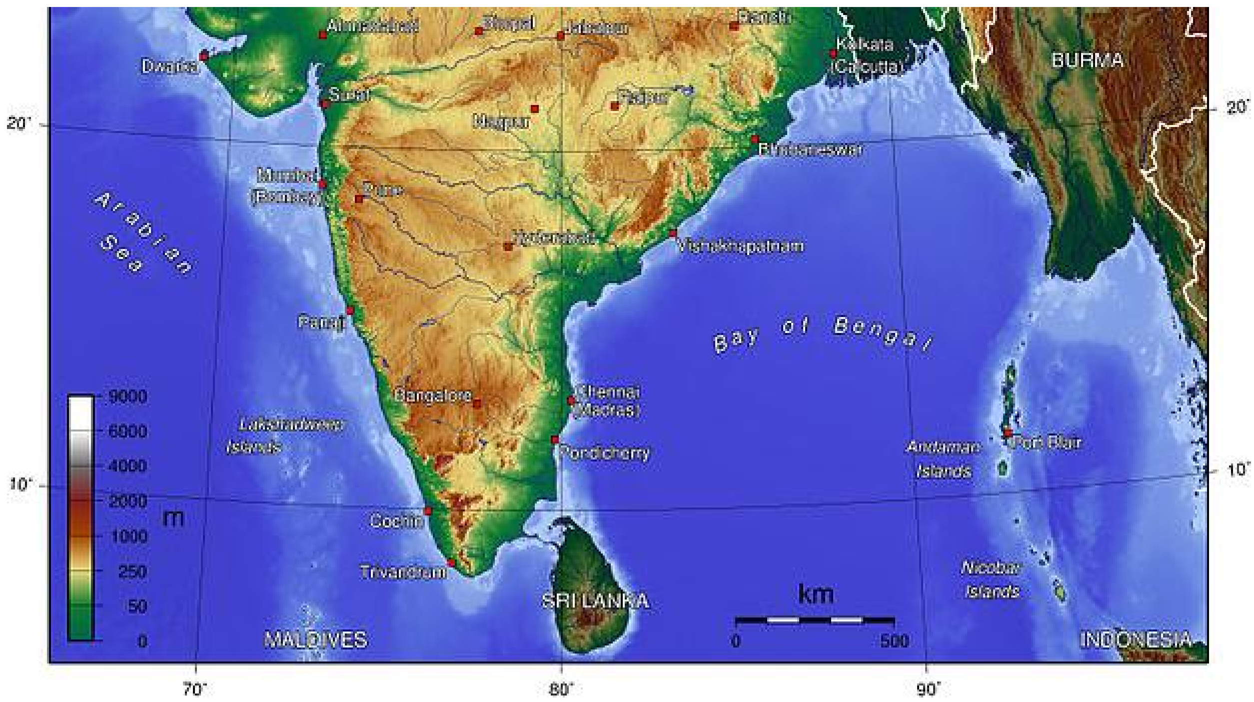

Figure 5: Coastal cities of India

There are 14 major rivers, 44 medium and a number of minor rivers that drain the Indian mainland and 97 major estuaries along the coast and numerous patches of mangroves and other wetlands such as lagoons, lakes and ponds. The enormous river runoff into the Bay of Bengal/Andaman Sea and huge consumption of synthetic fertilizers in South Asia, the total flux of dissolved inorganic nitrogen by rivers to the Bay of Bengal is relatively modest (< 0.5 Tg N a^{-1}) (Naqvi *et al*., 2010a). This, along with low upwelling in the Bay of Bengal, is probably why hypoxic conditions do not develop along the east coast unlike the west coast of India where conditions are conducive to the development of natural hypoxic zones (Naqvi *et al*., 2010b). The Arabian Sea experiences a strong upwelling associated with the south west monsoon whereas the Bay of Bengal has only a weak upwelling which is why there have been reports of natural hypoxic conditions in the Arabian Sea coast (Naqvi *et al*., 2000). It has also been presumed that higher surface production resulting from lower light intensities occurs in the Bay of Bengal although the column production is much higher in the Arabian Sea (Kumar *et al*., 2010). Primary productivity values ranging from 3.0 to 8.7 g C m^{-2} d^{-1} (>300 g C m^{-2} yr^{-1}) have been reported from the inshore waters of the east coast of India in June-July (Nair *et al*., 1973). Based on measurements during August-September 1978 Chlorophyll a up to 50 mg m^{-2} was reported inshore (Bhattathiri *et al*., 1980). These values are probably exceptional, often referring to inshore blooms. On the contrary, most measurements are in effect less than 0.5 g m^{-2} d^{-1} along with very low chlorophyll a (usually <0.1 mg m^{-3} or <10 mg m^{-2}).

Large river runoff supports primary production in coastal waters and the central part of the Bay of Bengal is less productive due to absence of large scale upwelling (Dwivedi, 1993). Secondary production has been reported to be highest from October to January (winter monsoon period) and lowest from June through September (summer monsoon) (Desai and Bharghava, 1998). In the east coast of India, phytoplankton blooms are common during February to May when the prevailing hydrobiological conditions are relatively stable. Reported major incidence of algal blooms along the coastal states of India in the different parts of Bay of Bengal is shown in **Figure 6**. During spring inter monsoon, eddies and recirculation zones from the coastal regions of Bay of Bengal due to the Western Bay of Bengal Current (WBC) were found to enhance phytoplankton growth. Blooms occurred usually just after the southwest to northeast monsoon transition during which the current direction changes from equator to the poles in the Bay of Bengal (Prasanna Kumar *et al*., 2007).

Figure 6: Distribution of Harmful algal blooms along the Bay of Bengal Coast

Reports on the eutrophication of estuaries and coastal waters are available from a few places in India. Nitrogen limitation has been reported from Mandovi-Zuari and Cochin estuaries on the west coast and Godavari and Hoogly estuaries on the east coast. Martin *et al*, (2011) report that anthropogenic nutrient loading (a six-fold increase in nutrient and cholorphyll levels during the last few decades) have caused a change in the benthic diversity of the Cochin estuary followed by an invasion of opportunistic polychaetes. In the Kodungallur-Azhikode estuary (Kerala, west coast), the major source of nutrients was associated with river discharge during the south-west monsoon (Jayachandran *et al*., 2012). Sarma *et al.* (2010) reported that river discharge had significant influence on nutrient loading in Godavari estuary. The N:P ratios were higher than Redfield ratio in both upstream and downstream of the estuary during no discharge period suggesting PO_4 to be a limiting nutrient for phytoplankton production, at levels < 0.10 µmol L^{-1} whereas suspended matter limited phytoplankton production during peak discharge period. Coastal waters were found to be significantly influenced by freshwater input during the north east monsoon. Also, there are reports that subsequent to the 2004 tsunami, phosphate concentrations have seen an increase possibly because of the incursion of the nutrient-rich coastal waters (Satpathy *et al*., 2010).

The world's largest natural hypoxic zone develops seasonally over the Western Indian continental shelf which appears to have intensified in recent years most likely because of enhanced nitrogen loading through runoff and atmospheric deposition (Naqvi *et. al*., 2000 and 2009). Balachandran *et.*

al., (2003) postulate a remote forcing from the land involving a subterranean flow through the submerged coral beds especially along the Vembanad Lake.

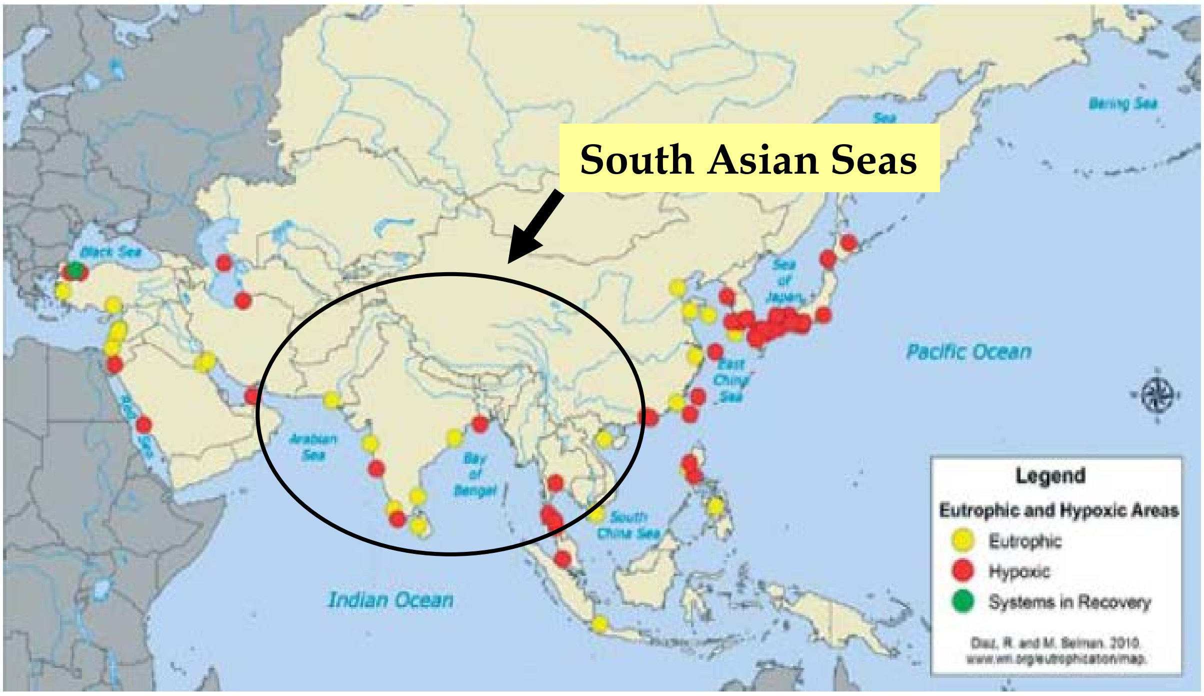

Figure 7: Eutrophic and hypoxic zones in South Asian Seas (Source: World Resource Institute, http://www.wri.org/resources/maps/coastal-eutrophic-and-hypoxic-areas-asia

An increasing human population along the coast, widespread use of septic tanks as well as agriculture and water management practices is believed to be the cause of increasing anthropogenic sources of nutrients into coastal waters (George *et. al*., 2013). On the east coast, studies carried out in Chilika Lagoon along the coast indicated that higher amounts of nutrients were found in the northern part of the lake which can be correlated with land drainage brought out by river systems through which the inland soil and agricultural fertilizers used for farming are washed out and added into lake water (Nayak *et al.* 2004). Major input of pollutants in the coastal environment of India is depicted in **Table 2**.

Table 2: Inputs of pollutants in the coastal environment of India (BOBLME 2011)

S. No.	Input / pollutant	Quantum –Annual
1	Sediments	1600 million tones
2	Industrial effluents	$50 \times 10^6 m^3$
3	Sewage -largely untreated	$1.41 \times 10^9 m^3$
4	Garbage and other solids	34×10^6 tonnes
5	Fertilizer –residue	5×10^6
6	Synthetic detergents –residue	1,30,000 tonnes
7	Pesticides –residue	65, 000 tonnes
8	Petroleum hydrocarbons (Tar balls residue)	3,500 tonnes
9	Mining rejects, dredged spoils & sand extractions	0.2×10^6 tonnes

Mangroves in India account for about 5% of the world's mangrove vegetation and are spread over an area of about 4500 km^2 along the coastal States/UTs of the country. Sunderbans in West Bengal accounts for a little less than half of the total area under mangroves in India. Assessment of mangrove cover has also been categorised into very dense mangrove (canopy density of > 70%), moderately dense mangrove (canopy density between 40 and 70%) and open mangrove (canopy density between 10 and 40%). According to the Forest Survey of India out of 487,100 ha of mangrove wetlands in India, nearly 56.7% (275,800 ha) are present along the east coast, 23.5% (114,700 ha) along the west coast and the remaining 19.8 % (96,600 ha) are found in the Andaman and Nicobar Islands. Studies of nutrient stoichiometry in the Indian mangroves (Sunderbans, Bhitarkanika, Coringa, Pichavaram and Mangalavanam) showed that despite high phosphate loadings along with nitrogen from both point and non-point sources to mangrove waters, N:P ratios (Sunderbans 11.43, Bhitarkanika 6.48, Coringa 5.46, Pichavaram 7.31 and Mangalavanam 4.64) deviated from the Redfield stoichiometry and also demonstrate that phosphorus was a limiting nutrient in all the mangrove ecosystems. Long term nutrient analysis in Pichavaram mangrove indicated that the significant increase in dissolved nutrients since the 1980s was mainly derived from non-point sources such as agriculture and aquaculture (Prasad, 2012).

The Coastal Ocean Monitoring and Prediction Systems (COMAPS) programme operated by the Ministry of Earth Sciences is to assess the health of India's marine environment and indicate areas that need immediate and long-term remedial action. Data on 25 environmental parameters including physical, chemical, biological and microbiological characteristics of water and sediment at about 76 locations are being collected with the help of seven R&D institutions in the 0-10 km sector of the coastline of the country. With respect to nutrients, data is being collected on nitrite, nitrate, ammonia, total nitrogen, inorganic phosphate and total phosphate. The major activity is to monitor the coastal water quality to understand the trend of marine pollutants load, whether increasing or decreasing, due to anthropogenic activities. Data indicate increasing trend of nitrogen species and a slight increase in phosphate over the last few years since the data has been made available (**Figure 8**A & B).

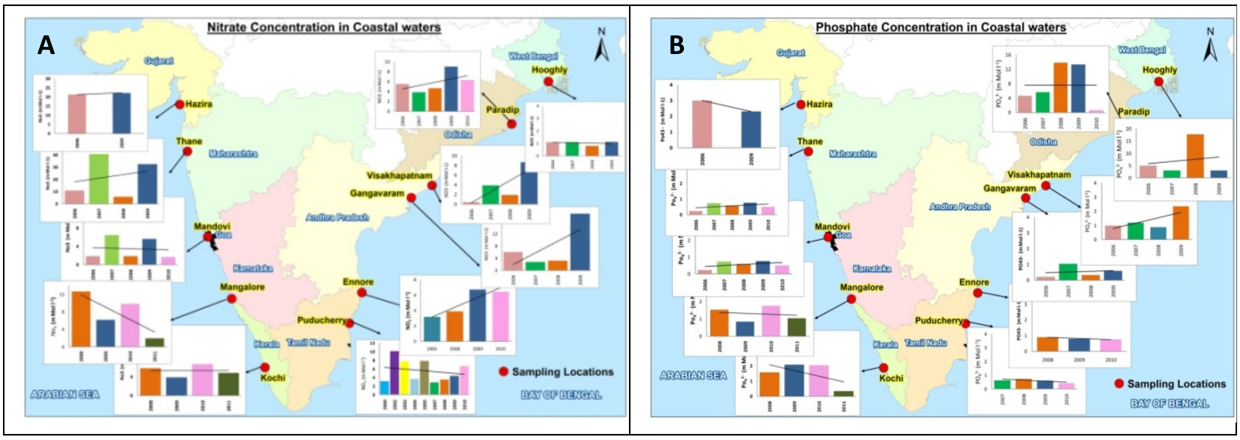

Figure 8: Nitrate (A) and phosphate (B) concentrations in coastal waters of India (Based on COMAPS data)

Overall, it may be concluded that the monsoon regime plays an important role in the transport of nutrients to the coast. In the non-monsoon period, river flows are low to minimal and pollution is dominated by the in-stream uses, sullage waters of rural communities and point discharges from urban/industrial sources, if any. Pollution due to agricultural return waters, either as wash-off or as seepage dominates during flood flows, with the pollution continuing for a month or two after the monsoons are over (Agrawal, 1999).

2.1.3. Maldives

The Republic of Maldives is an archipelago comprising of 1,190 small, low-lying islands grouped into 26 atolls that together form a chain over 820 kilometers in length, over an area of more than 90,000 sq. km in the Indian ocean. The Maldivian atolls stretch from 7° 06'35" north crossing the equator to 0° 42'24" south latitude and Between longitudes 72°33'19" east to 73° 46'13" east longitude in the north central Indian Ocean. Apart from the atolls, they comprise five oceanic faros (ring-shaped reefs exposed to the open ocean) and four oceanic platform reefs (reefs lacking deep lagoons that are exposed to the open ocean).

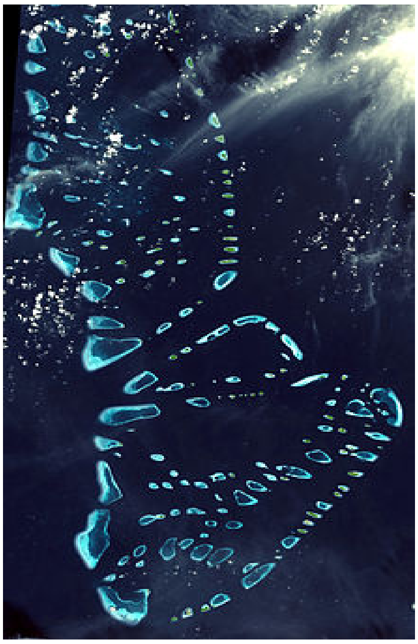

Figure 9: The Maldives (Source: Wikipedia)

The geographic distribution of population is unequal and density among atolls and islands (only about 200 of the 1200 islands are inhabited) differs greatly across the country with about a third of the population residing in the capital city Malé. Marine resources are the main natural endowment, with economic activities concentrated on fishing and tourism. There are no inland fisheries and no aquaculture in the Maldives. Fishing operations take place in off-shore, coastal and reef waters. Agricultural opportunities are very limited and farming is currently practiced in 76 inhabited islands and 600 uninhabited islands on lease basis where the lease holders go for semi-commercial type of farming ventures. However, there are growing concerns about groundwater pollution due to improper use of fertilizers as well as use of pesticides for agriculture.

Domestic sewage and waste generated from human activities remain an important source of pollution in Maldives (ME&E/Republic of Maldives, 2011

importance of which is increasing due to socio-economic development and tourism industry. Waste disposal practices vary among the islands and more often end up in the surrounding ocean contaminating the environment. It was estimated that 298,000 tons of waste was generated in Maldives in 2009. Management of solid waste has been one of the most pressing environmental issues in Maldives. While pollution from tourism industry, especially in case of resorts is guided by strict environmental laws, they do affect the overall pollution and nutrient status of the marine environment in and around Maldives.

2.1.4. Pakistan

Pakistan has about 1050 km long coastline extending from southeast (Rann of Kutch) to northwest till the Iranian border at the mouth of Dasht river (Gwader) along the Arabian Sea. It comprises of two distinct units, the coastal areas of Sindh which stretches over 250 km including Indus delta and Karachi coast, and the region of the Balochistan coast which stretches over 800 km. The Balochistan coastal belt is scarcely populated and is relatively pollution free. Sindh coastal belt, however, suffers very serious environmental problems because of greater population and industrial activities in

Metropolitan Karachi which is the largest city of Pakistan and is located on the coast of the Arabian Sea (**Figure 10**).

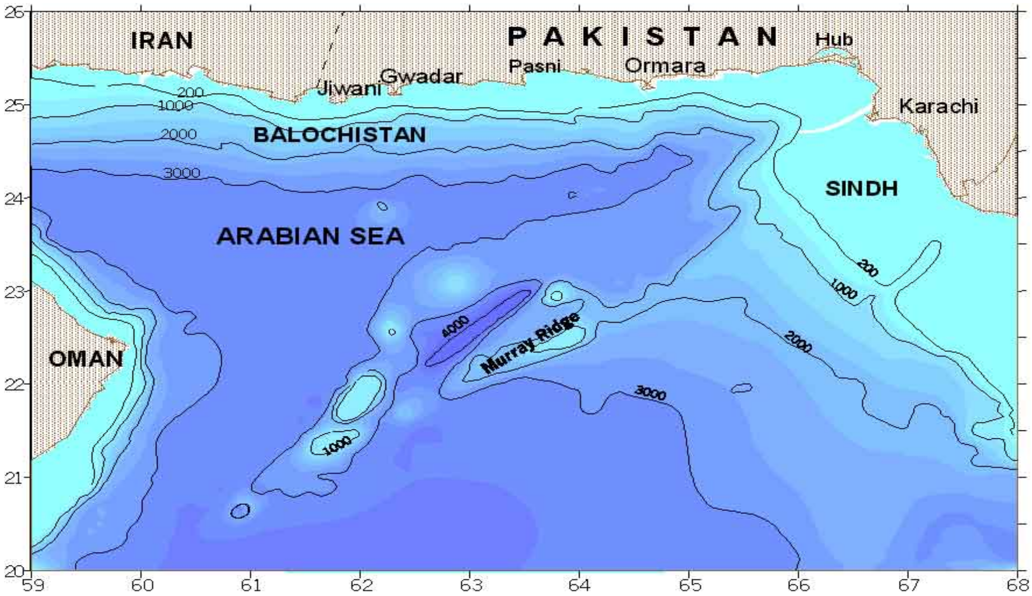

Figure 10: Coast line of Pakistan

The pollution load along the coast varies from place to place depending on the influx of pollution load due to anthropogenic activities. Predominant sources of the pollution of the coastal water include influx of municipal and industrial effluent, contamination from ships, ill planned developmental activities and oil spills in the marine environment (UNEP, 1986). Agricultural runoff also introduces large quantities of nitrogen and phosphorus into coastal waters. Intrusion of saline sea water in coastal aquifers has also significantly affected the groundwater quality of the coastal area.

Metropolitan municipal sewage and industrial effluents are the two major sources of coastal water pollution in Pakistan. The untreated effluent of more than six thousand industrial units scattered in six big industrial estates along with 300 Mgd municipal wastewater is discharged into Karachi coastal waters through Malir and Layari rivers (WWF, 2002). Layari river empties into Manora Channel while Malir river joins sea at the Ghizri creek lying on Southeast of Karachi Coast. Both the rivers act as open sewage channel, receiving highly polluted wastewater of industrial units mainly tanneries, textile, detergents, paints and dyes, pharmaceuticals, plastic, metallurgy, oil, food and beverages, lubricants, cement, auto engineering works etc. Suspended matter in the Creeks is in the vicinity of Karachi ranges from 25 to 178 ppm. An estimated BOD load of 1,500 tons/day is added into sea by these industries in addition to inorganic pollutants (ADB, 2007). The Layari river discharges 130,000 tons of solid nitrogen, 160,000 tons of organic matter, 800 tons of nitrogen compounds, 90 tons of phosphate compounds and 12,000 tons of suspended solid every year in Manora Channel (JICA, 2007).

Studies indicate that the Manora channel and its backwaters are highly polluted with effects of eutrophication observed in select spots. Blooms of phytoplankton as well as excessive seaweeds belonging to the genera *Enteromorpha* and *Ulva* were observed in certain seasons on the tidal flats of Korangi, Lyari outfall, backwaters of Manora channel, Gharo-Phitti creeks and in Sonmiami Bay (UNEP, 1986). Research on seasonal abundance of diatoms in correlation with the physico-chemical parameters of coastal waters of Manora Channel of Karachi suggested that organic loads due to coastal pollution decreased the abundance and diversity of diatom communities in the region (Naz *et al.,* 2013). Nutrient budget for the Khobar Creek in the tidal, estuarine part of the Indus River covering a length of about 40 km and a basin area of 36 km^2 indicate a heteotrophic denitrifying system (Inam *et al.*, 2004) indicating organic matter loading in the ecosystem.

2.1.5. Sri Lanka

The island of Sri Lanka lies in the Indian Ocean, separated from the Indian subcontinent by the shallow Gulf of Mannar and the Palk Strait. Five of the nine provinces of Sri Lanka have a maritime boundary and 14 out of the total 25 administrative districts are located within these five provinces. The 1625 km long coastline has a wide range of geomorphological features including coral reefs, extensive seagrass beds, mangrove forests, salt marshes, beaches, sand dunes, coastal wetlands, highly productive estuaries and lagoons. Coastal aquifers are an important source of drinking water for many coastal communities. It is reported that Sri Lankan coastal groundwater resources in most places appear to be contaminated by nutrient pollutants with the distribution of nutrients showing a clear correlation with anthropogenic activities and land use patterns (Jayasingha *et al*., 2012; Ileperuma, 2000).

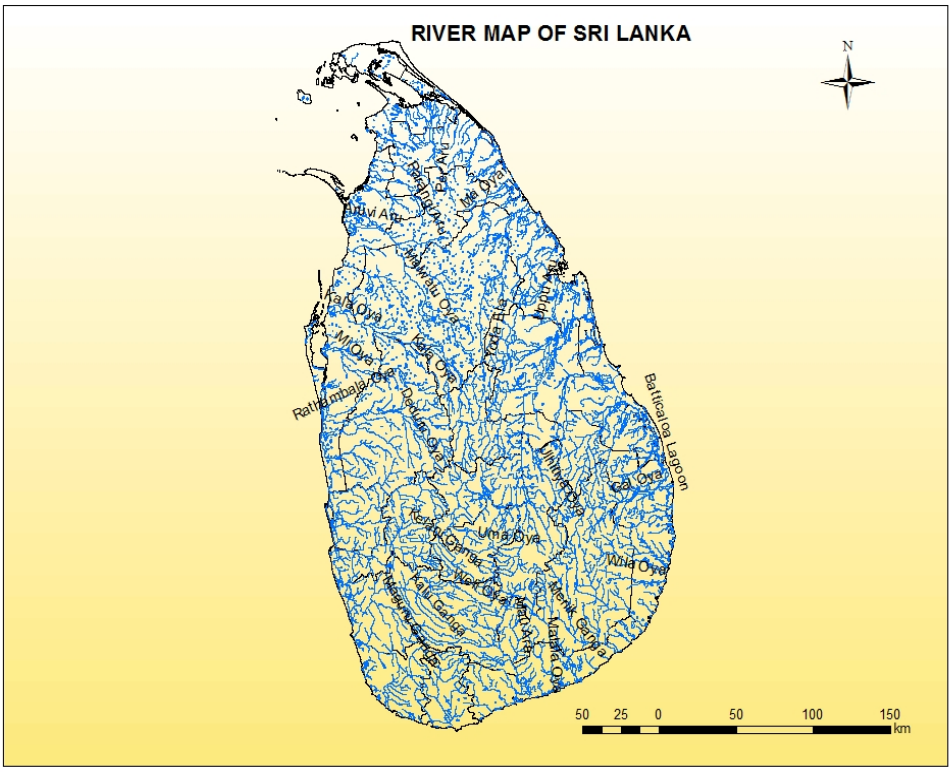

Figure 11: Geographical boundary of Sri Lanka with the river network and coastal lagoons (Source: Jayasuriya et al., 2006)

Coastal waters in Sri Lanka are polluted due to agricultural activities, release of untreated or partially treated solid wastes and effluents from industries, tourist resorts, aquaculture, and sewage (Joseph, 2003). These pollutants are often released directly to sea or into rivers and from there find their way to the sea. A LOICZ budget model was applied to Lunawa lagoon which indicated that the lagoon was a net source of DIN and DIP and appeared to be net heterotrophic and net denitrifying (Samarawickrama and Hettiarachchi, 2004). The same conclusion was drawn in the case of Negombo estuary too. The study concluded that while application of a single box model to the estuary did not indicate nutrient pollution problems, a multiple box system identified that there are certain regions in the estuary which exhibit nutrient pollution problems including nutrient loading from shrimp culture.

Overall, it can be concluded that most rivers in the South Asian region are net heterotrophic and net denitrifying and hence highly susceptible to nitrogen loading from anthropogenic sources. However, there are systems which are phosphorus limited as in the Indian east coast and these are susceptible to the newer pressures of phosphates from detergents apart from phosphates in wastewater. From the studied estuarine coastal systems of East and South East Asia region, trends of the CNP fluxes suggest that the net increase in terrestrial loading may be driving systems towards net autotrophy. The autotrophic-heterotrophic nature of an estuary is determined by three primary factors:

- the ratio of inorganic to organic matter inputs,
- water residence time and
- the overall lability of allochthonous organic matter inputs

This means that as inorganic matter input increases, the response of the system in terms of phytoplankton blooms also may increase and the system tends to eutrophic state.

2.2. Agricultural practices leading to nutrient enrichment

South Asia has the largest share of arable and permanent cropland in total agricultural land (91 per cent) in the world. It has 28 per cent of the world's agricultural population, which exists on about 13 per cent of the world's arable land. Except for Maldives, the role of agriculture in South Asian countries is notable playing a very significant role in national economies and rural livelihoods. Over the years, there has been a growing demand for high-value crops, which require assured water supply to minimize the economic risk though they could enhance rural livelihoods. However, low-value crops such as rice have a considerable impact on domestic food security. It should also be noted that the share of agriculture in GDP is declining, down to nearly 17 per cent in Sri Lanka and 19 per cent in India.

While the world demand for total fertilizer nutrients is estimated to grow at 2.0 per cent per annum from 2011 to 2015, Asia is the largest consumer of fertilizer in the world. Total fertilizer nutrient consumption in Asia is 60 per cent of the world total, and South Asia is the second largest fertilizer consuming region in the world (FAO, 2011) with consequent pollution especially related to fertilizer overuse (**Table 3**).

Table 3: Fertilizer consumption (kg nutrient per hectare of arable land)

Countries	Year								
	2002	2003	2004	2005	2006	2007	2008	2009	2011
Bangladesh	188.64	160.27	170.67	197.75	193.19	184.41	200.06	160.96	184.36
India	100.64	105.13	115.44	127.80	136.35	142.76	153.42	167.56	178.53
Maldives	6.00	8.00	10.37	29.67	117.67	87.33	22.33	7.33	3.66
Pakistan	140.84	145.95	157.67	175.19	177.51	169.81	171.93	242.16	217.14
Sri Lanka	304.56	259.18	287.01	255.29	291.31	288.52	311.71	281.37	280.75
South Asia	-	-	115.04	129.90	136.40	142.80	153.40	167.40	174.30

Source: http://data.worldbank.org/indicator/AG.CON.FERT.ZS/countries

2.2.1. Bangladesh

Based on import data, fertilizer use is increasing in Bangladesh (BBS, 2008). Import of fertilizers (Urea, T.S.P & S.S.P) for the year 2002-03 was only 842,000 tons, which increased to 2,234,000 tons in 2005-06. Studies made by Mahmood *et al.* (1994) from the mouth of Karnaphuli river to St. Martin's Island showed tangible concentrations of nitrate, phosphate and silicate that varied from 0.16 to 8.98 µg-at/1, 0.08 to 2.33 µg-at/1 and 0.67 to 63.31 µg-at/1, respectively.

The scenario of fertilizer use efficiency in coastal area of Bangladesh is different because of salinity and farmers growing traditional varieties of rice. Miah (2010) reported that the availability of phosphorus, potassium, sulphur, zinc and boron in all sites of coastal areas has significantly decreased. But some indications of sulphur build up in some locations such as Bhola, Porojpur and Noakhali existed. However, changes in nutrient status showed a significant depletion of plant nutrients supporting the overall degradation of land quality and soil fertility due to continuous cropping. In coastal areas, farmers grow less fertilizer responsive varieties. Hence only low amount of nutrients are anticipated to be exported to coastal environment from farmers' used fertilizers.

Arsenic contamination in Bangladesh and in West Bengal, India is now recognized as a trans-boundary issue. 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. The problem originated with intensive tapping of groundwater in West Bengal for irrigation and subsequently extended to the entire lower Indo-Gangetic plains to include Bangladesh. The arsenic rich minerals are distributed in an area of about 35,000 km2 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 (MOE&F Government of Bangladesh (2001)).

2.2.2. India

Being an agrarian country India uses large amounts of fertilizers and is globally second to China for use of fertilizer nutrients. Fertilizer is produced within the country and certain quantity is also imported from other countries. However, recent estimates of fertilizer residue input into the coastal seas are not available. A 1994 report estimated it to be of the order of 5 x 10^6 tonnes per annum while in the case of pesticides, it was estimated to be around 65,000 tonnes (deSa, 2011). A more recent estimate in the Kuttanad rice farming belt (Kerala, West coast of India) alone indicated a contribution of approximately 20,000 tonnes fertilizer/yr (Fertilizer Policy GoI, 2013). Associated with intensification of agriculture in coastal areas aided by modern salt-tolerant varieties and improved agricultural practices, nutrient transport to coastal water could be substantial.

Intensive agriculture is practiced along the east coast especially because of the large deltas that exist in this region. The main crop is paddy but other crops such as pulses and oil seeds are also cultivated. Cash crops like cotton and jute (especially in West Bengal and Odisha) are also grown. Coconut is grown along the coast in almost all the states and union territories. An example of the district wise cropped area of coastal districts in Odisha is provided in the **Table 4**. The situation is similar in the other states.

Table 4: Fertilizer consumption (kg nutrient per hectare of arable land)

S. No.	Name of the District	Paddy	Other Cereals	Total Cereals	Total Pulses	Total Food Grains	Total Oil Seeds	Total Vegetables	Total Spices	Total Fibres	Sugar-cane	Fruits
1	Balasore	240.3	0.9	241.3	20.3	261.5	15.0	31.7	7.1	3.0	0.1	7.3
2	Bhadrak	178.2	0.3	178.5	20.4	198.9	3.1	23.4	3.7	0.7	0.5	8.0
3	Ganjam	259.7	57.5	317.1	180.8	497.9	49.6	46.3	5.1	5.5	2.5	34.7
4	Jagatsinghpur	97.2	0.5	97.7	46.5	144.2	11.7	20.2	5.5	0.0	1.0	5.3
5	Khurda	110.7	1.1	111.8	43.0	154.9	3.8	27.4	1.6	0.3	0.7	20.9
6	Puri	172.2	0.4	172.6	45.2	217.8	11.8	17.0	1.0	0.0	0.4	18.4
7	Kendrapara	136.9	0.6	137.5	70.7	208.2	12.7	19.9	6.7	1.9	0.3	5.1

Source: www.cesorissa.org

A number of problems have been created due to agricultural practices including waterlogging and salinization of land due to excess irrigation and poor drainage; fertilizer usage that causes non-point source pollution and results in eutrophication of coastal waters and overuse of groundwater as well as its pollution.

2.2.3. Maldives

The share of agriculture in the national economy of Maldives has always been recorded as low and stagnant. Soils of Maldives are generally of low quality and hence easily prone to decline in productivity. To overcome this, fertilizer is used quite extensively, showing an increasing trend with 780 mt of fertilizers being imported in 2009 (Statistical yearbook, Department of National Planning, 2010, Govt. of Maldives). The freshwater lenses, on which the islands depend for their water supplies, are highly vulnerable to pollution caused by agrochemical misuse. The low level of organic matter in Maldivian soils could result into leaching of pesticides and fertilizers into the groundwater especially in the lagoons where high levels of nitrogen, potassium and phosphorous could cause algal blooms. That would result in coral death, ultimately causing severe ecological disturbance. As the area under cultivation rises, nearby mangrove swamps containing unique species will come under threat from the leaching of fertilizer and pesticides (Zuhair, 1996). In Thoddoo and Fuah Mulah, a GEF study in 2010 identified heavy use of fertilizers on agricultural farms as a source of pollution that had the potential to affect the freshwater aquifer of the island.

2.2.4. Pakistan

Agriculture is the mainstay of Pakistan's economy. It accounts for 24 percent of the GDP and employs 48.4 per cent of the total labour force. Over the years, total food crop production in Pakistan increased from 10 million tons in 1970/71 to about 33.7 million tons in 2010/11. Fertilizer consumption has increased several folds and reached one million nutrient tons in 1980/81, two million tons in 1992/93 and three million tons in 2002/03 with the current off-take being 3.93 million tons during the year 2010-11. The crop-wise per ha use of fertilizer generally varies with the farm size, sources of irrigation, educational level, land tenure and cropping system. A comparison between fertilizer recommendations and actual use shows that the N application rate is close to 80 of the recommendations compared with about 40 percent or less in the case of phosphate.

Over-application and use of chemical fertilizers is a common problem in Pakistan. About 50 per cent of fertilizers applied to crops are left behind as residues. The nutrients escape from the fields and are found in excessive quantities in underground waters, rivers, lakes and coastal waters. On average about 20 percent of nitrogen fertilizer is lost through surface runoff. Phosphorus which binds to the soil is generally lost through sheet and rill erosion from agricultural lands of Pakistan. The most important water pollution problems in the Indus Basin of Pakistan related to agriculture are: (i) excessive nutrients accumulating in surface and coastal waters that cause eutrophication, hypoxia and algal blooms; (ii) accumulation of nitrates in groundwater; and (iii) pesticides accumulated in groundwater and surface water bodies.

2.2.5. Sri Lanka

Agriculture sector has been the cornerstone of Sri Lankan economy and the culture, and it continues to play a central role in country's future socio-economic development strategies as well. Even though its contribution to the gross domestic production declined substantially during the past 3-4 decades (from 30 percent in 1970 to 12 percent in 2008), it is the most important source of employment for the majority of the Sri Lankan workforce. (CBSL, 2012). Synthetic fertilizers play an important role in maintaining the yield of crops and Sri Lanka leads the south Asian seas countries in terms of fertilizer consumption (kg nutrient per hectare of arable land).

Nagarajah *et al* (1988) reported that due to intensive cultivation of annual crops in Jaffna peninsula (North), the nitrate nitrogen levels in wells exceeds WHO recommended (10 mg/l) levels. Jaffna peninsula in Sri Lanka is an area of intensive agriculture using extensive organic and inorganic nitrogenous compounds. In a modelling study in the Chunnakam aquifer of Jaffna peninsula, average concentrations of NO_3–N and NO_2–N were 4.869 and 0.014 mg/L respectively and the aquifer vulnerability specific to nitrate contamination remain in "high" category. Although nitrogen loading at the domestic sources and irrigation is of the same order of magnitude, the loading from fertilizer input is much larger which is about 15 times higher. This finding suggests that the fertilizer input in agricultural areas constitute a significant contribution to the nitrogen content in the groundwater and soils in agricultural areas of Jaffna (Vithanage *et al*., 2014). Studies conducted in the Kalpitiya peninsula also indicated that leaching of chemical fertilizer from intensively cultivated lands seems to elevate the concentration of nitrates and phosphorus in ground water in both dry and wet seasons (Jayasingha *et al*.,2011). Author also reported that most wells had nitrate-N concentrations in excess of the WHO guideline building up of nitrate is quite dramatic and has been estimated at 1-2 mg nitrate -N/l per annum. A study of the domestic wells of Hambantota district indicated that mean values of NO_3^- and PO_4^{-3} concentrations were higher at some locations but the levels recorded were lower than SL standards (Perera *et al*., 2014).

Table 5: Fertilizer consumption (kg nutrient per hectare of arable land)

Area	Range of NO_3-N (mg/l)	Range of phosphate (mg/l P)
Tangalle		
Domestic wells (n=4)	0.568 ± 0.2a	1.20 ± 1.3a
Angunukola		
Domestic wells (n=5)	2.391 ±1.8b	0.677 ± 0.4a
Beliatta		
Shallow well (n=6)	0.168 ± 0.38ac	0.739 ± 0.32a
Balangoda (Reference site)		
Domestic wells (n=6)	0.444 ± 0.16acd	0.115 ± 0.16a

Source: Perera *et al*., 2014

There are several reports of eutrophication of water bodies and it is the end result of nutrients transported through runoff. Agriculture is often accused of being one of the main factors responsible for eutrophication. Nutrients enter a water body in different ways. A large portion of a water body may be covered by algae under these conditions. Such a formation is referred to as an algal bloom. More than 10 reservoirs in Sri Lanka including Kotmale reservoir have had algal blooms (Amarasiri, 2008). Some algal species are very toxic. Therefore, this situation should be considered when these reservoirs are used as sources of drinking water. All these water sources are directly connected with the coast. Intensive agriculture practiced areas such as Jaffna (north), Ampara and Batticalo (East), Puttlam and Kalpitiya (west) are very close to coast. Therefore, pollutants and contaminants coming from agricultural fields flow to the coast causing coastal pollution.

2.3. Aquaculture practices leading to coastal pollution

Fisheries and aquaculture are practiced to a great extent in south Asian countries and the produce serves as one of the major source of protein to combat malnutrition. Asia is the largest producer of cultured shrimp contributing 70 per cent of world production in 1998, of which South Asia's share was about 13 per cent. Shrimp aquaculture demands the use of a variety of chemicals apart from artificial feed to achieve higher production. Chemicals used in shrimp culture include disinfectants, water and soil treatment compounds, algicides and pesticides, plankton growth inducers (fertilizers and minerals) and feed additives. Highly polluted effluents from shrimp farms that are discharged into the coastal waters leads to eutrophication of the receiving waters.

2.3.1. Bangladesh

Shrimp represents Bangladesh's second largest export, contributing about 4per cent to GDP and employing approximately 1.2 million people in production, processing and marketing. Including family members, about 4.8 million Bangladeshi people are directly dependent on this sector for their livelihood (Loni and Bremer, 2013). In 2007-08, the shrimp farming area occupied nearly 217,877 hectares with about 80 per cent of the shrimp farming area in the southwestern region (Nupur, 2010). Studies have indicated that fertilizer (mineral as well as organic – cow dung) was the highest nutrient contributor into the shrimp ponds and a major portion accumulated in the sediments; nitrogen could have been lost through denitrification and ammonia volatilization processes (Barua and Choudhury, 2011). The coastal region, especially the southwestern portion (Satkhira, Khulna and Bagerhat) of Bangladesh, is one of the most promising areas for shrimp cultivation for two major reasons (Karim and Shah, 2001), first, its fresh- and saltwater resources are abundant in almost all seasons; second, the world's largest continuous mangrove forest, the Sundarbans, provides a food source and nursery for the offshore fishery. However, shrimp cultivation and human settlement are rapidly increasing in Cox's Bazar coast areas.

Das *et al.* (2004) reported that the mean levels of nutrients found in the shrimp cultured pond surface water in the southeast coastal region of Bangladesh were 108.780 mg/L for $CaCO_3$, 0.526 mg/L for NH_4^+ -N, 3.075 wt% for organic carbon, 7.00 mg/L for PO_4-P, 5.57 mg/L for NO_3-N. Nutrients loading were found to be decreased with distance from the shrimp farm discharge unit in estuarine water. The mean level of organic matter, total nitrogen, and organic carbon were found in higher concentrations in sediments of cultured pond compared to bottom soil of adjacent similar fallow land. The results revealed loading of nutrients at eutrophic level in estuarine water indicating a negative impact of shrimp culture. So, supplying farmers with alternative production systems with high land and water productivity is crucial for food security, enhancing farmers' livelihood and sustaining the environment of the coastal zone.

2.3.2. India

India has a long history of aquaculture, both in freshwater and brackish water. Aquaculture in India, in general, is practiced with the utilization of low to moderate levels of inputs, especially organic-based fertilizers and feed. Shrimp aquaculture is practiced mainly in Odisha (Chilika lagoon), Andhra Pradesh and Tamil Nadu. Aquaculture was popularized to bring in the Blue Revolution and while it has brought prosperity for some, it has been increasingly seen to be a problem industry because of unsuitable locations and unscientific practices in some cases. In some places, shrimp farms have come up in mangrove areas and have also resulted in salinization of the surrounding land, depletion of groundwater, release of inorganic nutrients as well as antibiotics and exotic species. India utilizes only about 40 percent of the available 2.36 million hectares of ponds and tanks for freshwater aquaculture and 13 percent of a total potential brackish water resource of 1.2 million hectares. Since the 1990s, there has been a huge increase in the construction of brackish water ponds for shrimp aquaculture when large areas along the coast were converted into aqua farms. In 2012, in India, shrimp accounted for around 50 per cent of the value of seafood exports with the increase in shrimp export achieved mainly by surge in production from aquaculture mostly contributed by the native shrimp species, the black tiger shrimp and supported by increased production of Vannamei shrimp (Narasimhan, 2013). There are various reports about the pollution loads due to shrimp aquaculture especially after harvest when the ponds are emptied and problems of algal overgrowth in receiving waters indicative of nutrients sourced from aquaculture wastes (Aquacuture Authority, 2001; Kutty, 2005; Rajitha *et al*., 2006; Putheti *et al.,* 2008).

Marine fisheries are an important traditional livelihood along coastal India and also contribute to the protein component of food. The marine fisheries sector has a very high population along the east coast. Traditional fishermen belong to specific castes and have their habitations very close to the shoreline. A variety of craft and gear combinations are used to catch fish. Information regarding the marine fishing sector along the east coast is provided in **Table 6**. Fish landing centres along the coast have been mapped in the **Figure 5**.

Table 6: Fertilizer consumption (kg nutrient per hectare of arable land)

S. No.	Details of fisheries	West Bengal	Odisha	Andhra Pradesh	Tamil Nadu	Puducherry
1.	Average Landings (2005) thousand tones	168.20	77.97	174.14	355.45	15.14
2.	Landing centres	44	57	271	352	26
3.	Fishing villages	346	641	498	581	28
4.	Fisherfolk families	53,816	86,352	129,246	192,152	11,541
5.	Fisherfolk population	269,565	450,391	509,991	790,408	43,028

Aquaculture activities are currently largely limited to the farming of crustaceans (e.g. shrimp, prawns and crabs) and seaweed; crustaceans; and seaweed. Although aquaculture is could have deleterious effects on coastal water quality, in terms of organic/nutrient pollution from uneaten feed or waste products, cleaning fluids and antibiotics in the feeds, and suspended solids from cleaning of ponds.

2.3.3. Maldives

The fisheries sector continues to remain imperative to Madivian economy albeit faced with a prolonged setback since 2006 and declining trend in total fish landings and contribution to the GDP. Coastal areas provide the foundation for the mari-culture (marine aquaculture) industry, which uses coastal space or relies on wild stock to produce valuable fisheries products, from tiger prawns to bluefin tuna. Human reliance on farmed fish and shellfish is significant and growing. Larger commercial reef fish, such as medium to large snapper, grouper, emperor and reef associated jack, are best caught by handlines and longlines. Other resources include aquarium fish, and non invertebrates, such as sea cucumber, lobster, giant clam and black coral. An increase in demand for reef fish from the tourism industry and overseas markets has raised the level of exploitation of particular reef fish varieties No commercial shrimp farming is reported from the Maldives.

2.3.4. Pakistan

Shrimp farming is being proposed in Pakistan especially in the deltaic areas but for now, it is not a significant activity (Fisheries Development Board, 2011).

2.3.5. Sri Lanka

Shrimp farming began in Sri Lanka in the early 1980s with the farming of the black tiger prawn, *Penaeus monodon* being successful and lucrative until major disease outbreaks occurred in the late 1980s. The shrimp aquaculture industry in Sri Lanka is concentrated in the North Western Province over a distance of about 120 km around Chilaw Lagoon, Dutch Canal, Mundal Lagoon system and Puttalam Lagoon, with 70per cent of farms depending on Dutch Canal for their water resources (Jayasinghe, 1995). In Puttalam district, the wetlands associated with the Dutch Canal have emerged as highly economically important. However, the development is haphazard. More than 1,300 farms are worked in this wetlands system in an area of 3,750 ha of which 48 per cent of the farms covering 40 per cent of the developed area are illegal and unauthorized. Lack of treatment of effluents before being let out resulted in severe eutrophication of the lagoon (Rohita, 2008).

BOBLME (2013) revealed that much of the coastal pollution in the Northwestern Province has been attributed to *ad hoc d*evelopment of aquaculture leading to the discharge of high amounts of effluents from shrimp ponds. This has already caused considerable pollution in the Dutch Canal (in the west) and the surrounding coastal areas. High levels of nitrates and phosphates released from shrimp farms into the coastal waters have caused eutrophication of nearby watercourses in the region and pollution of ground water. Corea *et al.,* (1995) reported that shrimp farm effluents reaching the Dutch Canal are high in total suspended solids (200-600 mg/l) and have high BOD levels (60-180 mg/l). These effluents cause heavy siltation in the canal increasing turbidity. High sulphides and ammonia levels in these waters are also attributed to shrimp farm effluents.

Shrimp farms in northwest are reported to discharge around 1,699 m^3 of pond water (containing high levels of nutrients and chemicals – lime and pesticides) weekly into the Dutch canal. Also, about 1,246 m^3 of water is discharged daily from the shrimp hatcheries in the area (CCD, 2006). It was revealed that current levels of pond water discharge are much higher than those already published. Pollution of the lagoons and estuaries also result in eutrophication, causing algal blooms that are often toxic, and oxygen depletion leading to mortality of natural fish and shrimp stocks in these water bodies (CCD, 2006).

2.4. Contribution of domestic sewage to coastal nutrient pollution

Domestic sewage includes household waste liquid from kitchen, washing, bathing and toilets. Untreated sewage contains water, nutrients (nitrogen and phosphorus) solids, pathogens, chemicals including detergents, oils and greases and heavy metals, among other constituents. While there is progress towards centralized collection and treatment of domestic sewage, in most countries, except for the large cities and towns, wastewater generated from homes is usually let untreated into the nearest watercourse.

2.4.1. Bangladesh

Although Bangladesh is still predominantly rural, the country has urbanised dramatically and since 1970 the urban population has risen from less than 8per cent to an estimated 27.5per cent in 2005. With explosive urban growth since the 1990s, capital city Dhaka's population has swelled by 40 per cent, faster than any other city of the world and is expected to be the fourth largest in the world with a population of 21.1 million by 2015. Other large cities are Chittagong and Khulna. Only a third of Dhaka city has wastewater collection and treatment facility while another third uses septic tanks. Most of the untreated or inadequately treated wastewater directly or indirectly reaches the river systems and finally reaches the bay through different canals, drains and estuaries. Sewage treatment systems are being planned in other urban centres (e.g. Khulna). Many of the cities and towns in Bangladesh contain swamps and lakes, which are used for informal aquaculture activities by local residents and the majority of these water bodies are contaminated with faecal matter (DFID, 2005).

Sewage of nearly 36 million people living in 19 Coastal districts directly or indirectly goes to the water systems (rivers) and eventually flows into the Bay of Bengal. In fact, none of the coastal cities have proper sewage system or sewage treatment plant in place. All the urban cities are supported by septic tank and pit sanitation. Poor households use community latrines. However, these systems are directly or indirectly connected to canals or rivers through surface drain of the city. This situation is becoming more serious due to increase of population in coastal districts and lack of proper sanitation as well as sewage treatment facilities. In addition, higher pollution load from industrial sources is generally accompanied by a higher risk of domestic and sewage pollution.

2.4.2. India

Domestic sewage is a major source of water pollution in India, particularly in and around large urban centres (BOBLME, 2011). Out of about 38,000 MLD of sewage generated, treatment capacity exists for only about 12,000 MLD. The existing treatment capacity is also plagued with operation and maintenance problems (CPCB, 2009). The total population of Class I cities (including metros) in coastal areas is 45 million and Class II towns is 2 million. The population of coastal metro cities alone is 31 million, which is 65 per cent of total population of coastal Class I cities and Class II towns. The city of Mumbai (Maharashtra) on the west coast alone generates 2400 MLD i.e. 38 per cent of the wastewater generated. It also

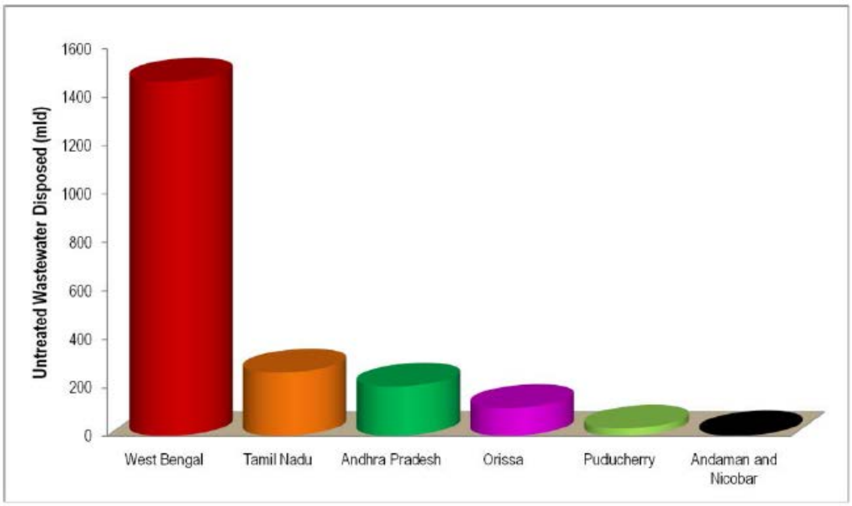

Figure 12: Untreated wastewater disposed to the coastal Bay of Bengal (Source: CPCB, 2002)

has treatment capacity of 2130 MLD (88 per cent of the sewage generated). Similarly the coastal cities of Chennai (Tamil Nadu) and Kolkata on the east coast generate large amounts of wastewater. It is therefore clear that if the wastewater generated by the larger cities is treated properly before disposal, a large proportion of the coastal pollution due to municipal waste disposal would be addressed. Current treatment capacity is less than 50 per cent of the wastewater generated. The wastewater from metros and Class I cities located on the coast is mostly disposed into creeks, canals or backwaters. It is estimated that 0.6 million tonnes of nitrogen and 0.1 million tonnes of phosphorus reach the coastal waters annually (CPCB, 2009).

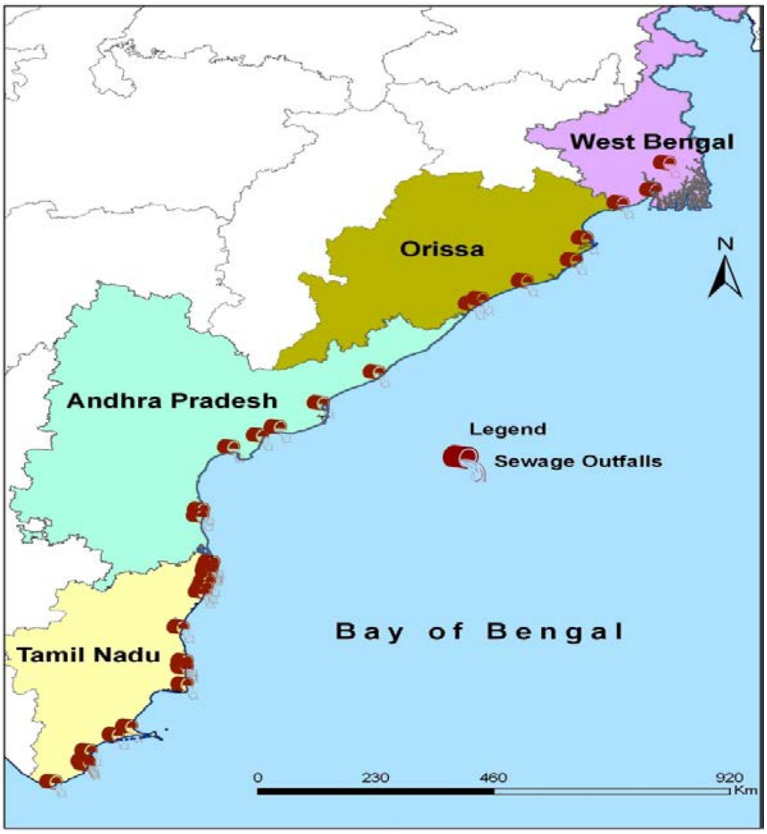

Figure 13: Location of Major Sewage Outfalls along the east coast of India

The wastewater let out through coastal outfalls is subject to water quality standards since water from the sea is also used for various activities. Based on the "designated best use", primary water quality has been specified for five designated best uses as shown in **Table 7**.

Table 7: Standards of seawater quality

	Class	"Designated use" of sea water
Sea water	SW-I	Shell fishing, Mariculture and Ecologically Sensitive Zones
Sea water	SW-II	Bathing, Contact water sports and Commercial fishing
Sea water	SW-III	Industrial cooling, Recreation (non-contact) and Aesthetics
Sea water	SW-IV	Harbour
Sea water	SW-V	Navigational and Controlled waste disposal

It is estimated that the Bay of Bengal receives ~400,000 tonnes of oil through i) oil spills, ii) crude oil residues and iii) wastewater effluents from refineries (which are land based) (BOBLME , 2011).

In order to create awareness among the public on the levels of marine pollution in the country, the Ministry of Earth Sciences has decided to publish the levels of pollution indicative parameters for the following locations at least every three months or as and when data are collected (East Coast commencing from 1st week of December 2006: Tuticorin, Cuddalore, Pondicherry, Ennore mouth, Bhimavaram, Kakinada, Gangavaram, Visakhapatnam, Paradip and Hooghly estuary.

2.4.3. Maldives

A hotspot analysis was carried out in 2010 for a GEF funded integrated water resources management project in the Maldives. On Gan island, coastal pollution was identified as a key issue of concern. The potential sources of pollution included discharge of untreated sewage effluent into the lagoon and the use of excess fertilizers in the agricultural land. The pollution sources in Hithadhoo, Thoddoo and Fuah Mulah were improper sewage disposal and inappropriate municipal solid waste management. In the capital island, chemical and biological contamination of groundwater due to household catch pits, junctions, vehicle garages and engine repair and maintenance workshops, increased coastal pollution from discharge of untreated domestic sewage effluent. Disposal of untreated sewage and food waste are believed to be major contributors to the nutrient influx to the marine environment. This is evident from the growth of seagrass beds in the vicinity of islands following inhabitation or increased population in the islands. There are neither existing guidelines nor a framework for monitoring and assessment of nutrient levels in the marine environment (BOBLME, 2010).

2.4.4. Pakistan

It is estimated that approximately 362 million gallons per day (MGD) of sewage is generated in Karachi and adjacent areas from domestic and industrial sources. Approximately, 60 % are industrial effluents and 40% domestic discharges. The industrial waste-water and sewage are discharged into the two seasonal rivers: the Lyari River and the Malir River of Karachi. These rivers act as main open sewers for liquid waste disposal from the city. The Lyari and Malir Rivers are thus contributing about 59% and 25% of the total pollution load of Karachi City respectively, while 15% of the pollution load is directly discharged into the adjacent open seacoast or discharged via Gizri, Korangi and Gharo Creek (Amjad and Rizvi, 2000). Much of the sewage effluents discharged through the Lyari River find their way inside the semi enclosed Karachi Harbour area. During high and low tide, the discharged effluents oscillate within the Karachi Harbour (length 8.2 Km). Ali and Jilani (1995) conducted chemical analysis of seawater samples taken from the Korangi industrial area effluent discharge site.

2.4.5. Sri Lanka

Like all other countries, surface inland waters in urban areas are polluted heavily with domestic sewage and industrial effluents, and in rural areas with agricultural runoff. Colombo is the only city in Sri Lanka with sewerage with 80 per cent of Colombo city area having access. The collected sewage is discharge into the sea through outfalls or directly discharge into the Kelani River or Beira Lake (a stagnated water body connected to the sea) without any treatment. The rest of the people have individual septic tank/soakage pit systems for sewage or domestic wastewater.

Over the years, environmental hazards related to solid waste have grown in Sri Lanka and continue to be a problem. From the total amount of waste collected daily by the Local Authorities island-wide nearly 75% is collected from the five Maritime Provinces. While western province account for 55% of the total solid waste, Colombo district alone has a daily collection of 43%. Other coastal towns also have problems of waste disposal. In the eastern province, the amount of solid waste produced estimated in tons/day is 45.75 in Ampara, 124.5 in Batticaloa and 87.4 in Trincomalee (ADB, 2003). Though the issue is more prevalent in urban areas, it is rapidly becoming a problem in rural areas as well.

Tourism expansion in Hikkaduwa, Beruwala and Unawatuna (southwest and south) areas has led to water quality degradation as well as visual pollution on beaches and near shore waters. The problem of sullage is particularly perceived as a problem associated with the larger hotels. The development of squatter settlements connected with tourism development is another cause for concern as it contributes to faecal pollution that is a severe threat to recreational activities such as contact sports in coastal waters (CCD, 2006). The high BOD and COD levels found during the one year study conducted by the University of Moratuwa in the coastal waters coincided with areas where tourism is predominant – Marawila, Mount Lavinia, Wadduwa and Beruwala showed high levels during the northeast monsoon as tourist season falls in the months of December and January (Jayaweera, 2003). Although Jayaweera (2003) presumed that the high faecal coliform levels at Ambakandawila were caused by effluent discharge from prawn hatcheries, doubts were raised at the national workshop in regard to the exact source of fecal coliform. Like in the industrial sector, many tourist establishments lack treatment facilities while those that possess such facilities seldom use them.

2.5. Industrial actions

The major input of nutrients, including both nitrogen and phosphorus, is from fertilizers and to a very small extent, in the formulation of detergents, used both the domestic and industrial sectors. In addition several industrial operations also release effluents that add to the nutrient budget of the coastal areas.

2.5.1. Bangladesh

The major point sources of pollution are untreated industrial wastes (also includes waste from ship Breaking yards), sewage disposal, solid waste, agrochemicals, waste due to land use changes, oil spillage etc. There are more than 8,542 industrials establishments (BOBLME, 2011) dealing with jute, paper and pulp, textiles, fertilizers, rubber and plastic, tannery, food and beverages, sugar, pharmaceuticals, tobacco, distilleries, cement clinker, ship breaking etc. on the coastal zone of Bangladesh. The textile industries discharge waste water of 40,000 m^3/day and pollution load of these industries is 26,000 kg/day. A rough estimation of Polychlorinated Biphenyls (PCBs) released from Ship breaking yards at Sitakunda, Chittagong at 22.5 tons per year has also been reported (Islam, 2004). The effluents are ammonia, chromium and other heavy metals from fertilizer and tanneries, phenols from pulp and paper, refinery, plastic, pharmaceuticals and paint industries (**Table 8**). There are also other acids, alkalis, organic and inorganic waste materials.

2.5.2. India

Particularly important in this regard are practices of pesticide and fertilizer use in agriculture and plantations, as well as aquaculture practices. Sea-based sources of pollution are of particular concern in areas of intense marine traffic such as the busy ports of Mumbai, Tuticorin, Chennai and Visakhaptnam. Approximately 95% of the country’s trade by volume and 70% by value is moved through maritime transport. There are eight major ports on the Bay of Bengal coast and fifty three minor ports. The capacity of major ports has increased from 574.77 million tonnes as on 31st March, 2009 to616.73 million tonnes as on 31st March, 2010. The major ports handled a total traffic of 530.53 million tonnes during the financial year 2008-09 and 411.95 million tones up to December 2009 in the financial year 2009-10 (GoI, 2009). Of particular concern is the potential for serious damage to livelihoods dependent on marine and coastal livelihoods in the event of major marine accidents such as oil or chemical spills from tankers. Major industries and mining activities situated within the coastal areas of India include textile industries, tanneries, paper and pulp mills, breweries, chemical factories, cement factories, sugar refineries, food processing industries (e.g. fish factories and slaughterhouses), fertiliser factories, oil refineries, and oil and gas exploration (an emerging activity). These contribute to transboundary marine pollution problems through inappropriate disposal of liquid wastewater, solid waste or atmospheric emissions.

Table 8: Standards of seawater quality

Parameters (mg/L)	Textile waste water	Tannery waste water	Pulp and paper waste water	Effluent standard (GOB, 1997)
BOD_5	8100	36000	600	50
COD	17100	56400	1700	200
Suspended solids	15221	7498	2024	150
Nitrate	200	700	-	10
Chloride	80000	62500	5900	600
Chromium	0.47	3818	-	0.5
Sulfide	-	1500	-	1.0

Source: Unnayan Shammannay, 2003 as cited by BOBLME, 2011

A number of power plants are located along the Bay of Bengal coast. The preference for the coast is due to the high volume of water for cooling that is required as the energy sector has mainly focused on coal fired thermal and nuclear power plants along the coast. Many refineries and oil terminals are also located along the coastline as indicated in **Figure 7**.

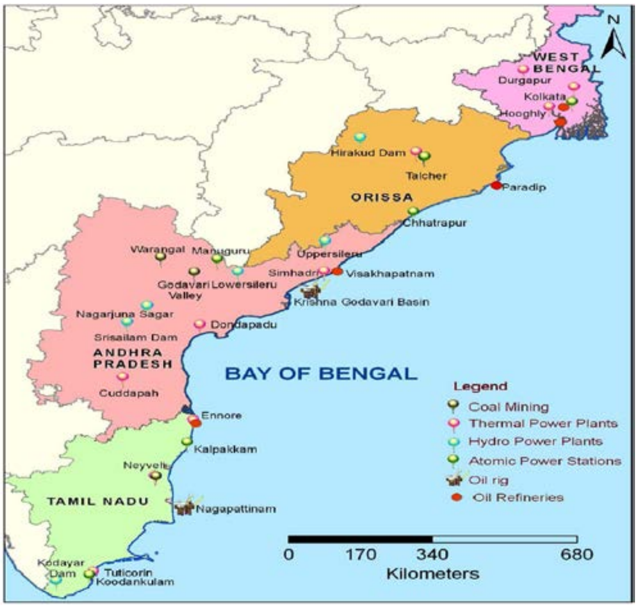

Figure 14: The Energy Map of the east coast of India

India has emerged as the third largest producer of nitrogenous fertilizers. The annual consumption of fertilizers, in nutrient terms (N, P & K), has increased from 0.07 million MT in 1951-52 to more than 28 million MT in 2010-11 and per hectare consumption, has increased from less than 1 Kg in 1951-52 to the level of 135 Kg now. The installed capacity of the domestic fertilizer industry was 129.45 lakh metric tonnes (LMT) of nitrogen and 62.13 LMT of P_2O_5 (phosphate) per annum as on 1.11.2010 (GoI, 2011).

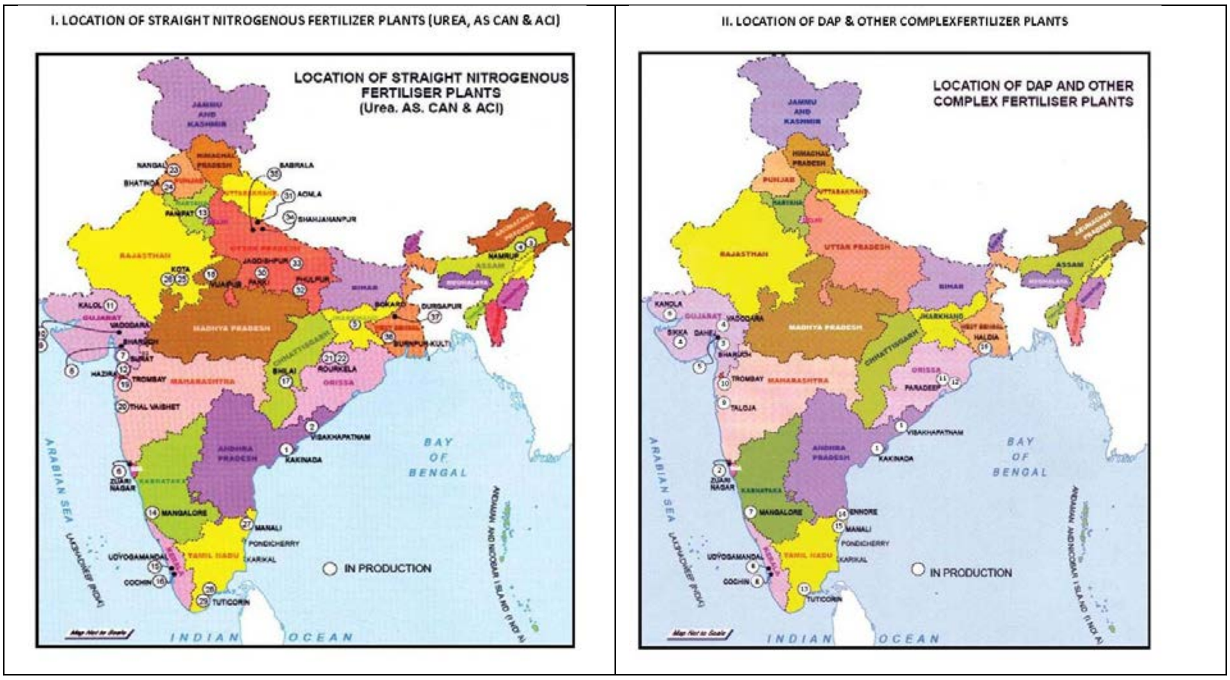

Figure 15: Location of fertilizer industries in India (Source: Ministry of Chemicals and Fertilizers, Govt. of India, 2011)

While bulk requirement of feedstock for manufacture of nitrogenous fertilizers is available from domestic sources, the same is not true for phosphates. India's phosphorous deposit is only $306x10^9$ kg—nearly 30 per cent of it is low-grade and useless for the fertiliser industry. Phosphorus fertiliser consumption, however, has increased from $53x10^6$ kg in 1960-61 to $7,300x10^6$ kg in 2009-10. It is likely to increase further and reach $14,000x10^6$ kg by 2030-31. Hence, bulk of the requirement of raw materials/intermediates is met through imports. It may be noted from the **Figure 3** (II) that DAP and other complex fertilizer plants are located close to large ports such as Paradeep, Visakhapatnam and Tuticorin on the east coast, Cochin, Mangalore and Zuari on the west coast. Reports on the pollution of ports as well as nearby coastal waters with effluents from the fertilizer industries are many (Zingde and Govindan, 2000; Shirodkar *et al*., 2009; Andrade *et al.,* 2011?; Jenaand Bhattamsira, 2009). However, no quantification of such pollution loads from either material handling in ports or from the industries is available.

Two large lagoons are located on the east coast of India, the Pulicat lagoon on the border of Andhra Pradesh and Tamil Nadu, and Chilika in Odisha. Both lagoons are rich in biodiversity and attract ornithologists as well as wild life enthusiasts from all over India and the world. The Sunderbans in West Bengal are the largest single stand of halophytic mangroves, and apart from these, places like Coringa mangroves in Andhra Pradesh and Pichavaram in Tamil Nadu have large mangrove stands with high biodiversity and therefore, high ecotourism potential. In addition, there are many important places of cultural tourism; standing out among them are Puri and Konarak in Orissa, Puducherry (Union Territory), and Mamallapuram, Poompuhar, Tranquebar and Kanyakumari in Tamil Nadu. A number of beaches are located along the east coast and some of the famous ones are the Digha in West Bengal, Puri-Konarak in Orissa, stretches near Visakhapatnam in Andhra Pradesh and the Marina beach in Chennai. The tourism sector is developing actively with the promotion of eco-tourism and beach resorts.

Figure 16: Location Map of tourist spots in East Coast of India

2.5.3. Pakistan

For the most part, marine and coastal zone pollution in Pakistan is limited to Karachi, a city of 22 million people that accounts for about 45 percent of the country's industry. All of Karachi's industrial waste, effluents, and domestic sewage, and all of the agricultural run-off from the hinterland and the Indus River find their way, untreated, into the Sea. **Table 9** gives a summary of pollution level at various sites on the Karachi coast.

Table 9: A summary of various types of pollution at different sites on Karachi coast (UNEP, 1986)

Area	Levels of Various Types of Pollution						
	Oil on water	Tar on beaches	Tar balls	Industrial	Domestic sewage	Sedimentation	Thermal
Paradise Point	-	-	+	-	-	-	-
Buleji	-	-	+	-	-	-	-
Hawks bay	-	-	+	-	-	-	-
Sandspit	-	-	+	-	-	-	-
Manora Channel	++++	+++	++	++++	++++	++++	+
Clifton	++	-	+	+	+	+	+
Korangi Creek	+	-	++	+	+	+	-

(+ low, ++ medium, +++ high, ++++ highest)

Karachi not only has the largest port in the country but it is also the industrial hub of the country and the main source of pollution in the coastal waters of Sindh. There are currently over 6000 big and small registered industrial units operating in Karachi. These industrial units are located in Sindh Industrial Trading Estate (SITE), Landhi, Korangi, Malir and the Port Qasim Authority area (PQA). There are more than 65 categories of industrial plants in the established industrial estates including, textile industries, tanneries, pharmaceuticals, plastic and rubber industries, steel foundries, metallurgical industries, electroplating and metal coating industries, glass, ceramics and tiles industries, cement industry, soap and detergents, fish processing industries, chemical industries, power plants, fertilizers and pesticides edible oils, automobile cable and conductor manufacturing etc. The industrial estates do not have a combined waste treatment plant anywhere on the premises. No comprehensive current data exist on either total industrial pollution loads or pollution intensities in Pakistan. Levels of six types of industrial pollutants— toxics, heavy metals, BOD pollutants, and suspended solid water pollutants, particulates, sulfur dioxide air pollutants— increased between six- and tenfold between 1963 and 1988, during which time GDP grew by a factor of three.

2.5.4. Sri Lanka

Major commercial ports contribute to pollution of coastal waters due to accidental release of oil. Poor reception facilities for waste oil, ballast and bilge waters cause the port waters to be polluted. There are specific arrangements for the disposal of waste oil from ships that call at the Port of Colombo during loading or unloading of cargo. About 36 private companies are registered with the Marine Pollution Prevention Authority (MPPA) to collect the oil waste, which is pumped, into bowsers directly from the ships. However, no regulating authority monitors the final disposal of this oil.

2.6. Burning of fossil fuels

The byproduct of fossil-fuel combustion, principally exhaust from motor vehicles and electric-power generation, is a major source of N to coastal waters in many regions (State of the Environment Maldives, 2011). This includes both direct deposition of airborne N onto the surface of coastal waters and deposition onto the landscape, where it subsequently washes or leaches into rivers or groundwater that flows into coastal ecosystems (Galloway *et al.*, 2008). The limited evidence available indicates that direct deposition of airborne N onto the water surface alone contributes from 1 percent to 40 percent of the total N entering an estuary, depending to a large extent on the size of the estuary relative to its watershed (Meyers *et al*., 2001). In general, the larger the estuary is relative to its watershed, the greater the percent of N that is deposited directly onto the water.

For estuaries that are small relative to the size of their watersheds, N deposition from the atmosphere onto the landscape, with subsequent runoff into the estuary, is probably a greater source than deposition of N directly onto the water surface. Unfortunately, the magnitude of this input is poorly characterized for most estuaries.

3. National, Legal and Policy frameworks and other actions

The **Table 10** gives a quick overview of the national legal and policy frameworks of the different countries that have a bearing on nutrient pollution of coastal waters.

Table 10. Legislation and Policy frameworks

Table 10: Legislation and Policy frameworks

Country	Policy, Action Plans	Legislation
Bangladesh	Different Ministries of the Government have announced, over the years, their respective policies for carrying out the mandates. The Ministries implement various programs directly and indirectly through their concerned agencies. There are national NGOs such as ASA, BRAC, and the Grameen Bank, and smaller local NGOs and internationally funded activities such as Danida's water supply and sanitation program. Some of the centrally adopted policies include: National Environment Policy and Implementation Plan (MoEF 1992) National Policy for Safe Water Supply and Sanitation (MoLGRD&C 1998) National Fisheries Policy 1998 National Agriculture Policy 1999 National Water Policy (MoWR 1999) National Shipping Policy (MoS 2000) National Land Use Policy (MoL 2001). Integrated Coastal Zone Management in Bangladesh (PDO-ICZM, 2003) Coastal zone policy and strategy, 2005	Bangladesh has 35 laws that exclusively deals with environmental issues and also has over a 100 laws that deal with the various aspects of the environmental issues. The following are the major legal instruments related to pollution control and conservation of biodiversity: *Water Prevention and Control of Pollution Act and Rules* Water Prevention and Control of Pollution Act, 1974 *The Environment Protection Act and Rules* Environmental Conservation Act, 1995 (amendment 2000, 2002) Environmental conservation Rules, 1997 Environmental Court Act, 2000 (Amendment 2002) The Wildlife (Preservation) Order, 1973 and Wildlife Preservation (Amendment) Act 1973 The Forest Act, 1927 (Amendment 1990, 2000) Biosafety Guidelines of Bangladesh, 2007 National Biodiversity Framework, 2007 *Water Quality Standards* National Water Policy (NWP), 1999 National Policy for Safe Water Supply and Sanitation (1998) National Water Management Plan (NWMP), 2001 *Agro-Chemical Pollution Control* Pesticides law, 1985 *Ongoing Ordinance, Rules & Guideline* Solid Waste Management Ordinance, 2010 Ship Breaking and Hazardous Waste Management Rule, 2010 Biosafety Ordinance, 2010 ECA management Ordinance, 2010

India	The Department of Ocean Development (DOD) established in 1981 formulated the first Ocean Policy Statement (OPS) of the country, which sets out the basic principles for development of ocean resources is to be carried out. India is the first country to adopt such a policy. National Environment Policy, 2006 The optimal utilization of fertilizers, pesticides and insecticides should be encouraged for improving the water quality. National Fertilizer Policy Government of India decontrolled Phosphatic and Potassic (P&K) fertilizers with effect from 25th August 1992 on the recommendations of Joint Parliamentary Committee. Consequent upon the decontrol, there was an imbalance in the usage of the nutrients of N, P & K (Nitrogen, Phosphate and Potash) and the productivity of the soil. Then the Government introduced Nutrient Based Subsidy Policy w.e.f. 1.4.2010 (w.e.f. 1.5.2010 for SSP) in continuation of the erstwhile Concession Scheme for decontrolled P & K fertilizers. National River Conservation Directorate (main focus is to reduce pollution inputs by constructing sewage treatment plants)	In order to protect its marine environment, the Government of India, even before 1992, had initiated a number of programmes. These acquired a new significance post-1992. To meet the objectives of Agenda 21 of UNCHE, continuous monitoring of ongoing projects, acquiring of new technology and implementation of already-existing policies is being actively carried out. Environment (Protection) Act, 1986 Environment (Protection) rules, 1986 Environment Impact Assessment Notification, 2006 Coastal Regulation Zone Notification, 2011 Water (Prevention and Control of Pollution) Act, 1974, amended 1988 Water quality standards The Air (Prevention and Control of Pollution) Act 1981, amended 1987 The Air (Prevention and Control of Pollution) Rules, 1982 The Air (Prevention and Control of Pollution) Rules, 1983 Air quality standards Insecticides Act, 1968
Maldives	National Environment Action Plan (NEAP) and the second National Environment Action Plan. (NEAPII) General Guideline for Domestic Wastewater Disposal 2006 National Wastewater Quality Guidelines, 2007 National Solid Waste Management Policy for the Republic of Maldives, 2008	Environment Protection and Preservation Act of the Maldives, April 1993 Environmental Impact Assessment Regulation, 2007 Draft Regulation of Environmental Liabilities, 2010 Pesticides Bill (Draft) 2010 Waste Management Regulation, 2014

Pakistan	National Environment Policy, 2005 (NEP-2005) Integrated Coastal Zone Management Plan (ICZMP) for Pakistan in 2011	Pakistan Environmental Protection Ordinance, 1983 Pakistan Environmental Protection Act, 1997 National Environmental Quality Standards (NEQS) (1993) Canal and Drainage Act (1873) Punjab Minor Canals Act (1905) Sindh Fisheries Ordinance (1980)
Sri Lanka	National Environment Policy 2003 National Policy on Solid Waste Management 2007 National Watershed Management Policy 2004 National Policy on Wetlands 2005 National Biosafety Policy 2005 National Water Policy 2014	National Environmental Act No. 47 of 1980 National Environmental (Amendment) Act, No. 56 of 1988 National Environmental (Amendment) Act, No. 53 of 2000 Marine Pollution Prevention Act No. 59 of 1981 and its amendment No.35 of 2008 Coast Conservation Act No. 57 of 1981 and amendment of 1988 Ambient air quality standards for Sri Lanka (gazette notification No. 850/4, Dec 1994) Coast Conservation (Amendment) Act 1988 (No. 64 of 1988) National Environmental (Procedure for approval of projects) Regulations No. 1 of 1993 Gazette Notification Number 772/22 dated 24th June 1993 Specifying the State Agencies which are PAAs (EIA) Gazette Notification Number 859/14 dated 23rd February 1995 National Aquatic Resources Research and Development Agency Act No. 54 of 1981 and its amendment Act No. 32 of 1996

4. Existing challenges, constraints and gaps

4.1. Challenges and Constraints

A major challenge is the inconsistent availability of information on phenomena such as algal blooms. For example, Bhat and Prabhu Matdonkar (2004) examined a database on research publications dealing with marine, brackish water and freshwater in India. They found only patchy and scattered efforts on bloom research with most of the publications due to instant response to the bloom episodes. The concept of blooms either in terms of their real extent or composition for a discernible consequence remained obscure along lack of clear distinction on the kind of blooms with terms like 'toxic', 'noxious' and 'nuisance' being used synonymously.

Bay of Bengal and the northern Indian Ocean region is considered to be deficient in nutrients. However, not many studies have been carried out for scenarios under reduced nutrient regimes. For example, simulation studies to understand the response of Vembanad Lake to reduction in phosphorus indicated that 12.5% of the existing load of phosphorous is necessary to achieve the targeted reduction in chlorophyll value of <10 mg/l so as to bring the lake to mesotrophic/oligotrophic level but the response will not be immediate with the lake moving to a new steady state (Bindu and Harikumar, 2007).

Another challenge is the lack of data. India being the largest of the five South Asian maritime countries has relatively extensive information on nutrients in coastal waters, but this may not be so for the other south Asian Seas nations. But even for Indian databases, estimates of total load from different sectors such as agriculture, sewage, aquaculture or industry are not available; or if available, quite limited. Information for other countries, especially for Pakistan, for example, is scarce and information are now emerging on the change in floral composition following nutrient leakage to the coastal areas. A major source of information is through international research projects (e.g. APN) or through donor agency reports (e.g. World Bank). Dependence on the internet for reports and technical papers, language issues (non-availability of information in English) and the vast literature that had to be combed to distil relevant information are some of the major constraints.

Coastal pollution is potentially a transboundary issue, but two conditions need to be met before it may be considered strictly transboundary: (i) the impacts of the contaminant/pollutant occur within the waters of a country that is not generating the contaminant or pollutant; and (ii) that there is a basin scale impact. With the possible exception of the long-term issue of expansion of bottom water anoxia in the upper Bay of Bengal, the threat from plastics and fishing gear in the north Indian ocean, and the Ganges-Brahmaputra-Meghna system where sewage and other forms of organic contamination are likely to be transboundary between India, Bangladesh, and Myanmar, most pollution issues in south Asian Seas region are likely to be more of local concern. However, these issues can be included as transboundary issues if the ecosystem degradation/loss contributes to a global environmental problem and finding regional solutions is considered a global environmental benefit.

4.2. Gaps

Pollution of oceans and coasts is rapidly becoming a major problem world-wide and the coastal areas of south Asian Seas is no exception. The coastal waters are under the constant threat of pollution from a number of land based sources apart from marine sources. Despite knowing the effects of land-based pollution on the coastal waters, direct and indirect discharge of wastes and effluents from untreated domestic and industrial sources continue reach the coastal waters.

There are basically two types of knowledge gaps in the region pertaining to pollution. There is a real lack of scientific information required for managing and reducing pollution in the region. This includes information on pollution hotspots, and on how and where pollution is attenuated on land, in rivers and in the sea. There is also a perceived lack of information. This is that the information does exist, but is not widely disseminated or available in the region, or is not in a useable form. This type of information includes knowledge on clean technologies for industry and treatment of wastes, and best practices for agriculture and aquaculture. The second gap in information is the lack of uniform standards for the establishment of permissible limits of toxic discharge. There is a need to establish the relationships between specific activities, the types and amount of pollutants they discharge and attenuation rates or carrying capacity of receiving environments. Without this information it is difficult for even the best-equipped institutions to enforce permissible limits and polluter pays policies.

Although there could be location-specific issues, most of the important information gaps for prudent management of the coastal/marine environment in the south Asian Seas region include:

- Seasonal and annual variation in pollution loads from land-based activities,
- Extent of contamination of coastal sediments as a result of land based activities,

- Coverage, treatment types, and discharge data for urban sewerage systems to determine effectiveness and efficiencies of these systems.
- Knowledge about the chemical, physical, hydrological and biological processes taking place in estuaries, marine habitats, coastal waters and the inter-dependency among various marine resources.
- Impact of coastal aquaculture on mangroves and other coastal habitats,
- Coastal erosion due to human activities
- Ballast water disposal into coastal waters and its impact as well as information on Invasive Alien Species
- Oil pollution from ports, oil rigs as well as spills during transportation
- Marine Litter related data
- Information on bioaccumulation, bio-concentration, bio-magnification and trophic transfer of critical pollutants

5. Policy actions to address gaps

Effective ecosystem-based actions need to integrate social, economic and environmental concerns, the cornerstones of sustainable development. The actions needed are broad and need to approach the main issues from different angles, including changes in the way people think, through to empirically analysing the problems of pollution, and making interventions at a range of governmental and geographic scales. The following are some of the issues crying for attention for defined policy actions:

a. *Ecology*: Strict enforcement of laws and policies. Wherever needed amendments to the existing legislation be carried out to ensure the objectives of sustainable coastal management and restraining harmful impact on coastal ecology.
b. *River management*: River conservation program have direct linkage with coastal habitat conservation. However, very little efforts have been made at linking river conservation program with coastal conservation activities. A comprehensive approach to river conservation in terms of land use planning, scientific urban management, industrial sitting, transportation of chemicals, and discharge of effluents need to be adopted.
c. *Develop quality standards for coastal waters*: Almost all the countries have some defined standards for water quality, especially for drinking water. However, a uniform standard on primary water quality criteria for the coastal waters and designated best use in the identified stretch of the coastal segment is of great importance. Obviously this needs to be backed by a long-term water quality monitoring program.
d. *Managing pollution sources on the land*: Nutrient leakage from fertilizer use in agriculture is one of the important contaminant to the seas. All the countries in this region excepting Maldives have an intensive agriculture based economy and the use of fertilizer nutrients is on the rise. Thus, reducing the overflow of nutrients through increase in the nutrient use efficiency of the agricultural system is an urgent necessity. The efforts of Bangladesh in increasing the use efficiency of fertilizer N is a good pointer (Sutton et al., 2013). This, in fact could be a win-win situation whereby use of costly chemical fertilizer can be reduced thereby reducing both the cost of cultivation as well as nutrient leakage.
e. *Integration and coordination*: Develop national and sub-regional policies for conservation, protection and sustainable development of ocean and marine resources. They will integrate these policies with their larger national and sub-regional sustainable development policies, so that synergy in the achievement of the larger objectives can be ensured. A close interaction among the stakeholders (both at Government and non-Government level) through use of latest technologies including remote sensing and information technology would be more appropriate for large-scale integration and coordination among the member states.

6. Recommendations

There are major concerns over the effective institutional harmonization (between government agencies, among NGOs as well as between governments and NGOs). Addressing these concerns, which are essentially about governance issues, is fundamental to the future development of policies for sustainable management of coastal areas and demonstrates how these issues cannot be separated from the wider social and political conditions of countries. Training, educating, awareness program, legal enforcement mechanisms, financial mechanisms, contingency planning, research and monitoring, and public participation are necessary to achieve this goal. The following are some of the recommendations that can be operationalized

a. Nutrients like nitrogen and phosphorus that are necessary for food production should be captured and recycled. The use efficiency of many of the nutrients is abysmally low and integrated R&D efforts should be initiated to increase their use efficiency so as to maintain agricultural production with lower amount of nutrient use while preventing their leakage to the environment.

b. Oceans and coastal areas offer interplay of numerous natural and man-made factors. Unfortunately, very little survey and research work has been done to critically understand the interaction. Important information such as chemical run-off from inorganic fertilizer and pesticides to water bodies, economic valuation of important features such as wetlands, studies on pollution loads of rivers and major water bodies in the region are lacking. Similarly, data on physico-chemical property of coastal water and their biotic influence on eco-system also need to be studied by making efforts for joint study / research program on some of these critical issues.

c. Ecosystem health report cards are an effective means of tracking and reporting the health of a waterway at both local and regional scales. River/estuary/bay health can be affected by elevated nutrient and sediment loads, adversely influencing water quality and biological diversity. For the report card, river/ estuary/ coastal health is defined as the progress of six indicators towards established ecological thresholds. The three water quality indicators are chlorophyll a, dissolved oxygen, and water clarity: and the three biotic indicators are aquatic grasses (submerged aquatic vegetation), Benthic Index (soft bottom only), and Phytoplankton Index. In India, ecosystem health report card has already been developed for Chilika lagoon and has been highly successful in stimulating confidence among the stakeholders of the lagoon. Efforts are also underway to develop similar ecosystem health report card for the coastal areas of Gujarat in the north-west part of India.

d. There is a strong need for not only creating a greater stakeholder involvement but also to create and support the existing program for spreading awareness and educating stakeholders about the three pillars of sustainable development. The campaign would require association of several small grass-root level organizations. Building awareness is the foundation for a large scale voluntary compliance regime. The youth and the school going children are the most critical targets for spreading education and awareness. This endeavour is not to be restricted to coastal areas alone, as whatever is done in the upper reaches, ultimately, influences coastal environment. School curricula need to be reviewed in order to ensure mainstreaming of environmental issues.

e. All States in the region are signatory to the major international conventions concerning hazardous chemicals and other major pollutants. Adequate national and local legislations to implement international commitments have to be put in place. The States would look into their international commitments and identify special areas for legislation, so that legislation can be developed in these specific areas within a time bound manner as per the requirement of the international convention. In this direction regional multi-lateral bodies like SACEP can play an active role in introducing collaborative research efforts.

7. Conclusions

South Asian estuaries appear to be largely heterotrophic and denitrifying systems and hence maybe influenced by nitrogen pollution. Most centres of high population are located near rivers or watercourses. All the south Asian countries having maritime boundary excepting Madives, have agriculture as the major activity and leakage of fertilizer N and P and pesticides remain the major source of pollution. Treatment of sewage before it is let into receiving waters is limited and hence sewage is also an important source of nutrient pollution in this region. Data on livestock sources of nutrients into receiving waters are not available though they may be considered as another important source considering the large livestock population in the South Asian countries. Other local factors including use of detergents and washing clothes by the river resulting in loading of detergent phosphates into the system could be other major source. The problem of detergent phosphates can become significant when the receiving water body is phosphorus-limited, which is what has been observed in some locations on the east coast of India.

Inorganic fertilizer usage in terms of tons of nutrient per 1000 ha has been steadily increasing in India and Pakistan though it is coming down marginally in the other countries in the region. This is likely to contribute to an increase in the amount of fertilizer residue reaching the coast. However, there are no quantified estimates of such contributions especially through non-point sources. A few nutrient budget studies are available but studies simulating variations in nutrient inputs and the response of the receiving waters are scarce. An integrated approach towards studying and implementing the accrued knowledge will enable proper management of south Asian seas and long-term sustainability of its natural resources.

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Bangladesh, India, Indonesia, Malaysia, Maldives, Myanmar, Sri Lanka and Thailand are working together through the Bay of Bengal Large Marine Ecosystem (BOBLME) Project to lay the foundations for a coordinated programme of action designed to better the lives of the coastal populations through improved regional management of the Bay of Bengal environment and its fisheries.

The Food and Agriculture Organization (FAO) is the implementing agency for the BOBLME Project.

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