



Coastal Ecosystem – Features, Constraints and Future Suggestions: An Overview¹

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Coastal ecosystem poses a delicate equilibrium between land and water masses amongst its different components but with high degree of vulnerability in spite of bountiful natural resources. The equilibrium is further under serious threat due to climate change and global warming. On the other hand, it is significant that coastal marshes tend to sequester carbon continuously with increasing storage capacity and with time, and thus regarded as a valuable C sink per unit area, particularly in the tropics, to negate adverse impacts due to global warming. Planning for effective and sustainable development warrants specific attention to maintain the equilibrium. This will require adoption of integrated approach to soil and water management, in the first place, and through it or otherwise, necessary measures to conserve the ecology. Piecemeal approaches to reclaim location specific problems or interference with the hydrology of the rivers *per se* for short term gains for increase of productivity or otherwise, disregarding completely the practices on integrated management of different intervention areas and thereby conserve the ecology in coastal plains, may offset the equilibrium, as experienced in different parts of the world, leading to such adverse impacts, such as seawater intrusion into inland areas, massive loss of mangroves, coral reefs, seagrasses and various other aquatic plant & animal species, sedimentation & erosion, tidal flooding, subsidence of land, etc. The influx of reckless application with fast increasing dose of nitrogen or other inputs resulting in nutrient imbalance through human activities in the adjoining inland and coastal areas are glaring examples leading to such phenomena as eutrophication and formation of dead-end zones in the coastal water bodies. Policy approach for water budgeting of different water resources, preferably on watershed basis, with minimal or planned dependence on abstraction of the underground water should be an essential strategy to be drawn in order to ensure sustainable increase in crop water productivity as well as water productivity in other sectors all along the coast. It is emphasized that Govt has the scope to develop more comprehensive climate change policies to mitigate weather adversities causing colossal loss due to impacts of the natural disasters. There is a need for development and validation of location specific rice-based diversified farming models for both east and west coasts of the country. These models should be cost-effective and environmentally sustainable and can optimize utilization of natural and human resources. Dissemination of rice-based farming systems will need support facilities in terms of capacity building, partnership development, market intelligence and micro-finance. It is strongly urged to explore and exploit non-farm actions, be it ecotourism or beyond, seriously, alongside application of on-farm activities, to improve livelihood sustainably with full protection to ecology of the area in the coastal ecosystem.

(Key words: *Coastal ecosystem, Technological constraints, Climate change, C sequestration, Production systems, Soil and water management*)

‘Coastal plain’ is the landward extension of the continental shelf or the sea and commonly used for agriculture and allied activities as well as for few other occupational purposes, but is generally distinctly differentiated from other ‘main’ components, viz., estuaries, coral reefs, salt marshes, mangrove swamps, macrophyte dominated regions, continental shelves, etc. Rather, coastal plains may, in some cases, include few such main components within its spatial boundary,

and are in dynamic equilibrium with each other, together present the ‘coastal ecosystem’. In other words, though at a given time the area under each component is well demarcated and thus areas may be estimated with some degree of precision, it may alter, even considerably, over a long time from one component to another or *vice versa* because of geomorphologic changes due either to or a combination of climatic, hydrological, geological and anthropogenic factors, in support of

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which there are plenty of examples all over the globe. This suggests its vulnerable nature, in other words stability of the coastal ecosystem at large, extent of which is much more than other ecosystems. Stability of the ecosystem should be of vital importance for the very high population density living along the coast.

Of the four factors mentioned above, possibly nothing can be done to control the geological factors in order to mitigate the vulnerability of the ecosystem except taking indirect measures by avoidance through advance message network, while for factors related to climatic phenomenon, increasingly gaining importance due to global warming, little can be done to contain it so far, and for the other two some exercises may possibly be undertaken to improve stability location-wise as well as globally. It should be worth to gauge the vulnerability or stability of the coastal ecosystem – its method and the extent, the factors affecting it and future predictions, and the nature of influence on the ecological balance at large including soil and water salinity, cropping system, and biogeochemical characteristics of the coasts, and finally suggest the adaption measures. This calls for a new concept for integrated coastal area development, the main fulcrum of which should rest on the scope to improve the stability of the ecosystem on a temporal scale, the impact of global warming notwithstanding.

Coastal areas in India and elsewhere are by and large heavily populated. Nearly 40 % of cities larger than 500,000 population in India are located in the coast. Overall about 50-70 % of the global population lives within 100 km of the coastline covering only about 4 % of earth's land (Poyya and Balachandran, 2008), thereby drawing heavily on coastal and marine habitats for food, building sites, transportation, recreational areas, and waste disposal. According to another estimate (Wikipedia, 2009), coastal areas (within 200 km from the sea) share less than 15% of the earth surface area, and this predicts that three-fourths of the world population are expected to reside in the coastal areas by 2025. It is important that coastal ecosystems have an economic value beyond their aesthetic benefit supporting human lives and livelihoods. By one estimate (Poyya and Balachandran, 2008), the combined global value of goods and services from coastal ecosystems is about US\$ 12-14 trillion annually - a figure larger than the United States' Gross Domestic Product worked

out in 2004. Notwithstanding these facts, the areas face a number of challenging areas worth consideration for planned development, and these include a series of constraints threatening productivity in agriculture and allied areas, the very base for the livelihood of the poverty-stricken inhabitants, human and climate induced factors threatening the ecological sustenance, and catastrophic effects of the weather disaster, which further aggravates due to climate change phenomenon. If the strength in this ecosystem rests with bountiful natural resources the weakness also lies in the same and its unplanned and arbitrary use, deserving therefore appropriate and scientific exploitation, in the first place, of the land and water preferably in an integrated fashion.

Definition and delineation of coastal areas

As per the 1991 notification, the Coastal Regulation Zone (CRZ) in India extends upto 500 km from the high tides and includes the land between high tides and low tide lines. The ecosystem thus includes saline, brackish (mixed saline and fresh) and fresh waters, as well as coastlines and the adjacent lands, the latter being the landward extension or the coastal plain. The different components, like estuaries, macrophyte communities, mangroves, coral reefs, salt marshes and the remaining continental shelves normally present in the coastal ecosystem, are in dynamic equilibrium and believed to be highly vulnerable to any change in the system. Velayutham *et al.*, (1998) for the first time made a scientific attempt to characterize soil resources and their potentials of the coastal plains belonging to different Agro-ecological Sub Regions (AESR) in India showing a total of 10.78 million hectare area including the islands. Delineations made by them need to be further refined with due consideration to the prevalence of biota or their remnants, an all-important parameter, in the ecosystem.

Technological constraints

Different factors limiting agricultural productivity as well as ecological sustenance of the coastal plains are listed as (1) Excess accumulation of soluble salts and alkalinity in soil, (2) Pre-dominance of acid sulphate soils, (3) Toxicity and deficiency of nutrients in soils, (4) Drainage congestion particularly in low lying areas, (5) Inadequate availability of good quality water suitable for irrigation, (6) Intrusion of seawater into coastal aquifers, (6) Shallow depth to underground water table generally

rich in salts, (7) Periodic inundation of soil surface by the tidal water *vis-à-vis* climatic disaster and their influence on soil properties, (8) Heavy soil texture and poor infiltrability of soil, (9) Eutrophication, hypoxia and nutrient imbalance, (10) Erosion and sedimentation of soil, and (11) High population density, etc.

A number of location specific studies have been conducted for the management of coastal stressed soils for higher agricultural productivity through drainage & desalinization of water congested areas particularly in the low lying belts through adoption of appropriate sub-surface drainage or through suitable land shaping technique, leaching of excess soluble salts in saline soils, reclamation of acid sulphate and sodic soils, and remedial measures of the nutritional disorders, etc. Methods developed for each will be sustainable in the long run if due attention is paid to integrated practices of land and water resources and through it or otherwise the necessary measures to conserve ecology at the same time.

Soil health and carbon sequestration

The importance of improved soil quality in the coastal plains through higher SOC level of the soils is established. IRRI characterized lowland rice soils (excluding deepwater rice) in Asia in respect of soil quality (Haefele and Hijmans, 2009), which includes large areas under coastal plains. They grouped soil qualities into four categories. These were: Good, Poor, Very Poor and Problem soils. 'Good' and 'Poor soils' represent those with different degrees of weathering but without major constraints; 'Very Poor' represents soils with multiple chemical constraints (acidity, deficiency of phosphorous, or toxicities of iron and aluminum); while 'Problem soils' represent those with the most frequently cited soil problems, including acid sulphate, peat, saline, and alkaline soils, which partly cause low fertility, and partly soil chemical toxicity.

Modeling C sequestration so far indicated that coastal marsh ecosystems tend to sequester C continuously with increasing storage capacity as marsh age progresses and its area increases. Thus, C sequestration in coastal marsh ecosystems under positive accretionary balance act as a negative feedback mechanism to global warming. Choi and Wang (2004) were of the opinion that dynamics of carbon cycling in coastal wetlands and its response to sea level

change associated with global warming is still poorly understood. However, they also observed during their study at Florida that salt marshes in this area have been and continue to be a sink for atmospheric carbon dioxide. Because of higher rates of C sequestration and lower CH₄ emissions, coastal wetlands could be more valuable C sinks per unit area than other ecosystems in a warmer world. Brigham *et al.* (2006) stated that the estuarine wetlands sequester carbon at a rate about 10-fold higher on an area basis than any other wetland ecosystem due to high sedimentation rates, high soil carbon content, and constant burial due to sea level rise.

In India, possibly, the first ever study made by Bhattacharyya *et al.* (2000) more than a decade back showed SOC pool in two soil strata under different physiographic regions including coastal areas. The data based on soil analyses covering 43 soil series showed the SOC data varied from 2.4 Pg to 10.9 Pg from 30 cm to 150 cm soil depth. It will be prudent to concentrate on elaborate studies in future on monitoring SOC pool in different soil strata in coastal areas over a long period of time, and relate them with sea level rise, extent and nature of land submergence with water, seawater quality, extent and nature of vegetative cover, relevant soil and climatic parameters, nature and amount of agricultural, industrial and city effluents discharged into the sea, and any other anthropogenic factors of the locality likely to influence SOC, etc. It should also be possible to create a databank on SOC and related factors of the long time past using radiocarbon dating.

Integrated soil and water management

If the water table, rich in salts, is present at a very shallow depth (generally not exceeding a depth of 2 m below the soil surface), it contributes salts to the root zone during the dry season through upward capillary rise in response to evapotranspiration demand of soil moisture. The net salt loading in the root zone will be positive (salinity will build up) or negative (desalinization will take place) depending upon the relative rate of recharge of salts by upward rise to rate of downward flux of salts through leaching. The relative salt loading will thus be treated generally as positive during dry season, and negative (waterlogging on the soil surface) during wet season due to high rainfall, and the process will be repeated in each year

in a seasonally cyclic mode.

Working models have been developed, even for small holdings dominating the coastal ecosystem, based on the hydrological processes, and the same validated for different agro-climatic regions in India for (i) computation of soil water balance, (ii) optimal design of water storage in the 'On-farm reservoir (OFR)' by converting 20 % of the watershed, (iii) design of surface drainage in deep waterlogged areas to reduce water congestion in 75 % of the area, and (iv) design of a simple linear programme to propose optimal land allocation under various constraints of land, water or other critical inputs to arrive at a contingency plan for maximization of profit. It has also been reported to use remote sensing and GIS in mapping lowland lands and performance assessment of irrigation/ drainage systems (Ambast and Sen, 2006).

Irrigation water resources

In spite of the coastal ecosystem presenting a delicate equilibrium among the different components there is however no firm strategy, as of now, for exploitation of water resources for irrigation and other purposes for long term solution in any sector. Planning should be such as not to disturb the ecosystem in the long run. It is suggested that location specific programme on water allocation under different sources should be drawn up for each region, based on soil, climate, water, and crop parameters, as well as their spatial variations, as per appropriate strategies to be worked out, with minimal dependence on abstraction of water from the underground aquifer, but with increasing dependence on other means, like use of surface water sources by recycling of rainwater stored and fresh water available using innovative seawater desalination technology, and conjunctive use of marginally saline water available, with overall target to increase water productivity and cropping intensity phasewise, and conserve the ecosystem at the same time. Future vision on water budgeting in the coastal areas in India, which should be the crux towards planning for integrated and efficient land and water management practices, along with conceptualizing a model specifically designed for water budgeting for the coastal watersheds including all its components, have been worked out recently to ensure long term sustenance by Sen and co-workers.

Seawater intrusion into inland areas may be minimized, if not to be eliminated altogether, through structural measures or with the help of 'Optimization Models', the latter however is yet to be validated through testing under wide variety of situations in order to suggest optimal location of pumping with reference to the coast, rate & frequency of pumping of underground water, etc.

Agri-horti production system

The coastal areas in countries like India are endowed with abundant sunshine, solar as well as wind energy, precipitation, diverse soils, physiography, climate, etc. and therefore, have tremendous opportunities for supporting a host of perennial and annual crops like trees, fruit plants, cereals, root crops, pulses, oilseeds, commercial crops, vegetables, etc. In addition, prospects of fishery, poultry, animal husbandry, sericulture, mushroom cultivation, bee-keeping and dairying are also enormous. Rice-based cropping systems are more dominant in the coastal plain tracts. In a field experiment on deep poorly drained alluvial soil in Balipatna Block in Odisha having average annual rainfall of 1480 mm, a modified soil physical environment through 5m x 30m alternate raised and sunken beds was studied in 2002-04 for seven different cropping systems. The highest rice equivalent, water expense efficiency, net water productivity, net returns, and B/C ratio were achieved with rice-fish in the sunken bed and pointed gourd + snake gourd in the raised bed system. Many developing countries in Asia, Africa and Latin America are reported to possess rich genetic resources of tuber and root crops, and there is significant opportunity for exchange of plant genetic materials.

Certain plantation crops, especially coconut, areca nut and cocoa have received major attention in the coastal areas. Mixed and intercrops in the coconut and areca nut based cropping system have helped in augmenting overall production capacity as well as in improving economic returns of the farmers in a sustainable manner. The coconut-based farming system comprising coconut, grass, dairy, poultry and fishery has proved more economical and sustainable. Several benefits relating to sustainability and profitability accruing from diversified and integrated farming are as under:

- ♦ Efficient conservation and optimization of natural resources
- ♦ Productive recycling of organic wastes among different components of farming system
- ♦ Enhancement of soil health including organic carbon status and microbial activity
- ♦ Prevention / minimization of soil erosion and other land degradation hazards
- ♦ Improvement of soil productivity capacity
- ♦ Reduction in use of external inputs and hence, less crop production cost
- ♦ Increased environmental and ecological safety
- ♦ Meeting multiple demands relating to fodder, feed, food, fibre, fertilizer, fuel, timber, medicine, etc.
- ♦ Greater employment, livelihood and nutritional opportunities
- ♦ Regular flow of higher income leading to poverty alleviation
- ♦ Insulation of farmers against risks arising from calamities, such as drought, weather aberration, pest virulence, etc.
- ♦ Security of greater self reliance among farming community
- ♦ Ecological and biological stability of natural resources as well as of productivity

Cropping systems

Almost the entire coastal area is grown with rice, mostly rainfed, under different land situations depending upon level of soil salinity, topography, and depth to waterlogging often subjected to floods. The elite rice varieties developed, identified so far (as per personal communication received from CSSRI, Regional Station Canning, WB) are summarized as:

Upland (Salinity EC_e 6-9 dS m^{-1} , waterlogging up to 0-20 cm): Canning 7, CSR 4 (Mohan), CSR 36, Bidhan 2, CST 7-1

Medium land (Salinity EC_e 6-8 dS m^{-1} , waterlogging up to 0-30 cm): CSR 1 (Damodar), CSR 2 (Dadsal), CSR 3 (Getu), Talmugur, Nona-Bokra, CSRC(S) 21-

2-5-B-1-1 (IET-17343/ Namita-Dipti), IR-72046, CSRC(S) 2-1-7 (IET 13428/ Sumati), CSRC(S) 11-5-0-2 (Utpala), CSRC (S) 5-2-2-5 (IET12855/ Bhutnath), Nonasail selection (CSR 6)

Medium lowland (Salinity EC_e 5-7 dS m^{-1} , waterlogging up to 30-40 cm): SR 26B, CSRC(S) 7-1-4 (IET 18250/ Amal Mana), Sabita, Patnai 23

Lowland (Salinity EC_e 4-6 dS m^{-1} , waterlogging upto 40-60 cm): Malabati, Kalamota, Sadamota (Selection), Tilak Kachari, FR 13A, IR 72046, NC-678, Asfal, Najani, Kumragour

The total cultivated area in the eastern coastal plain is about 8.58 million hectares with a cropping intensity of 134%. Rice-based production system is the major form of land utilization pattern. Important crops and cropping pattern prevalent in different States in eastern coastal plain are listed in Table 1.

Although West coast region receives higher rainfall, many places experience severe scarcity of water during summer months as the rainfall is concentrated during four months of the monsoon period. The coastal plains and valleys of the region are dominated by rice and rice-based cropping systems. The rice-based cropping systems include rice-cowpea (Alsando), rice-groundnut under residual moisture situations in rice fallows from early December to March and rice-vegetables, rice- sweet potato in areas where life-saving irrigation can be provided by traditionally developed sunken wells in rice lands mostly in *Khar* lands. These constitute the predominant cropping pattern, which dominates nearly 39-40 percent of the agrarian scenario in the region. Besides, there are high prospects for plantation and horticultural crops, both as sole crops as well as inter- or mixed crops, in the region from both commercial and ecological points of view. Exploitation of value addition of a number of these crops adds to their commercial interest. In Goa alone, an area of 99,672 ha (58% of the total cropped area) is under horticultural crops and there is an increasing trend during recent past both in area (5.53%) and production (6.19%). The plantation crops of the region include coconut, cashew, areca nut, oil palm, rubber, banana, pineapple, vanilla, ginger, turmeric, black pepper and a number of other spice crops. Besides, there are high prospects of a number of vegetable and fruit crops.

Livestock production system

Coastal areas offer scope for farm diversification through integration of horticultural crops, aquaculture, livestock, agro-forestry and other enterprises in rice ecologies. Such an approach can be a strategic road-map towards food, nutritional, income and employment security in the fragile coastal ecosystem. Farming system approach used in the west coast for coconut garden, for example, involves cultivation of fodder grass in the interspaces of coconut palms, maintenance of milch animals and recycling of cattle manure in the coconut-fodder-pepper mixed crops stand. This model (Sen *et al.*, 2010) generated additional employment to the tune of 356 mandays and ensured better returns without any yield decline in coconut. Some examples are cited below especially suitable for the east coast.

Dairy farming

The total milk produced by the coastal states of India is quite significant. Some of the major milk

practised in some Asian countries. Ducklings (7-20 days old) can be released at 200-400 per ha in the rice field after 10-20 days of planting and can be raised till flowering of the crop. After the rice harvest, ducks may be allowed to again forage in the field. On-farm demonstration trials on rice-duck farming in northeastern and southern regions of Bangladesh, showed feasibility of rice-duck system as well as benefits in terms of about 20% higher yield of rice and 50% higher net return compared to sole rice farming. Moreover, this system can improve nutritional status of the resource poor farmers besides, opportunities of women's participation (Sen *et al.*, 2010).

Rice-fish production systems

Rice-fish farming technology options are available for various waterlogged and salt affected ecologies in both east and west coasts of the country. The mixed or concurrent rice-fish-prawn and rice-fish-horticulture-livestock based diversified farming systems are suitable in non-saline waterlogged and

Table 1. Important crops and cropping systems in coastal ecosystem of different States of Eastern India (Saha *et al.*, 2008)

State	Field Crops	
	Wet season	Dry season
Andhra Pradesh	Rice, cotton, sugarcane, tobacco, groundnut	Blackgram, greengram, groundnut, chilli
Odisha	Rice, jute, sugarcane	Rice, blackgram, greengram, chilli groundnut, sunflower
Tamil Nadu	Rice, sugarcane, sorghum, pearl millet, tapioca	Rice, groundnut, cotton
West Bengal	Rice, jute	Rice, barley, lathyrus, sunflower, sugarbeet, chilli, watermelon

production centers of the country are located in coastal parts of Gujarat, Andhra Pradesh, and Tamil Nadu. The higher milk production in these regions may be attributed to the better animal management practices, availability of feed and fodder, efficient milk procurement and processing facilities. Dairy farming may be an attractive option for farmers and will contribute to ensuring economic and nutritional security. Certain region-specific dairy products like chhana based sweets (e.g. rasogolla and sandesh) though originated in West Bengal and Odisha, have become popular throughout the country (Sen *et al.*, 2010).

Rice-duck farming

Duck rearing in rice field is a profitable and environmentally sustainable farming option and is

deepwater and low to moderately saline areas. While, mixed, sequential and rotational rice-fish-/prawn culture can be practiced in flood plains and medium to high saline ecologies. Other remunerative crops and animal-based components can also be integrated for higher farm productivity, income and employment.

The rice-fish fingerlings production system is feasible in irrigated and shallow favourable lowlands with production potential of about 3-12 t ha⁻¹ of rice (two crops) and 100-300 kg fish fingerlings in a season.

Rice-grow-out fish-prawn mixed culture can produce about 2-10.0 t ha⁻¹ of rice grain (two crops) and 200-1200 kg fish ha⁻¹ yr⁻¹. The net income in rice-fish farming is ₹6,895-10,781 ha⁻¹, as compared to ₹4,037 ha⁻¹ from rice alone. Integration of vegetables and fruit crops on bunds can further

increase the productivity and net farm income to the tune of ₹22,450 ha⁻¹ yr⁻¹ (Sen *et al.*, 2010).

Rice- fish diversified farming systems

The ICAR-National Rice Research Institute, Cuttack, Odisha has developed adoptable technology models for rainfed medium-deep lowlands (upto 50 cm water depth) and deepwater (500-100 cm water depth) situations. Components such as improved rice varieties, fish, prawn, ducks, *Azolla*, and other crops (pulses, oil seeds, vegetables, watermelon) after wet season rice in the main field and vegetables, fruit crops, floriculture, apiculture, mushroom, agro-forestry, poultry and goater, etc. on bunds are grown in rainfed waterlogged areas. In deepwater areas, multitier farming system can be practiced with the components like, different short term and perennial fruit crops in tier I (upland), tuber crops and vegetables in tier II (upland), rainfed lowland rice (tier III) followed by crops like sweet potato, pulses, oilseeds, vegetables, watermelon and deepwater rice (tier IV) followed by rice and vegetables in the field. Fish and prawn are grown along with rice crop during wet season and later in the connected pond refuge (micro-watershed) during winter and summer seasons. Poultry, duckery, agro-forestry, fruit and plantation crops and other components are taken up on bunds of the system.

The productivity in the rice-fish diversified farming systems ranges from 16-18 t of food crops, 600-1000 kg of fish and prawn, 500-700 kg of meat and 8,000-12,000 eggs in addition to flowers, fuel and fibre wood and rice straw and other crop residues as feeds for livestock from one hectare of farm area. These systems can annually generate a net income of ₹40,000-1,30,000 depending upon the components and level of their management besides, additional employment of 250-300 man-days over rice farming. This farming system can increase farm productivity up to 15 times, income up to 20 folds and employment by two times over mono-cropping of rice. Adoption of the system in coastal plains of Odisha, resulted about 15 times increase in net farm income, besides higher employment generation. At CSSRI, Regional Station Canning (WB) economic evaluation was made for diversified cropping system under OFR (on-farm reservoir) technology, developed and subsequently tested in farmers' fields at a village site located at

Canning. The additional incomes, in addition to normal practice of rainfed *Kharif* rice alone, accrued per hectare were to the tune of ₹440/- due to growing of plantation crops on the bunds, while the values were ₹2525/- and ₹12,000/- on account of pisciculture in the storage reservoir with and without bund around it, respectively (Sen *et al.*, 2010).

Coastal saline ecologies

The rice-fish production systems in coastal saline ecology include mixed farming of salt tolerant lowland rice crop and freshwater fish and prawn after proper desalinization of field with rain water during wet season followed by salt water fish and prawn farming during dry season. The productivity in this system ranges from 3.0-4.0 t ha⁻¹ of rice and 500-600 kg ha⁻¹ of fish and prawn during wet season and 400-600 kg ha⁻¹ of salt water fish and prawn during dry season. The net income is in between ₹8,000-23,000 ha⁻¹ yr⁻¹ compared to ₹5,100 ha⁻¹ yr⁻¹ in the case of rice (wet season crop) alone. The income increases to about ₹33,000 ha⁻¹ yr⁻¹ with the addition of vegetable crops during wet season. Sequential and rotational rice-fish farming systems are suitable for coastal wet lands/flood plains. In these systems, fish culture is done during wet season and rice crop (improved varieties) is grown during dry season. The productivity ranges from 3.3-7.0 t ha⁻¹ in the case of rice and 350-1600 kg ha⁻¹ yr⁻¹ in case of fish with net income of ₹25,000-62,000 ha⁻¹ yr⁻¹. The rotational rice-fish system enhances farm income by about 72% over the traditional farming in flood prone areas of coastal Kerala. Rice-fish culture in mono-cropped coastal saline rice fields of high rainfall region of Bangladesh provided higher farm income (cost/benefit ratio, 1.6-2.79 vs 1.87 in rice mono-cropping), in addition to large potential of fish (tilapia) fingerling production in coastal paddy fields.

Rice-fish farming accrues many benefits such as cost-effectiveness, higher rice bio-mass yield and environmental sustainability, as there are reports of 50% decrease in water salinity after five years in fish refuge/ micro-watershed and reduction of greenhouse gases to the level of 30% in CH₄ (Lu and Li, 2006) and 32% in N₂O.

Poultry birds' rearing is another profitable option in coastal areas. Small scale backyard poultry farming with coloured dual purpose birds in super-cyclone

affected coastal Odisha, provided a net profit of about ₹350 per bird, besides eggs to the poor farm families.

Among other alternative farming systems, environmentally sustainable shrimp farming as per the guidelines of Coastal Aquaculture Authority Act, 2005 and mud crab culture are the highly profitable options. Shrimp farming can provide a productivity of about 1.5 t ha⁻¹ and net income of ₹1.66,000 ha⁻¹ yr⁻¹, while mud crab fattening can give a very high annual net farm income of ₹1,41,800 by raising six cycles of crop in a 0.1 ha tidal pond. However, Integrated Coastal Zone Management should be taken into consideration in planning for any developmental activities in coastal areas.

There have been stress on the issues of conservation of native and local livestock in the recent past, the important ones being Garol sheep of Sundarbans, Swamp buffalo of Sundarbans, Nicobari fowls of Andaman & Nicobar Islands, Black Bengal goats, Gir cattle, etc. Billy, the goat breed resident of Barren Island in the Andamans (Barren Island is home to the only active volcano in the country) has survived the volcano's eruption by migrating to the unaffected side of the island, feeding on its sparse foliage, and surviving on seawater. Generically, Billy is a feral goat-nomadic, untamed-in barren Barren island. Few other animals have been known to withstand the vagaries of such a harsh environment. Feral goats like Billy could be bred in "Zero management farms" that can provide enormous quantities of mutton at next to no cost. For one, the feral goat could be the answer to the livestock problems of drought-affected regions, where fresh water is in short supply. Secondly, research work on its kidney, which has adapted to sea water could yield rich results (Drinking saline water can kill a human being in a matter of days). But how did Billy get on Barren Island in the first place? But if Billy is such a hot property, then why isn't he world-famous yet? It will be quite some time before Billy finds his way to fame, which is bound to land it up on elite dinner tables.

In addition, livestock and poultry strains of economic importance in different coastal areas should be identified and conserved. For example, improved strains of birds as backyard

poultry units in tribal areas may be identified and conserved. Appropriate genetic engineering and other biotechnological tools should be utilized for developing improved breeds with specific desired characters for the region. Technological improvement and popularization of duck rearing should be given importance (Sen *et al.*, 2010).

Ecology

Forest resources

The present status of forest areas in the East and West coastal belts constitute only about 18.7 and 29.0 percent, respectively of the total geographical area of the country. The forest coverage in the A & N Islands, however, is as high as nearly 88 percent of its total land area. Mangroves growing under natural conditions along the coastal shoreline occupy nearly 0.4 million hectare (6460 km²) in the country comprising about 7 percent of the world's mangroves. Reefs are not abundant along the Indian coast occupying only 7 percent to a coastal length of 420 km. Seagrasses, on other hand, intermingle with both mangrove and reef communities at their respective seaward and landward boundaries. In the Indian coastline the seagrasses were found to be efficient in cleansing the water contaminated by oil spills and effluent discharge to the extent of 20-100 percent in the Gulf of Mannar and Palk Bay (Sen *et al.*, 2000).

In spite of the fact that mangroves have a very useful role to maintain the level of CO₂ and other toxic gases in the atmosphere they also remove toxic materials and excess nutrients from estuarine waters. In addition, sediment and other inert suspended materials are mechanically and chemically removed from the water and deposited in the marsh or swamp, reducing the sedimentation of navigation channels and shellfish beds. The vegetation also slows the surge of floodwaters and may help to reduce the severity of flooding. Vegetation serves to stabilize estuarine shorelines and prevent erosion; for example, mangrove trees not only preserve shorelines, but actually can extend the land's edge by trapping sediments and building seaward. Thus, mangroves support unique coastal ecosystems especially on their intricate root systems. In areas where roots are permanently submerged, they further play a role of hosting a wide

variety of organisms, including algae, barnacles, oysters, sponges, and bryozoans, which all require a hard substratum for anchoring while they filter feed. Shrimps and mud lobsters use the muddy bottom as their home. Mangroves thus form a vital food web link among various aquatic and wild animal species. It is irony that, globally, about 50 percent, and in some countries, as high as 85 percent, of mangrove forests have been lost in the last 50 years mostly due to human interventions. An estimated 35% of mangroves have been removed due to shrimp and fish aquaculture, deforestation, and freshwater diversion. Hydrology of the rivers in the coastal ecosystem or any other human intervention including soil and water management practices in the coastal plain that might threaten the natural forest environment should be highly unwarranted.

Sedimentation and erosion

The dynamics of alluvial landscapes and natural sedimentation patterns that determine the nutrient and energy flows in coastal areas are increasingly being modified by human activities, in particular those that affect water flows (dams, increased water extraction, deviation of rivers) and erosion, and especially due to deforestation. This prevents or slows down vertical accretion, thus aggravating salt water intrusion and impairing drainage conditions in riverine, delta or estuarine areas. It reduces or blocks sediment supply to the coast itself, which may give rise to the retreat of the coastline through wave erosion. Beach erosion is a growing problem and affects tourism revenue, especially in island nations. In the Caribbean, as much as 70 percent of beaches studied over a ten-year period were eroded.

Eutrophication, hypoxia, dead zones and nutrient cycle

The urban developments are taking up fertile agricultural land and leading to pollution of rivers, estuaries and seas by sewage as well as industrial and agricultural effluents. In turn, this is posing a threat to coastal ecosystems, their biological diversity, environmental regulatory functions and role in generating employment and food. Overuse of fertilizer can result in eutrophication, and in extreme cases, the creation of 'dead zones'. Dead zones occur when excess

nutrients - usually nitrogen and phosphorus - from agriculture or the burning of fossil fuels seep into the water system and fertilize blooms of algae along the coast. In dead zones, huge growth of algae reduces oxygen in the water to levels so low that nothing can live. There are now more than 400 known dead zones in coastal waters worldwide, compared to 305 in the 1990s, according to a study undertaken by the Virginia Institute of Marine Science. Those numbers were up from 162 in the 1980s, 87 in the 1970s, and 49 in the 1960s. In the 1910s, only four dead zones were identified (Minard, 2008). Hypoxia in the Northern Gulf of Mexico, commonly named as the 'Gulf Dead Zone', has doubled in size since researchers first mapped it in 1985, leading to very large depletions of marine life in the affected regions (Portier, 2003).

The World Resources Institute (2006) reported that driven by a massive increase in the use of fertilizer, the burning of fossil fuels, and a surge in land clearing and deforestation, the amount of nitrogen available for uptake at any given time has more than doubled since the 1940s. In other words, human activities now contribute more to the global supply of fixed nitrogen each year than natural processes do, with human-generated nitrogen totaling about 210 million metric ton per year, while natural processes contribute about 140 million metric tons. This influx of extra nitrogen has caused serious distortions of the natural nutrient cycle. In some parts of northern Europe, for example, forests are receiving 10 times the natural levels of nitrogen from airborne deposition, while coastal rivers in the Northeastern United States and Northern Europe are receiving as much as 20 times the natural amount from both agricultural and airborne sources (Coastal Wiki, 2008).

Climate Change and its impact

Destruction of habitats in coastal ecosystem is caused by natural disasters, such as cyclones, hurricanes, typhoons, volcanism, earthquakes and tsunamis, frequency of which is increasing at almost exponential rate with time (Sen, 2010), causing colossal losses worldwide. Each year an estimated 46 million people risk flooding from storm surges.

It has also been predicted (IPCC, 2007) that increase in sea surface temperature of about 1-3°C might result in more frequent coral bleaching events and widespread mortality unless there is thermal adaptation or acclimatization by corals.

The impacts on sea level rise are expected to be more local than global. The relative change of sea and land is the main factor. Many cities, for instance, even suffer land subsidence as a result of ground water withdrawal. This may be compounded with sea level rise, especially since rates of subsidence may exceed the rate of sea level rise between now and 2100. In India, potential impacts on 1 m sea level rise might lead to inundation of 5,763 km² of land including Ganges-Brahmaputra delta facing flood risks from both large rivers and ocean storms. Apart from the inundation of low lying coastal areas, including parts of many major cities, more significant are the direct loss of land caused by the sea rising and the associated indirect factors, including erosion patterns and damage to coastal infrastructure, salinization of wells, sub-optimal functioning of the sewage system of coastal cities (with resulting health impacts), loss of littoral ecosystems and loss of biotic resources. Climate change thus affects wide array of sensitive sectors like agriculture, forestry and fishery and thereby the livelihoods of millions of coastal communities.

Regarding climate change policies, it is mentioned that the coverage of GoI on coastal protection has been limited to soft activities which include high resolution modelling, development of salt tolerant crops, timely forecasting and warning of flood and cyclones occurrences, and enhanced plantation and regeneration of mangroves and coastal forests. Unlike Bangladesh sharing similar coastal ecologies in as far as Sundarbans is concerned, 'adaptation' to the miseries due to the weather extremes has been little emphasized in the policy of India. 'Mitigation' policies are also widely different in the two countries. Even policies and strategies to tackle loss of marine and coastal eco-region are widely different. India however gives considerable importance to mitigating greenhouse gas emission through expansion of renewable wastes and afforestation. Making note

of such wide variation in the country-wise policies on key issues on climate change in Sundarbans it is strongly advocated, to start with, undertake integration of the policies of the two countries, and possibly Nepal also, all sharing the GBM basin, under the aegis of SAARC, to address key concerns and vulnerabilities, and discuss all related issues with open mind having full regards to geo-political sovereignty of the countries.

Lowlying coastal soils

The probable effects on soil characteristics of a gradual eustatic rise in sea level will vary from place to place depending on a number of local and external factors, and interactions between them (Brammer and Brinkman, 1990). In principle, a rising sea level would tend to erode and move back existing coastlines. However, the extent to which this actually happens will depend on the elevation, the resistance of local coastal materials, the degree to which they are defended by sediments provided by river flow or longshore drift, the strength of longshore currents and storm waves, and on human interventions which might prevent or accelerate erosion.

Sediment supply and deltaic aggradation

In major deltas, such as those of the Ganges-Brahmaputra and the major Chinese rivers, sediment supplies delivered to the estuary will generally be sufficient to offset the effects of a rising sea level, but on the other hand it would impair the drainage system as well.

In coastal lowlands which are insufficiently defended by sediment supply or embankments, tidal flooding by saline water will tend to penetrate further inland than at present for the lack of adequate drainage in case of the former, extending the area of perennially or seasonally saline soils. Where *Rhizophora* mangrove or *Phragmites* vegetation invades the area, would over several decades lead to the formation of potential acid sulphate soils. Impedance of drainage from the land by a higher sea level and by the correspondingly higher levels of adjoining estuarine rivers and their levees will also extend the area of perennially or seasonally reduced soils and increase normal inundation depths and durations in river and estuary basins and on levee backslopes. In sites which become

perennially wet, soil organic matter contents will tend to increase, resulting eventually in peat formation. On the other hand, where coastal erosion removes an existing barrier of mineral soils or mangrove forest, higher storm surges associated with a rising sea level could allow seawater to destroy existing coastal eustatic peat swamps, which might eventually be replaced by freshwater or saltwater lagoons.

Subsidence of land

The probable response of low lying coastal areas to a rise in sea level can be estimated in more detail on the basis of the geological and historical evidence of changes that occurred during past periods when sea level was rising eustatically or in response to tectonic or isostatic movements, e.g. around the Southern North Sea; in the Nile delta; on the coastal plain of the Guyanas; in the Musi delta of Sumatera. Major shifting of the river course of the Ganga-Brahmaputra river system and a large number of their tributaries took place due to neo-tectonic movement in Bengal basin during 16th to 18th century, which eventually led to massive change of the hydro-geological properties in lower Ganges delta affecting livelihood in both India (related areas) and Bangladesh. Contemporary evidence is also available in areas where land levels have subsided as a result of recent abstraction of water, natural gas or oil from sediments underlying coastal lowlands. Further studies of such contemporary and palaeo-environments are needed together with location specific studies in order to better understand the change processes, identify appropriate responses and assess their technical, ecological and socio-economic implications.

Erosion

It is an important area influenced by the climate change with rising temperatures leading to rise in the sea's water mass. In India the mainland consists of 43 % sandy beaches, 11 % rocky coast with cliffs, and 46 % mud flats and marshy coast (SAARC Disaster Management Centre, 2009). The damages caused by sea erosion in different coastal states in India alone show a staggering annual loss of Rs. 368.4 crores. Various preventive and mitigation measures have been suggested and

being adopted, which are mainly of two types: (i) Structural measures and (ii) Non-structural/ soft measures.

Agro-ecotourism

In Kerala, Goa and adjoining areas, spice gardens are given another dimension in terms of their role in tourism industry. "Agro-Ecotourism" is the symbiotic association of farming sector and tourism industry. Spice crops are the destinations of Agro-ecotourism for Western or European tourists in Goa. Tropical spice crops as kokum, black pepper, clove, nutmeg, cinnamon, cardamom, all spice, vanilla, etc coupled with native fruit crops like banana, jack fruit, bread fruit, mango, cashew, etc., are incorporated in palm-based farming systems or agro-forestry systems with specific orientation towards Agro-ecotourism gardens. It is strongly suggested for Sundarbans, based on the lessons learnt, to explore newer development options for livelihood security in non-farm sector through ecotourism with mangrove destinations.

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