Review Article

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Improving agricultural productivity through diversified farming and enhancing livelihood security in coastal ecosystem with special reference to India

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ABSTRACT

Nearly 40 % of cities larger than 500,000 populations are located in the coast in India, and yet threatened by a series of factors affecting the livelihood and very sustenance of the ecosystem. Notwithstanding, it has an economic value beyond their aesthetic benefit supporting human lives and livelihoods. By one estimate the combined global value of goods and services from coastal ecosystems is about US$ 12-14 trillion annually. The ecosystem, especially the coastal plain under inhabitation, spanning over 10.78 million ha area in India and mostly rice-based, merits appropriate attention to improve their livelihood through use of suitable diversified farming practices. The paper discusses, along with advancement of agricultural sciences suitable to the ecosystem, various farming practices including rice-horticultural/plantation crops, rice-fish/prawn, rice-duckery/goatery and their economic impacts. While projecting on the various ecological factors, mainly of natural or anthropological origin, threatening the sustenance of the ecosystem worldwide, the paper focuses on complete lack of information or even systematic attempts made so far to monitor the parameters. At the end, it suggests the strategies to be adopted on disaster management, livelihood security, and poverty alleviation, keeping in view of the climate change phenomenon, in tune with international mandate, for drawing long term action plan applicable to this ecosystem in India.

Key words: *coastal ecosystem, agricultural productivity, farming practices, livelihood, India*

Various risk factors have been identified to affect poverty in different time frames, which are socio-technological constraints including macro-economic imbalances limiting agricultural and related productivity levels, rising food prices and resource scarcity, climate change and lack of environmental sustainability, lack of infrastructural facilities, ethnic and other social crises, inappropriate mindset for the acceptance of improved technologies, health related issues, etc.

Of all the major ecosystems which factor in agricultural or food production, being at the very base of poverty alleviation programme, 'coastal' is probably the most important one. Nearly 40 % of cities larger than 500,000 population are located along the coast in India. Overall about 50-70 % of the global population live 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[a]), coastal areas (within 200 km from the sea) share less than 15 % of the earth surface area, and the latter also predict that three-fourths of the world population are expected to reside in the coastal areas by 2025. Different countries with coastal boundaries have varying proportion of the total area exposed to the sea, expressed as coastline: total area of the country (km km^{-2}). The top-most sovereign countries in terms of coast $area^{-1}$ ratio (Wikipedia, 2009[b]) are Tokelau (10,100), Federal States of Micronesia (8,706), Palau

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(3,316), Northern Mariana Islands (3,107), Maldives (2,147), Monaco (2,051), Marshall Islands (2,044), Cocos (Keeling) Islands (1,857), Gibraltar (1,846) Macau (1,464), Nauru (1,429), Kiribati (1,409), Saint Martin (1,093), Pitcairn Islands (1,085), Seychelles (1,079), and Christmas Island (1,030). India, Bangladesh and USA have low coast/area ratio of 2, 4 and 2, respectively. However, it is not the coast/area ratio alone but also the total coastline, population density and anthropogenic factors, topography and related soil properties, protection measures undertaken, and natural disasters caused by the sea and through its interaction with climate and under-sea tectonic movement of the earth, that factor in not only to influence the agricultural production but also the nature and extent of vulnerability of the ecosystem per se in a country.

Coastal ecosystem

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. The problems of livelihood in these areas are compounded manifolds owing to a series of technological, administrative and socio-economic constraints. A holistic look at the interaction matrix of factors, which are interdependent on each other, impacting on the coastal ecosystem is presented schematically in Fig. 1. Unfortunately, at the global level, until very recently, not much serious and concerted attention has been paid for mitigating the problems for sustainable development in the coastal ecosystem. Attempt for improving on the agricultural front, which is the focal theme of this paper, though should be at the center stage from daily livelihood point of view in this ecosystem, is still in the back seat in majority of the areas. This is possibly because of the 'slow-poisoning kind of effect' of this sector, arising out of poor agricultural practice and/or inability for the poor to pay for the commodities as a result of insufficient food production, that normally goes un-noticed among the poverty-stricken mass, vis-à-vis catastrophic effects with heavy toll on lives and properties due to climatic disasters. Exceptions are India, Bangladesh and possibly a few other countries paying concerted attention on the coastal ecosystem for improvement in agricultural front in particular.

Definition and distribution

A coastal ecosystem includes estuaries and coastal waters and lands located at the lower end of drainage basins, where stream and river systems meet the sea and are mixed by tides. The ecosystem includes saline, brackish (mixed saline and fresh) and fresh waters, as well as coastlines and the adjacent lands. Coastal wetlands are commonly called as lagoons, salt marshes

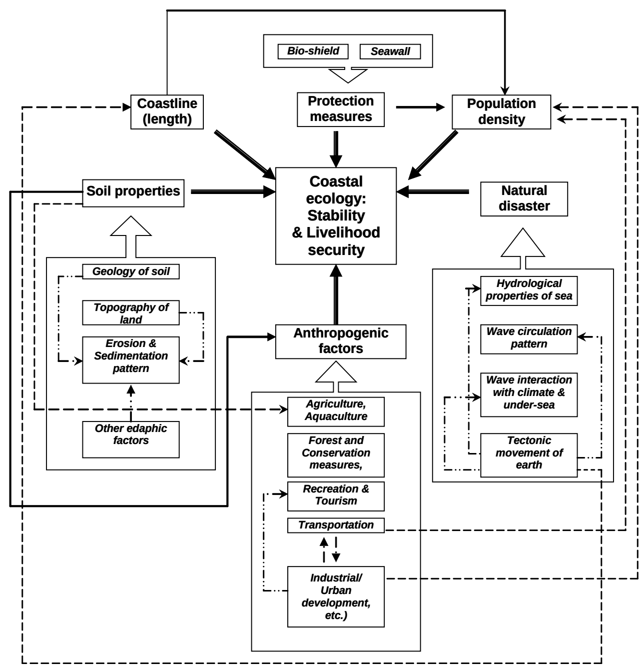

Fig 1. Interaction matrix of factors influencing stability and livelihood of the coastal ecosystem

or tidelands (US Fish & Wildlife Service, 2009). According to World Resources Institute (WRI) coastal areas may be commonly defined as the interface or transition areas between land and sea, including large inland lakes. Coastal areas are diverse in function and form, dynamic, and do not lend themselves well to definition by strict spatial boundaries. Unlike watersheds, there are no exact natural boundaries that unambiguously delineate coastal areas at the global scale. According to them, the world coastline extends from 350,000-1,000,000 km in length, depending upon how finely the 'length' is resolved. More comprehensively, the coastal ecosystem has been defined by Sen *et al*. (2000) as representing the transition from terrestrial to marine influences and vice versa. It comprises not only shoreline ecosystems, but also the upland watersheds draining into coastal waters, and the nearshore sub-littoral ecosystems influenced by land-based activities. Functionally, it is a broad interface between land and sea that is strongly influenced by both.

Coastal soils along with their characteristics have been described comprehensively on a global scale by Schwartz (2005[a]) but no attempt has been made to delineate the zones from inlands based on scientific criteria. Estimates available world over have generally been made arbitrarily based on length of the coastline times a fixed distance landward, varying from 50 to 200 km as followed by different countries, from the shore assuming the zone representing coastal ecosystem different from that for inland part of the country. Velayutham *et al*. (1998) for the first time described soil resources and their potentials for different Agro-ecological Sub Regions (AESR) in the coastal ecosystems of India showing total of 10.78 million hectare area under this ecosystem (including the islands) in the country. Coastal soil per se does not have much significance as far as its productivity is concerned unless it is considered in association with other relevant ecological factors describing the ecosystem owing to the latter's significant influence on threatening its very stability, which is unlike any other ecosystem. It should therefore be necessary, in priory, to delineate and characterize the coastal soils in each country based on sound scientific criteria, and alongside consider the relevant ecological factors which render the ecosystem concerned generally fragile in nature due to various risk factors, often complementing with each other, involved for planning for sustainable development with a holistic approach (Fig. 1).

Risk factors

According to an estimate by Dirk *et al.* (1998), 51 percent of the world's coastal ecosystems appear to be at significant risk of degradation from development related activities. Europe, with 86 percent of the coastline at high or medium risk, and Asia, with 69 percent in these categories, are the regions most threatened by degradation. Worldwide, nearly three-fourths of marine protected areas within 100 km of continents or major islands appear to be at risk. These were preliminary estimates and lack precision as commented upon by WRI. However, the data suggest already an alarming state towards destabilizing the ecosystem, notwithstanding that the estimate did not even take into consideration other important factors like agricultural and allied developments, deforestation, fishing, population density, and climatic disturbances with significant adverse contribution.

Indian context: Of the two coastlines in India length of the East coast is more than that of the West. The continental shelf is more than the coast. The continental shelf of 0-50 m depth spreads over 1,91,972 sq km and between 0-200 depth over 4,52,060 sq km. The shelf is wide (50-340 m) along the East coast. The Exclusion Economic Zone is estimated at 2.02 million sq km.

Practically no systematic study was earlier made to demarcate the coastal soils based on well-defined scientific indices valid for the different sub-ecosystems in this country. Notable among the past works was that of Yadav *et al*. (1983) who suggested 3.1 million hectare area (including mangrove forests), while Szabolcs (1979) suggested 23.8 million hectare under coastal salinity in India. The coastal saline soil has been used by various workers almost synonymously with coastal soil per se which is not correct since all coastal soils are not saline in nature. None of the above estimates appear to have been made on sound scientific basis. However, the compilation made by Velayutham *et al*. (1998) on the soil resources and their potentials for different Agro-ecological Sub Regions (AESR) of India showed a total 10.78 million hectare area (Fig. 2) under this ecosystem (including the islands) in India, which was the first scientific approach for delineation of the coastal ecosystem.

Coastal Regulation Zone (CRZ) in India

The coastal areas less than 10 meters above the mean sea level constitute only 2% of the global level, but they house 10% of the world's population and are vulnerable to the storm surges and increased intensity of tropical cyclones. 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. This area comprises coastal stretches of seas, bays, estuaries, creeks, rivers and back waters, which are influenced by the tidal action in the landward side during the strong tide.

The CRZ is subdivided into 4 categories on the basis of ecological similarity, geomorphological features and demographic distribution. The CRZ I is

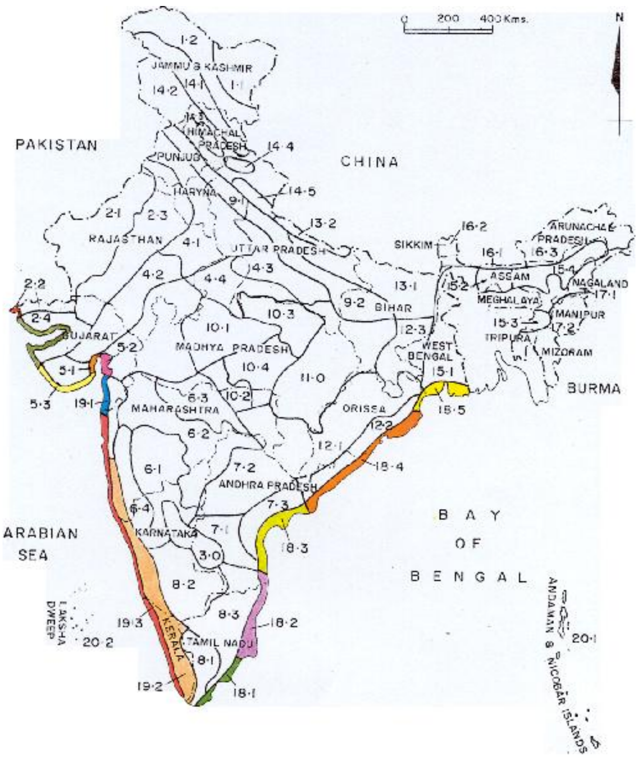

Fig. 2. Coastal areas of India (AESR wise) (Source: Velayutham *et al*. (1998)

ecologically sensitive to high tides; the CRZ II is largely urban and developed; the CRZ III is rural and undeveloped; and CRZ IV includes Andaman and Nicobar Islands. No development is permitted in CRZ I area, while development is allowed in CRZ II on the landward side of existing authorized structures. In CRZ III, land upto 200 meters from the high tide line is no-development zone and is mainly restricted to agriculture and essential use of local inhabitants. Construction of traditional dwellings is permitted between 200 and 500 meters of the high tide line.

The management of these CRZ areas entails enormous difficulties because of ambiguities in demarcating high tide line and also in distinguishing developed area. According to 2005 report of M.S. Swaminathan Committee considerable confusion exists among different agencies regarding definition of high tide level. These issues, therefore, need to be resolved to facilitate proper administration of these CRZ areas. The quality of coastal ecosystem is being threatened by contamination and degradations. With increasing pollution of the oceans, the mammals like seals, whales and dolphins are affected and coral reefs as well as other habitats get destroyed. According to the Inter-Governmental Oceanographic Commission of UNESCO, about 90% of resources in minerals, oil and natural gas can be exploited from the sea beds of the oceans.

Factors Limiting Plant Growth

Coastal soils in a number of situations are constrained by various technological factors limiting the agricultural productivity and therefore merit attention. The salient factors are (i) Excess accumulation of soluble salts and alkalinity in soil. (ii) Pre-dominance of acid sulphate soils. (iii) Toxicity and deficiency of nutrients in soils. (iv) Intrusion of seawater into coastal aquifers. (iv) High depth to underground water table rich in salts. (v) Periodic inundation of soil surface by the tidal water vis-à-vis climatic disaster and their influence on soil properties. (vi) Heavy soil texture and poor infiltrability of soil. (vii) Eutrophication, hypoxia and nutrient imbalance. (viii) Erosion and sedimentation of soil. (ix) High population density

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 Orissa 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, arecanut and cocoa have received major attention in the coastal areas. Mixed and intercrops in the coconut and arecanut 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 (Yadav, 2008). (i) Efficient conservation and optimization of natural resources. (ii) Productive recycling of organic wastes among different components of farming system. (iii) Enhancement of soil health including organic carbon status and microbial activity. (iv) Prevention / minimization of soil erosion and other land degradation hazards. (v) Improvement of soil productivity capacity. (vi) Reduction in use of external inputs and hence, less crop production cost. (vii) Increased environmental and ecological safety. (viii) Meeting multiple demands relating to fodder, feed, food, fibre, fertilizer, fuel, timber, medicine, etc. (ix) Greater employment, livelihood and nutritional opportunities. (x) Regular flow of higher income leading to poverty alleviation. (xi) Insulation of farmers against risks arising from calamities, such as drought, weather abberation, pest virulence, etc. (xii) Security of greater self reliance among farming community. (xiii) Ecological and biological stability of natural resources as well as of productivity.

Cropping system

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 ECe 6-9 dSm^{-1}, waterlogging up to 0-20 cm): Canning 7, CSR-4 (Mohan), CSR-36, Bidhan-2, CST 7-1. Medium land (Salinity 6-8 dSm^{-1}, waterlogging up to 0-30 cm): CSR 1 (Damodar), CSR 2 (Dasal), 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 ECe 5-7 dSm^{-1}, waterlogging up to 30-40 cm): SR 26B, CSRC(S) 7-1-4 (IET 18250/Amal Mana), Sabita, Patnai 23. Lowland (Salinity ECe 4-6 dSm^{-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% (Subba Rao *et al.*, 2001). 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.

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

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, arecanut, oilpalm, rubber, banana, pineapple, vanilla, ginger, turmeric, black pepper and a number of other spice crops (Korikanthimath *et al*., 2007). Besides, there high prospects of a number of vegetable and fruit crops.

Agro-eco-tourism: In Kerala, Goa and adjoining areas, spice gardens are given another dimension in terms of their role in tourism industry. "Agro-Eco Tourism" is the symbiotic association of farming sector and tourism industry. Spice crops are the destinations of Agro-eco tourism 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-eco tourism gardens (Korikanthimath *et al*., 2007).

Crop improvement in rice

Developing salt tolerant varieties: Traditional salt tolerant rice landraces such as Pokkali and Nona Bokra, have often been used in conventional breeding programs to develop high yielding salt tolerant cultivars. The tolerance of the breeding lines, however, is not as high as that of the traditional donors, reflecting the difficulty in obtaining high tolerance while avoiding the negative characteristics of the donor landraces (Gregorio *et al*., 2002). This complexity, together with the multiple traits involved and the diversity of target environments slowed progress in development and adoption of new varieties. Ismail *et al*. (2008) proposed a breeding strategy to select separately for individual component traits and then combine them in a single variety to achieve higher levels of tolerance. This approach is recently becoming more feasible through the application of QTL mapping to genetically dissect tolerance into discrete QTLs for different physiological traits, and then pyramid them through marker assisted selection (MAS) for multiple tolerances. For this purpose, a recombinant inbred line (RIL) population between the tolerant landrace Pokkali and sensitive IR29 identified several QTLs of reasonable effects, few of them map to regions containing candidate genes for salinity tolerance (Bonilla *et al*., 2002, Ismail *et al*., 2007). One of these QTLs on chromosome 1, designated *Saltol*, explains 43% of the variation for seedling Na^+ uptake. Recent efforts at IRRI include targeting these QTLs for fine mapping, candidate gene analysis, and development of a marker assisted backcrossing system to combine them in suitable genetic backgrounds. The *Saltol* locus was mapped to a 1.2 Mb interval and is currently being introgressed into several popular rice varieties adapted to coastal areas, using marker aided selection. Longer term strategies will work towards fine mapping additional QTLs and cloning tolerance genes for pyramiding multiple tolerances for salinity and other prevailing abiotic stresses for wider adaptation. In India, work has been initiated at CRRI to collect rice landraces from coastal saline areas of Orissa and West Bengal and evaluated for salinity tolerance at seedling stage in solution culture at an EC of 12 dS m^{-1}. Some of the tolerant genotypes were utilized in breeding programme for developing salt tolerant varieties. A number of crosses were made using popular high yielding rice varieties and salt tolerant donors. Introgression of *Saltol* QTL into popular high yielding varieties has been made by utilizing FL 378, FL 478 and FL 496 as donors through both conventional and marker assisted breeding. Two varieties, namely Luna Suvarna and Luna Sampat were released by Odisha State for cultivation during wet season in coastal saline areas under shallow lowland condition.

Developing varieties adapted to flood prone areas: Breeding to improve rice productivity in flood prone areas has been ongoing for the last two decades but with limited progress (Ismail *et al*., 2008). However, the recent identification and cloning of *Sub1*, the major QTL for submergence tolerance, substantially accelerated these efforts. *Sub1* was identified on chromosome 9 from FR13A (Fig. 2), and was recently cloned, and *Sub1A*, an ethylene responsive like factor (ERF), was identified as the gene underlying this QTL (Mackill *et al*., 1993, Xu and Mackill, 1996, Xu *et al*., 2006). *Sub1A* confers a high level of submergence tolerance. An efficient maker assisted backcrossing system was developed and used to incorporate this gene into popular rice varieties (Neeraja *et al*., 2007) and the lines with *Sub1A* gave 2-3 times the yields of the sensitive parent under submergence for a period of 12-17 days (advantage of 1-2 tons ha^{-1}). This gene was successfully incorporated into six popular rice varieties and preliminary testing of these introgression lines in farmers' fields has confirmed that *Sub1* varieties can provide protection against short term flooding. *Sub1A* has a large effect that is independent of genetic background and has no negative effects on yield or other economic traits. Varieties with the *Sub1A* gene have the same yield and other agronomic and quality characteristics as the original variety, and they can be used to replace these varieties in flood prone areas. Seeds of these newly developed varieties are being multiplied for large scale dissemination in flood prone areas that are experiencing flash flooding.

Designing varieties suitable for coastal zones: The multifaceted abiotic stresses in coastal areas (high salinity and other soil problems, submergence, stagnant flooding, and drought), mean that most areas are monocropped with rice during the monsoon season. Local rice varieties have some level of tolerance of these conditions, including water stagnation, but their productivity is very low. During the rest of the year, the area remains fallow due to high soil and water salinity and lack of good quality irrigation water. We aim to combine *Sub1A* with tolerance to longer duration partial flooding common in coastal areas, as well as with tolerance to salt stress conferred by *Saltol*. Our long term goal is to develop resilient varieties combining tolerances to major abiotic stresses prevailing in coastal areas, through the development of effective breeding tools that can help dissect and incorporate tolerance into modern varieties and breeding lines adapted to these areas. Combing the use of varieties with broader tolerance to these stresses, with proper and affordable management options, can ensure higher and stable food production in coastal areas (Ismail *et al*., 2008).

Tolerance to pest and disease problems in rice

Use of biotechnological tools : Various biotechnological tools have been used at Central Rice Research Institute, Cuttack to enhance the pest resistance in rice and minimize yield losses (Pandey *et al*., 2008). The resistance genes for bacterial blight and yellow stem borer have been transferred into high yielding varieties from wild rices. DNA markers linked to gall midge resistance genes, *Gm4* in PTB 10, *Gm5* in ARC5984 and root-knot nematode resistance genes in Ramakrishna were identified. Three bacterial blight resistance genes (*xa 5*, *xa13* and *Xa21*) and two blast resistance genes (*Pi-2t* and *Pi-9t*) were introduced into high yielding varieties through molecular breeding approach. Initial yield trials indicated that some of pyramided lines gave higher yields over parental checks. Different isolates of bacterial blight and blast pathogens collected from different cultivars were fingerprinted and some isolates were pathotyped using host differentials. The reactions of resistance genes to isolates indicated the possibility of deploying appropriate gene combinations in high yielding varieties. Five populations of root-knot nematode from Mandya, Trichi, Amana, Kamakhyanagar and Cuttack were fingerprinted using RAPD markers. Potato trypsin inhibitor gene (PIN II) was introduced to elite *indica* cultivars, Swarna and Pusa Basmati 1. Two transgenic lines each from Pusa Basmati 1 and Swarna showed higher level of resistance to yellow stem borer and leaf folder. *Wolbachia*, an endosymbiotic, obligate and α-proteobacteria infection was reported for the first time from India in rice gall midge, white-backed planthopper, and leaf folder and case worm. Further work indicated the involvement in post embryonic development of gall midge. The functional genomics tools have been applied to identify genes associated with resistance to brown plant hopper. Microsatellite analysis led to identification of three markers, linked to QTLs associated with BPH resistance in Salkathi.

Integrated 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 may 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 every year in a seasonally cyclic mode.

Sen and Oosterbaan (1992) presented a practical working method on integrated water management for Sundarbans (India) through surface gravity induced drainage during dry/wet season through land shaping-cum-excess rainwater storage for irrigation during dry season. They computed for the same region drainable surplus, which may be stored for irrigation during dry (deficit) period. Ambast and Sen (2006) developed a computer simulation model and a user-friendly software 'RAINSIM' for the same, developed primarily for Sundarbans region for small holdings, based on the hydrological processes, and the same tested duly 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. They also reported use of remote sensing and GIS in mapping lowland lands, vegetation, crop yield estimation, along with performance assessment of irrigation/ drainage systems.

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. The European Commission (2007) observed, based on a study by Spanish researchers, how an inappropriately planned coastal development could lead to increasing water consumption to unsustainable levels, for which future planning for sustainable development, based particularly on water resources, should be such as not to disturb the ecosystem in the long run. The technological developments in this region should focus on the areas, viz. artificial recharge of the aquifer, recycling of water, desalinzation of seawater, weather modification, improved irrigation management practices, and use of marginally poor quality water.

Few case studies of water use through structures in Odisha :

There is a good scope of expansion of the coastal area under micro water resource development, i.e., by creating water harvesting structure (WHS). In coastal saline area (0-10 km from sea) of Odisha there is a large patch near Erasama near the Hansua creek, length varying from 10-15 km and width varying from 5-7 km from the sea. With sandy zone up to 5-10 m below ground level, huge amount of water is stored into this zone. Water table in the area varies from 0-150 cm below ground level during monsoon receding up to 1-2 m during post monsoon season especially in waterlogged areas. Depth of engrossed sea water (saline) table varies from 3-7 m below ground surface and fresh rainwater floats above it, which can easily be harvested for fish production and irrigation. Based on the above data, Directorate of Water Management Bhubaneswar has developed a design for water harvesting structure which has been constructed in the super cyclone affected area on participatory basis to make the project sustainable. In this system small water harvesting structure is constructed with an inlet to a depth of 3-4 m or less to harvest surface water in rainy season and to harvest seepage water in dry season after each pumping session. This structure will provide water for paddy nursery raising in June and will irrigate additional area during dry season as well as summer. It can also be used for aquaculture and aquatic crops like water chestnut, etc. This system has been proved very effective in providing assured irrigation (Sahoo *et al*., 2005).

Selection of site: This system can be installed at any place which is nearer to the creek and where a sand zone is underneath within 10m below ground level. This zone is locally called Bellary in the state of Orissa. In Paradip and Erasama zone, this type of land is available in a vast stretch of area within 5-10 km from sea. There should be arable land and habitation near the zone for taking up farming in both wet and dry season. Seepage rate should be more than 10 mm per day. There should be clayey zone below the surface up to first 3-4 m.

Design and construction of water harvesting structure: The design of the water harvesting structure depends upon expected rate of seepage. If the rate of seepage is more, then the area of tank is reduced and vice versa. The recuperation rate by pumping test at different site for 556 m^3 to 899 m^3 SSWHS varies from 1.58 $m^3\ hr^{-1}$ to 4.07 $m^3\ hr^{-1}$ in sandy zone and from 1.01$m^3\ hr^{-1}$ to 3.4 $m^3\ hr^{-1}$ in clayey zone. Capacity of structure may vary from 200 m^3 to 1500m^3. The depth of structure may also vary from 2-4 m.

Performance and economics of the system: The economics is given in Tables 2 and 3. This year also in case of SSWHS in Ersama same trend continued. In case of more participation by farmers, the water productivity, benefit cost ratio and cropping intensity increased. When the farmers' participation increased from 40% to 67%, the water productivity increased by 42% and when participation increased to 80%, again it increased by 55%. Same was true for B.C ratio also.

Table 2. Performance of Water Harvesting Structure in 60:40 participatory basis

Group No	Capacity (m^3)	Cost (Rs)	K.I. (Rs)	R.I (Rs)	F.I (Rs)	T.I (Rs)	T.E (Rs)	B.C Ratio	W.P. Rs /m^3	C.I (%)
I	1287.4	17733	8760	36120	5600	50,440	21,030	2.32	32.4	300
II	4571.0	16265	8040	22330	9100	39,470	15,675	2.41	20.0	275
III	899	15110	5640	5400	6900	17,940	10,390	1.63	13.7	200
IV	1011.5	13646	5880	9988	3300	19,168	8,210	2.19	13.1	200
V	779	7409	3972	9000	4715	17,687	7,030	2.41	17.6	180
VI	556	7490	4999	11363	6030	22,392	10,100	2.15	31.3	200
VII	1152	15200	4196	5976	10,130	20,307	9,315	2.01	13.9	180
	Total =7255.9	Average	2.16	20.3	219.3					

* KI = wet income, RI = Rabi Income, FI = Fish Income, TI = Total Income, TE = Total Expenditure, BC = Benefit Cost, WP = Water Productivity, CI= Cropping Intensity

Micro Tube Well: These are shallow tube wells. The technology was experimented in coastal area of Astarang block in Puri district of Orissa. In these areas the saline water is 20 m below ground level. Mixed water is available from 15 m to 20m.Tube wells of several diameters up to 15 cm and several depths up to 20m were tried with different energy unit. It was found that diameter up to 7.5 cm and depth up to 13 m with energy unit of 1.5 to 2 hp was more practicable and suitable. Tube Wells of other dia and depth with energy unit more than 2 hp were proved ineffective as it discharged saline water after 2 or 3 seasons of pumping. In case of micro tube well at Astarang performance index has been given in Tables 4 and 5 for different mode of participation. The tube well of 5cm dia and 13m depth costs around Rs 2476/-. The benefit cost ratio varies from 2.2 to 2.6. The water productivity varies from Rs3.32 to Rs 3.53 per cubic meter. This tube well irrigates around 1.5 to 2.5 ha depending on crop during rabi season.

Table 3. Performance of SSWHS on different mode of participation

Mode of participation	Benefit m^3	B.C Ratio	Av. W.P Rs m^{-3}	F.I Rs m^{-3}	T.I (Rs m^{-3})
40:60	14.56	2.16	20.3	6.30	25.82
33:67	25.14	2.23	35.06	14.56	44.70
20:80	28.79	2.58	45.94	14.91	46.00

Impact: The technology has been taken by State Government and is implementing in coastal area. There was a ban during 2002 regarding tube well construction in coastal area but seeing our technology the government has lifted the ban during 2008 and allowed subsidy for this type of micro tube well. The technology was highly appreciated by Orissa State Government and the irrigation department has implemented in Krushnaprasad block of Puri district. An external funded project on this technology was also sanctioned by TIFAC and was implemented through our Institute at Satyabadi and Kanas block of Puri District. The number of micro tube well has been increased from 10 in Astarang at 2004 to 75 in 2009. This was also constructed on participatory basis. The performance is given in Table 4.

It is seen that water productivity is less than SSWHS as there is no fish component. But the water productivity, cropping intensity benefit per ha increases as the mode of farmers' participation increases (Table 5). Incase of 10% participation, BC ratio is 2.33 where as it increases to 14% when participation increases to 50%. When it increases to 70%, B.C ratio further increases to 26%. Benefit per hectare increases from Rs 12,747/- to Rs 19,199 when participation changes from 10% to 70%. Hence for sustainability of the system participatory water resource development is essential.

From the above study it is established that participation of farmer by paying 40% of the cost of SSWHS on the 1st year and 67% of the cost in the 2nd year and 80% of the cost in 3rd year gave them the ownership feeling and they do not take it as government donation or work. Similar was in case of Micro Tube Well. Since the system worked with cyclone ravaged poor people in Orissa successfully this might also work in all coastal areas. This gave a new insight for development of small-scale water resources in coastal areas.

Table 4. Performance of micro tube well 90:10 participatory basis

Group No	Area Irrigated (ha)	KI (Rs)	R.I (Rs)	S.I. (Rs)	T.I (Rs)	T.E (Rs)	Benefit (Rs)	B.C Ratio	W.P. Rs m^{-3}	C.I (%)
I	4.5	37,100	50,300	9,066	96466	42,800	53,666	2.24	3.88	200
II	3.3	25,500	50,500	5,638	81638	35,300	46,338	2.29	3.67	180
III	3.9	26,600	60,800	8,727	96,127	43,800	52,527	2.18	4.55	270
IV	3.2	23,000	40,600	8,523	72,173	28,700	43,473	2.49	2.10	150
V	4.1	31,550	51,150	9,101	91,801	37,100	54,701	2.45	3.94	270
VI	4.6	37,300	46,700	10,981	94,981	39,100	55,881	2.41	3.77	190
VII	4.0	35,000	36,200	8,242	79,442	34,100	45,242	2.30	2.91	170
	27.6					Total	351828	Av. 2.33	Av. 3.54	Av. 197.1

* KI = wet income, RI = Rabi Income, FI = Fish Income, TI = Total Income, TE = Total Expenditure, BC = Benefit Cost, WP = Water Productivity, CI= Cropping Intensity

Table 5. Performance index of micro tube well in different modes of participation

Mode of participation	Benefit Rs ha^{-1}	Av. B.C Ratio	Av. W.P. Rs m^{-3}	C.I (%)
90:10	12,740	2.33	3.54	197.1
50:50	14,500	2.70	4.21	250.0
30:70	19,199	3.17	5.57	280.0

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 generated additional employment to the tune of 356 man days and ensured better returns without any yield decline in coconut (Manjunath, 2002). 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 production centers of the country are located in coastal parts of Gujarat, Andhra Pradesh, and Tamil Nadu (Kumar, 2008). 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 Orissa, have become popular throughout the country.

Rice-duck farming : Duck rearing in rice field is a profitable and environmentally sustainable farming option and is 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' participation (Panda, 2004; Hossain *et al*., 2005).

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 deepwater and low to moderately saline areas. While, mixed, sequential and rotational rice-fish-prawn culture can be practised 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 (Sinhababu and Venkateswarlu, 1998). 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 Rs 6,895-10,781 ha^{-1}, as compared to Rs 4,037 ha^{-1} from rice alone (Ghosh, 1992; Sinhababu and Venkateswarlu, 1998; Mishra and Mohanty, 2004). Integration of vegetables and fruit crops on bunds can further increase the productivity and net farm income to the tune of Rs 22,450 ha^{-1} yr^{-1} (Rautaray *et al*., 2005).

Rice-fish diversified farming systems : The Central Rice Research Institute, Cuttack, Orissa 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 goatery, etc. on bunds are grown in rainfed waterlogged areas. In deepwater areas, multitier farming system can be practised 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 Rs 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. These 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 (Sinhababu,1996; Sinhababu *et al.*, 2008, Sinhababu and Adhya, 2009). Adoption of the system in coastal plains of Orissa, resulted about 15 times increase in net farm income, besides higher employment generation (Sinhababu *et al.*, 2006). 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 additional to normal practice of rainfed kharif rice alone, accrued per hectare were to the tune of Rs. 440/- due to growing of plantation crops on the bunds, while the values were Rs. 2525/- and Rs.12,000/- on account of pisciculture in the storage reservoir with and without bund around it, respectively (Ambast *et al*., 1998).

Coastal saline ecosystems :

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 Rs 8,000-23,000 $ha^{-1}yr^{-1}$ compared to Rs 5,100 $ha^{-1}yr^{-1}$ in the case of rice (wet season crop) alone. The income increases to about Rs 33,000 ha^{-1} yr^{-1} with the addition of vegetable crops during wet season (Ghosh *et al*, 1985; Biswas *et al*, 1990; Ghosh, 1992). 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 350-1600kg $ha^{-1}yr^{-1}$ in case of fish with net income of Rs 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 (Padmanabhan *et al.*, 2001; Padmakumar, 2006). 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 (Sarkar *et al*, 2005). 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 (Sinhababu *et al.*, 2008) and reduction of green house gases to the level of 30% in CH4 (Lu and Li, 2006) and 32% in N_2O (Datta *et al*., 2009).

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 Orissa, provided a net profit of about Rs 350 per bird, besides eggs to the poor farm families (Sinhababu *et al*, 2006.).

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 1.5t and net income of Rs 1.66,000 $ha^{-1}yr^{-1}$ (Anon, 2005), while mud crab fattening can give a very high annual net farm income of Rs 1,41,800 by raising six cycles of crop in a 0.1 ha tidal pond (Anon, 2006-10). 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 & Nicrobar 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 valcano'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 seawater 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 (Yadav, 2008).

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.

Threats to Ecology

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, 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. As the microscopic plants die and sink to the ocean floor, they feed on bacteria, which consume dissolved oxygen from surrounding waters. This limits oxygen availability for bottom-dwelling organisms and the fish that eat them. In dead zones, huge growths of algae reduce 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). He studied changes in microbial communities as a result of oxygen depletion, the potential contribution of increasing hypoxia to marine production and emission of N_2O and CH_4, and the effect of hypoxic development on methyl mercury formation in bottom sediments.

The World Resources Institute 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 tons per year, while natural processes contribute about 140 million metric tons (Table 6). 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).

Table 6. Global sources of Biologically Available (Fixed) Nitrogen

Anthropogenic sources	Annual release of fixed nitrogen (teragram)
Fertilizer	80
Legumes and other plants	40
Fossil fuels	20
Biomass burning	40
Wetland draining	10
Land clearing	20
Total from human sources	210
Natural sources, viz. Soil bacteria, algae, lightning, etc.	
Total from natural sources	140

Source: World Resources Institute (2006)

Climate change

Destruction of habitats in coastal ecosystem is caused by natural disasters, such as cyclones, hurricanes, typhoons, volcanism, earthquakes and tsunamis causing colossal losses worldwide. Each year an estimated 46 million people risk flooding from storm surges. Ironically, the frequency of natural disasters is increasing with time, almost exponentially, due to climate change, as sea level rise also follows almost the similar trend (Sen, 2009). Coasts in many countries, therefore, increasingly face severe problems on account of sea level rise as a consequence of climate change (Fig. 3), leading to

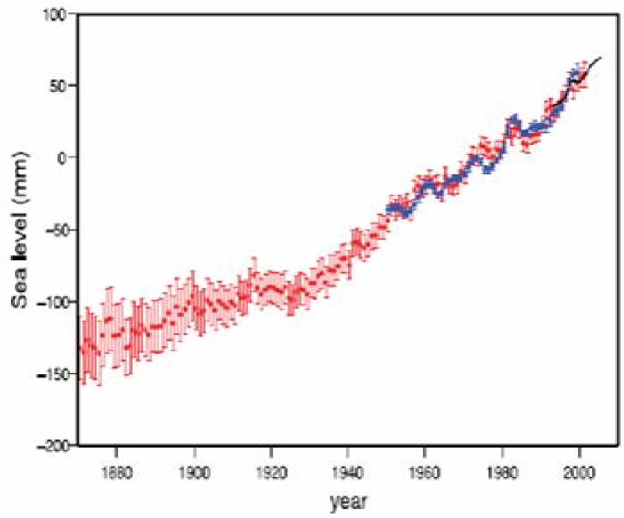

Fig. 3 **Global average sea level rise since 1961 at an average rate of 1.8 mm per year and since 1993 at 3.1 mm per year (Source Pachauri,2008b)**

potential impacts on ecosystems including damage to reefs or move large amounts of bottom material, thus altering habitat, biological diversity, and ecosystem function. The worst scenario projects sea level rise of 95 cm by the year 2100. It is projected, as extreme cases, the majority of the people who would be affected in different countries are China (72 million), Bangladesh (13 million people and loss of 16 percent of national rice production), and Egypt (6 million people and 12 to 15 percent loss of agricultural land), while between 0.3 percent (Venezuela) and 100 percent (Kiribati and the Marshall Islands) of the population are likely to be affected (Pachauri, 2008a,b). 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.

Population growth

Apart from climate change population growth is possibly the single most factor, other than those directly or indirectly related to crop production, impacting livelihood in the coastal ecosystem. Around the world maximum people die of drowning by storm surge. It is just astonishing to note that in the cyclone of 1970 that struck Bangladesh more than 300000 people met a watery grave. Similar things happen in Australia too, but casualties were less because of lesser density of population on the vulnerable areas (Joshi, 2007). A list of 5 deadliest natural disasters on the coast is shown in Table 7. It has been projected that number of people living within 100 km of coastlines will increase by about 35 percent in 2050 as compared to that in 1995. This type of migration will expose 2.75 billion people to coastal threats from global warming such as sea level rise and stronger hurricanes in addition to other natural disasters like tsunamis (Goudarzi, 2006). In another estimate (Schwartz, 2005b), the expected change of the population (or population density) from 2000 to 2025 regionwise shows increase in almost each coastal area. The estimates (population within 100 km of the coastline) show increase by 25% in Asia (except Middle East), 52% in Middle East and North Africa, 81% in Sub-Saharan Africa, 20% in North America, 31% in Central America and Caribbeans, and 32% in each South America and Oceanea, while there may be decrease by 2.5% in Europe. In India, according to the Department of Ocean Development, there are 40 heavily polluted areas along the Indian coast (Dubey, 1993).

Table 7. List of 5 deadliest natural disasters on the Coast (Source: Wikipedia, 2009b)

Rank	Event	Location	Death toll
1	1931 China floods	China	2,000,000-4,000,000
2	1887 Yellow River Flood	China	900,000-2,000,000
3	1970 Bhola cyclone	Bangladesh	500,000
4	1839 India cyclone	India	$\geq$ 300,000
5	2004 Indian Ocean tsunami	Indian Ocean	229,866

Integrated Coastal Area Management

The coastal ecosystem represents an extremely important region from economic, ecological, social, and recreational points of view, yet highly vulnerable to various natural disasters punctuated by climate change which renders it critical and warrants special attention for improvement in productivity and sustenance. The multifaceted approach to the management of coastal resources (Scialabba, 1998) has become known as integrated coastal area management (ICAM) or integrated coastal zone management (ICZM). Pernetta and Elder (1993) have described it as meaning `the process of combining all aspects of the human, physical and biological aspects of the coastal zone within a single management framework', which should be in greater overall benefits than pursuing sectoral development plans independently of one another.' ICAM programmes should be tailored to fit the institutional and organizational environment of the countries or regions involved, including the legal, political and administrative structure, cultural patterns and social traditions. It can be a strategy for an entire country, or can focus initially on special management areas selected on the basis of priority of management issues, their tractability to management interventions and the level of private or government support locally, regionally or nationally.

A number of different processes can be followed to rehabilitate coastal livelihoods in disaster affected areas, and it is important to stress that there is no blueprint or single correct approach (Pomeroy *et al.*, 2006). However, it is vital that the process be well planned at the operational level and be participatory, involving consultation and collaboration with the community. In terms of long term plan for rehabilitating coastal livelihoods following steps are suggested: (1) defining the target area, (2) community entry and integration, (3) assessments of resources, needs and opportunities, (4) education and capacity development, (5) rehabilitation plan, (6) Long term sustainability plan, and (7) adaptive learning through monitoring and evaluation.

Pomeroy *et al.* (2006) also observed in the wake of the Asian tsunami tragedy, that large volumes of aid and a vast array of actors have flowed into affected areas. There is a very real risk when rehabilitation responses to this and future disasters developed from simplistic thinking and dominated by easy and ill-considered options, such as replacing lost boats and gear, which can lead to increased fishing capacity, further creating unsustainability of stocks and threats to livelihoods, or providing equipment and infrastructure for new income generating schemes that are poorly suited to the local context. Rehabilitation should look beyond reinstating the problems of the past and seek to address the root causes of vulnerability of coastal people and communities and to build their resilience to future threats and capacity to exploit opportunities. Rehabilitation of coastal livelihoods is not merely about giving people jobs; it requires addressing fundamental social, economic and environmental reforms that affect coastal communities and livelihoods. It requires engaging a much broader array of actors across government, civil society and the private sector to build both understanding of the reforms needed and the commitment to undertake them.

Samarakoon (2007) in the proceedings on the workshop on tsunami affected Asian countries stated that "building back better" by incorporating sound integrated coastal planning and management (ICM) has been beset with contradictions since the tsunami of 26 December 2004. Low-cost programmes on how to save lives were ignored at vulnerable locations, particularly in Indonesia. This was evidenced by the tsunami of 17 July 2006 which killed about 600 people in Java. Adding to existing contradictions, the complexity of the task has been increased by tensions among coastal land uses during the past decade. Tensions stemmed mainly from the magnitude of financial investments and political power driving change. Small scale artisanal fisherfolk and farmers were the worst affected by the tsunami but were also the poorest and least powerful except where they were well organized, as in Kerala. The general absence of tenure and property rights with legal forms of representation has been a major obstacle faced by coastal resource users because they were dependent mainly on customary rights. Failure to safeguard livelihoods and diminishing income from natural resources was driving increasing numbers of these unskilled and semi-skilled workers to foreign employment, particularly from Bangladesh, India and Sri Lanka where most of the coastal poor lived. A "remittance windfall" has resulted despite governance failure. ICM in the post-tsunami era needs to entrench governance, community, ecology, science and market aspects more firmly while enhancing opportunities for the coastal poor. Carefully designed tenure rights are an instrument that can provide cohesion and political power to enable negotiation for improved governance.

According to Kesavan and Swaminathan (2006) the imminent threat to livelihood security is from a vicious spiral among environmental degradation, poverty and climate change-related natural disasters interacting in a mutually reinforcing manner. The M.S. Swaminathan Research Foundation at Chennai has developed a biovillage paradigm and rural knowledge centres for eco-technological and knowledge empowerment, with pro-nature, pro-poor and pro-women orientation, of the coastal communities at risk.Yumuang (http://www.Disaster livelihhod\

systematic geography and integrated coastal zone management (ICZM) for thailand.htm) provided some new key concepts and ideas of systematic geography that can be applied in integrated coastal zone management (ICZM) for Thailand. The important tools for studying the fields of systematic geography include: cartography, geographic information systems (GIS), remote sensing, mathematic modeling, and statistics were also briefly introduced.

Sudmeier-Rieux *et al.* (2006) while recommending on the ecosystem based approach for post-disaster reconstruction and restoration for a better livelihood commented that a comprehensive approach to disaster management involves a number of actors and actions outside the expertise and realm of environmental organizations. In the direct aftermath of a disaster, saving lives and providing for safety and basic needs is clearly the domain of emergency professionals and humanitarian agencies. As the focus turns to human livelihood recovery, clean-up, and preparing for future hazards, however, considerable negative long term consequences can arise from neglecting environmental concerns. Although many existing environmental guidelines, laws and policies are relevant to post-disaster emergency response and reconstruction efforts, they are rarely applied in times of crisis. In many cases they are not integrated with the procedures of humanitarian agencies and others involved in emergency response, who are generally the first on the ground. They also cannot be easily utilized by non-specialists. The way forward is clear: organizations and professionals involved in humanitarian assistance and in environmental management need to work together more closely to develop workable solutions and bring about real integration on the ground. They suggested a model (Fig. 4) as a general approach on Integrated Disaster Risk Management Cycle recommended by Dolmecemascolo (2004), subject to its adaptation based on individual case. To make this plan effective it will require significant pre-disaster preparation, coordination and communications by professionals in civil defence, emergency response units, and environmental and humanitarian agencies. Once the immediate focus has turned from saving lives to clean-up recovery, it is possible to act quickly while still respecting minimum environmental standards for waste management. This again requires pre-disaster training, coordination and the ability to conduct rapid environmental assessments.

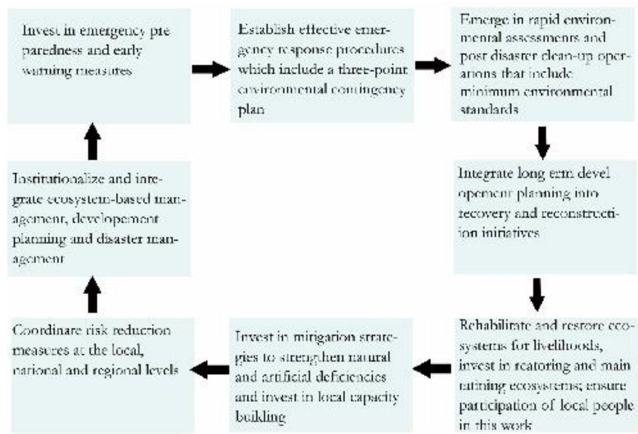

Fig. 4. Integrated disaster risk management cycle (Source: *Dolmecemascolo 2004*)

The same process can be applied while establishing temporary or transitional shelters. Activities that can worsen environmental problems include dumping waste materials in wetlands, and situating temporary shelters on sensitive sites.

Ecosystem rehabilitation and restoration are the key components of livelihood recovery. Once the initial damage has been assessed, the next step is to include stakeholders in restoring the ecosystems on which they depend for food, supplies and protection. Progress towards recovery needs to be monitored and adjusted, taking into account factors such as invasive species and demand for materials. At the same time, steps are required to be planned and executed during monitoring of the recovery to mitigate future risks in their living conditions through both structural adaptation strategies and non-structural capacity building strategies.

Geevan (1996), while discussing on the activities on the coastal ecosystem with special reference to Kerala (India) made two-fold suggestions: a) to emphasise the urgent implementation of Coastal Regulation Zone (CRZ) and b) to articulate a case for a more stringent and comprehensive approach to coastal zone management covering both the coastal land and water. According to him, the CZM needs to cover both landward and seaward sides. It was argued that regulating the activities on a narrow strip along the shore would be inadequate to protect the coastal and associated ecosystems, that it needed to be based more on periodic assessment of environmental impacts than on mere static zoning to regulate development, and finally that it might form part of a larger strategy for conservation of biodiversity and ecologically balanced sustainable development on the coast. Apart from the strategies listed above a large number of national and international disaster warning systems and collaborations using advanced electronic and telecommunication networks have been initiated at various levels, a detailed account of which has been presented by Yadav (2008).

While climate change is not the only threat to natural resources and livelihoods, climate-induced changes to resource flows will affect the viability of livelihoods unless effective measures are taken to protect and diversify them through adaptation and other strategies. The debate over climate change has now reached a stage where all but the most extreme contrarians accept that, whatever happens to future greenhouse gas emissions, we are now locked into inevitable changes to climate patterns. Many, including the scientists working with the Intergovernmental Panel on Climate Change, (IPCC), have concluded that these changes are already underway. The emergence of this consensus has led to increasing attention being paid to the issue of how to respond (IISD, 2003). For too long the whole climate change debate has focused at the global level, both in terms of global climate and in relation to the global economic and political system. A Task Force meeting organized in November 2001 by IUCN-The World Conservation Union, the International Institute for Sustainable Development (IISD) and the Stockholm Environment Institute (SEI) was a non-governmental response to the emergence of adaptation as the leading issue in the global climate change debate. It seeks to inform and challenge conventional wisdom in this field, and in particular, to bring together the different perspectives needed for successful adaptation. These perspectives come from four main constituencies-disaster reduction, climate change action, biodiversity conservation, and poverty alleviation-each with their own understandings of and responses to the climate change dilemma. Drawing from each of their experiences and emerging priorities, the Task Force identified the need for an integrated approach to climate change adaptation based on the livelihoods of vulnerable communities (IISD, 2003). The Task Force specified the following areas:

I. To make and demonstrate a compelling case for an alternative approach to climate change adaptation based on vulnerability reduction.

II. Specifically, to promote natural resource based approaches for the reduction of vulnerabilities. These approaches should provide multiple benefits: they should generate immediate economic returns to poor people, sustain and diversify their livelihoods, conserve ecosystems and, where possible, sequester carbon.

III. To offer convincing demonstrations of how on-the-ground livelihood activities can link with policy processes to reduce existing and future climate-related vulnerabilities that poor people face in different parts of the world.

IV. To identify multi-stakeholder, participatory processes that form the basis for the selection, implementation and appraisal of adaptation strategies. It is assumed that national governments, multilateral and bilateral development agencies and banks, the private sector, the scientific community, civil society and other stakeholders will participate in the implementation process.

V. To critique the prevalent policy approach for addressing adaptation, especially the artificial distinction between climate change and climate variability and the assumption that adaptation needs to focus on global rather than local processes.

The Task Force has tried to present a rationale for adopting an adaptation approach that reduces climate-related vulnerability through ecosystem management and restoration activities that sustain and diversify local livelihoods. This calls for a greater emphasis on micro-level approaches to vulnerability reduction and a closer collaboration between disciplines, agencies and sectors to scale up these activities and integrate them into emerging policy frameworks, needless to mention, with priorities on poverty reduction (IISD, 2003). 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.

According to Sen (2010), although management of salt affected soil catches immediate attention of all concerned for augmenting productivity in the coastal ecosystem, the various ecological factors discussed above, to speak the least, besides a few others, like under-sea tectonic movement along with off-shore and on-shore protection measures required to be undertaken, demand that it should be mandatory to give a holistic look to their interaction matrix for integrated coastal zone management, and not the management of the salt affected soils alone, to ensure lasting stability of the ecosystem. Finally, climate change is likely to have significant impact on the coastal ecosystem more than other areas impacting the very livelihood system apart from productivity. Drawing of both long term and immediate contingency plans to ensure lasting stability through appropriate conservation and harness of rich bio-resources coupled with efficient disaster management are needs of the hour.

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