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An overview of Coastal Ecosystem Structure, Dynamics and Management - Need for a Holistic Approach

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ABSTRACT
Coastal zones throughout the world have historically been among the most heavily exploited areas because of their rich resources. In coastal countries today an estimated half of the total populations live in coastal zones, and migration from inland areas to the coast is increasing. Not surprisingly, there is also a sharp conflict between the need for immediate consumption or use of coastal resources and the need to ensure the long-term supply of those resources. In many countries this conflict has already reached a critical stage, with large parts of the coastal zone polluted from local or upland sources, fisheries severely degraded or destroyed, wetlands drained, coral reefs dynamited and beaches long since ruined for human enjoyment. If the coastal zones are to be restored, appropriate and effective action is urgently needed. To answer this need, a management system has to be designed: Holistic or Integrated Coastal Zone Management (ICZM) and for this purpose it is essential to first understand the structure and dynamics of coastal ecosystem. We believe that this exposition, even though of basic academic interest, would provide needed introduction to the subject and enable the young researches (interested in carrying out scientific studies and environmental up-gradation activities that basically help the society) in better moulding of their research programmes.

INTRODUCTION

Coastal corridor or the coastal zone is the nerve centre of any country, as it is rich, dynamic and vibrant. Many of the major cities, world over, are located in these corridors. In our country also many large cities are located in this corridor. Coastal environments worldwide are subject to increasing pressures from rapid population growth and diversifying resource use. At the same time these environments experience variations in natural processes, over wide magnitude and frequency scales, for example from short duration, high intensity storms to long term relative sea level fluctuations. Despite its potential importance, the coastal ocean has been relatively neglected until recently; probably because of its intrinsic complexity. And as such, developing area specific environment up gradation models is the need of the hour.

The coastal zone is the interface where the land meets the ocean, encompassing shoreline environments as well as adjacent coastal waters. Its components can include river deltas, coastal plains, wetlands, beaches and dunes, reefs, mangrove forests, lagoons, and other coastal features. The limits of the coastal zone are often arbitrarily defined, differing widely among nations, and are often based on jurisdictional limits or demarcated by reasons of administrative ease. The coastal ocean is a shallow (<200 m) area, where land, ocean and atmosphere interact; in oceanography this region is termed the Epipelagic Zone. It is the portion of the global ocean where physical, biological and biogeochemical processes are directly affected by land. It is either defined as the part of the global ocean covering the continental shelf or the continental margin. It can readily be appreciated that none of these concepts has a clear operational definition.

The coastal zone contains a diversity of habitats including coastal heath-lands and forests, dunes, beaches, salt marshes, estuaries, wetlands, embayment, islands and intertidal zones. Despite its relatively modest surface area, the coastal zone plays a considerable role in the biogeochemical cycles, because virtually all land-derived materials (water, sediments, dissolved and particulate nutrients, etc.)

enter this region in surface runoff or groundwater flow. These terrestrial inputs are changing, largely as a consequence of human influence; about 40% of the world population lives within 100 km of the coastline, and this proportion is increasing. In addition, the coastal ocean exchanges large amounts of matter and energy with the open ocean. As a consequence of these external influences the coastal ocean constitutes one of the most geochemically and biologically active areas of the biosphere. We will first briefly describe various elements constituting the coastal zone. Since those who are engaged in management of the coastal ecosystem and those who are affected by the ecosystem degradation have limited understanding of the structure and dynamics of coastal ecosystem, we have added in this write-up a detailed exposition of various components of coastal ecosystem and the way natural phenomena are influencing changes in the structure of coastal corridor through various dynamic processes.

ESSENTIAL ELEMENTS OF COSTAL ZONES

The costal zones are dynamic due to continuous interaction between land and ocean. The various natural phenomena responsible for the interaction are briefly explained below (description and figures are adopted from Skinner, Brian J. and Stephen C. Porter, 1995 and http://www.tulane.edu/~sanelson/Natural_Disasters/coastalzones.htm)

Tides: Tides are due to the gravitational attraction of Moon and to a lesser extent, the Sun on the Earth.The tidal bulges result in a rhythmic rise and fall of ocean surface, which is not noticeable to someone on a boat at sea, but is magnified along the coasts (Figure 1).

Usually there are two high tides and two low tides each day, and thus a variation in sea level as the tidal bulge passes through each point on the Earth's surface. Along most coasts the range is about 2 m, but in narrow inlets tidal currents can be strong and fast and cause variations in sea level up to 16 m.

Non tidal Sea level changes

While sea level fluctuates on a daily basis because of the tides, long term changes in sea level also occur. Such sea level changes can be the result of local effects such as uplift or subsidence along a coast line. But, global changes in sea level can also occur. Such global sea level changes are called **eustatic** changes. Eustatic sea level changes are the result of either changing the volume of water in the oceans or changing the shape of the oceans. Global warming, for example could reduce the amount of ice stored on the continents, thus cause sea level to rise.

Oceanic Currents: Oceanic circulation is three dimensional. Most visible to humans are the surface ocean currents that are mainly driven by the wind. Vertical currents and deep ocean currents are driven by upwelling and down-welling near the coasts and differences in density, temperature and salinity between the surface waters and the deep ocean waters. The surface waters of the ocean move in response to winds blowing over the surface. The surface currents have the following properties: Because of the Coriolis Effect, circulation is clockwise

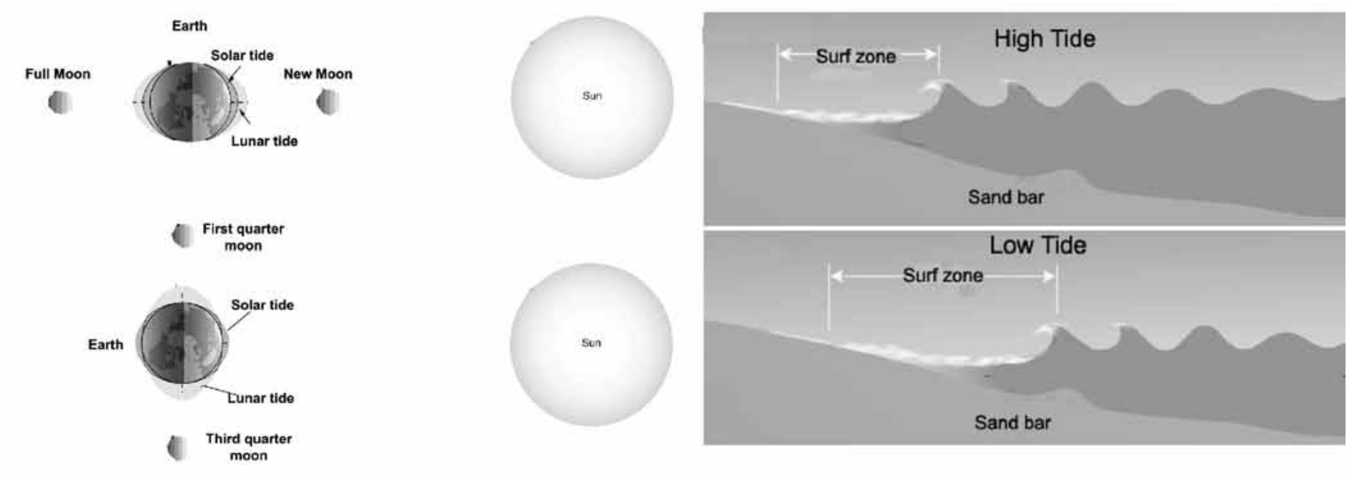

Figure 1. Tidal bulge due to Moon's attraction (left) and High tide and Low tide positions over the beach (right).

in the northern hemisphere and counter clockwise in the southern hemisphere. In each hemisphere cooler waters from higher latitudes circulate toward the equator where they are warmed and circulate back toward the poles. As surface waters approach the coast, they have to push the water down in order to make room for more water to come in. This results in down welling currents. If surface waters move away from the coast, water from below rises to replace the water removed, resulting in upwelling. Seawater also circulates vertically as a result of changes in density controlled by changing salinity and temperature.

Ocean Waves:

Waves are generated by winds that blow over the surface of oceans. In a wave, water travels in loops over the water surface with their diameter decreasing with depth. When waves approach shore, the water depth decreases and the wave will start grazing the bottom. Because of friction, the wave velocity decreases, but its period remains the same resulting in decrease in wavelength. As the wavelength shortens, the wave height increases. Waves that crash onto the beach are called breakers. Wave energy is dissipated by turbulence, which creates frothy white water in the surf zone. A surge of water (swash) rushes up the beach face. Gravity pulls the backwash down the slope of the beach. Rip currents form where water is channelled back into ocean. Waves generally do not approach shoreline parallel to shore. Instead some parts of waves feel the bottom before other parts, resulting in wave refraction or bending. Wave energy can thus be concentrated on headlands, to form cliffs. Headlands erode faster than bays because the wave energy gets concentrated at headlands.

Coastal Erosion and Sediment Transport:

Coastlines are zones along which water is continually making changes. Waves can both erode rock and deposit sediment. Because of the continuous nature of ocean currents and waves, energy is constantly being expended along coastlines and they are thus dynamically changing systems, even over short (human) time scales.

Erosion by Waves: The motion of waves is only felt to a depth of 1/2 times the wavelength. Thus, waves can only erode if the water along a coastline is shallower than ½ times the wavelength. But, when the wave breaks as it approaches the shoreline, vigorous erosion is possible due to the sudden release of energy as the wave flings itself onto the shore (Figure 2).

Rigorous erosion of sea floor takes place in the surf zone, i.e. between shoreline and breakers. In the breaker zone rock particles carried in suspension by the waves are hurled at other rock particles. As these particles collide, they are abraded and reduced in size. Smaller particles are carried more easily by the waves, and thus the depth to the bottom is increased as these smaller particles are carried away by the retreating surf. Furthermore, waves can undercut rocky coastlines resulting in mass wasting processes wherein material slides, falls, slumps, or flows into the water to be carried away by further wave action.

Sediment that is created by the abrasive action of the waves or sediment brought to the shoreline

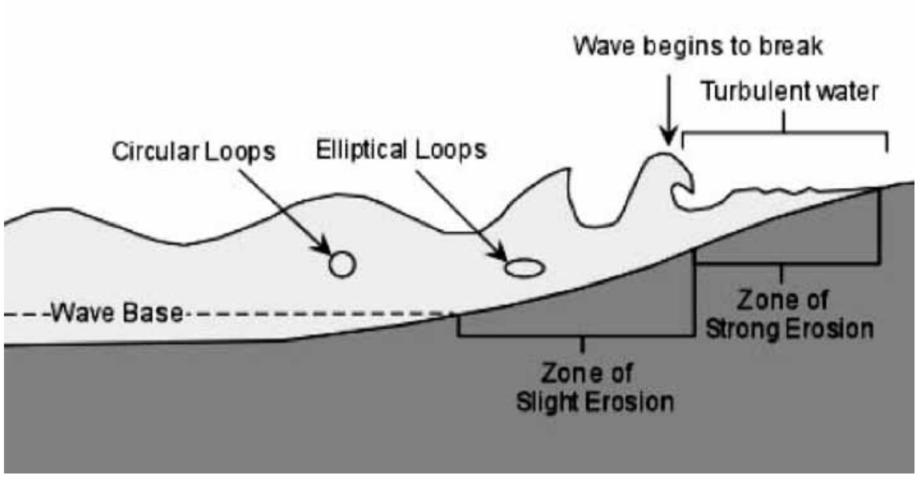

Figure 2. Coastal erosion due to ocean waves.

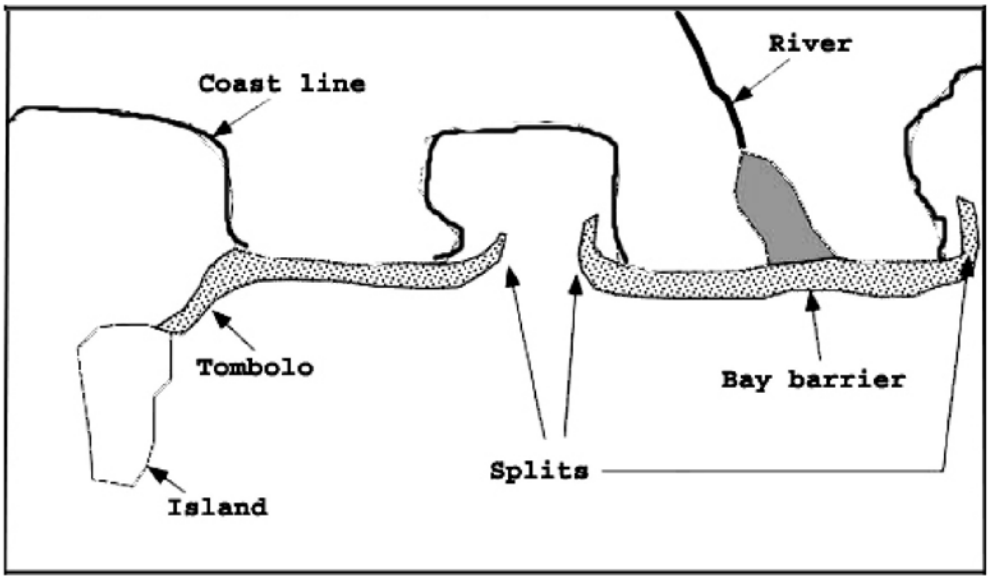

Figure 3. Coastal processes; formation of splits, tombolo and barriers as a result of balancing between wave energy and sediment supply

by streams is then picked up by the waves and transported. The finer grained sediment is carried offshore to be deposited on the continental shelf or in offshore bars, the coarser grained sediment can be transported by long-shore currents and beach drift.

Coastal Processes: Coastlines represent a balance between wave energy and sediment supply. If wave energy and sediment supply are constant, then a steady state is reached. If any one of these factors changes, then shoreline will adjust. For example, winter storms may increase wave energy.If sediment supply is constant, fine grained beach sand may be carried offshore resulting in pebble beaches or cobble beaches. Due to input of sediment from rivers, marine deltas may form and due to beach and long shore drift such features as spits, tombolo, and bay barriers may form (Figure 3).

Types of Coasts

The character and shape of coasts depends on such factors as tectonic activity, the ease of erosion of the rocks making up the coast, the input of sediments from rivers, the effects of eustatic changes in sea level, and the length of time these processes have been operating.

Rocky Coasts

In general, coastlines that have experienced recent tectonic uplift as a result of either active tectonic processes or isostatic adjustment after melting of glacial ice form rocky coasts with cliffs along the shoreline (Hanson 2009). Anywhere wave action has not had time to lower the coastline to sea level, a rocky coast may occur. Because of the resistance to erosion, a wave cut bench and wave cut cliff develops. The cliff may retreat by undercutting and resulting mass-wasting processes. Because cliff shaped shorelines are continually attacked by the erosive and undercutting action of waves, they are susceptible to frequent mass-movement processes which make the tops of these cliffs unstable areas for construction. If subsequent uplift of the wave-cut bench occurs, it may be preserved above sea level as a marine terrace.

In areas where differential erosion takes place, the undercutting may initially produces sea caves. If sea caves from opposite sides of a rocky headland meet, then a sea arch may form. Eventual weakening of the sea arch may result in its collapse to form a sea stack.

Beaches: A beach is the wave washed sediment along a coast. Beaches occur where sand is deposited along the shoreline (Figure 4).

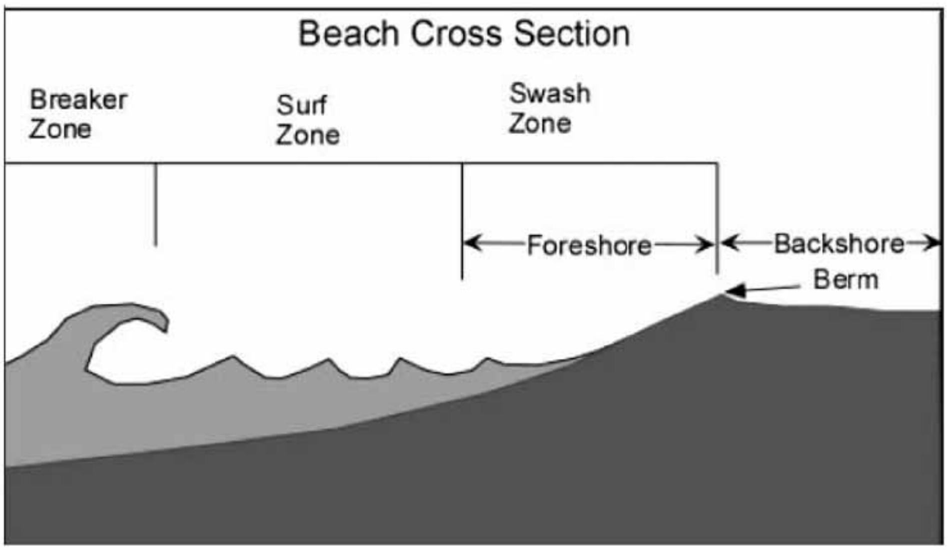

Figure 4. Cross section of a beach showing various subdivisions

A beach can be divided into a foreshore zone, which is equivalent to the swash zone, and backshore zone, which is commonly separated from the foreshore by a distinct ridge, called a berm. Behind the backshore may be a zone of cliffs, marshes, or sand dunes.

Barrier Islands - A barrier island is a long narrow ridge of sand just offshore running parallel to the coast. Separating the island and coast is a narrow channel of water called a lagoon. Most barrier islands were built during and after the last glaciation as a result of sea level rise. Barrier islands are constantly changing. They grow parallel to the coast by beach drift and long shore drift, and they are eroded by storm surges that often cut them into smaller islands.

Reefs and Atolls - Reefs consist of colonies of organisms, like corals, which secrete calcium carbonate. Since these organisms can only live in warm waters and need sunlight to survive, reefs only form in shallow tropical seas. Fringing reefs form along coastlines close to the sea shore, whereas barrier reefs form offshore, separated from the land by a lagoon. Both types of reefs form shallow water and thus protect the coastline from waves.

However, reefs are highly susceptible to human activity and the high energy waves of storms. In the deeper oceans reefs can build up on the margins of volcanic islands, but only do so after the volcanoes have become extinct. After the volcanism ceases, the volcanic island begins to erode and also begins to subside. As the island subsides, the reefs continue to grow upward. Eventually, the original volcanic island subsides and is eroded below sea level. But, the reefs trap sediment and a circular or annular island, called an atoll, forms.

Estuaries- Coastal river valleys flooded by sea water are called estuaries. They are characterised by mixing of fresh and salt water. Most modern estuaries are related to sea level rise since the last glaciation.

Tidal Flats - These are zones along the coast that are flooded during height tides and form in the intertidal zones lacking strong waves. They are common behind barrier islands or in estuaries.

ACTIVE COASTAL ZONES AND ANTHROGENIC DAMAGES

Coastal zones are continually changing because of the dynamic interaction between the oceans and the land. Waves and winds along the coast are both eroding rock and depositing sediment on a continuous basis, and rates of erosion and deposition vary considerably from day to day along such zones. The following natural events have strong influence on coastal zones.

Sea Level Rise –Various factors affect the volume or mass of the ocean, leading to long-term changes in eustatic sea level. The two primary influences are temperature (because the density of water depends on temperature), and the mass of water locked up on land and sea as fresh water in rivers, lakes, glaciers, polar ice caps, and sea ice. Over much longer geological timescales, changes in the shape of oceanic basins and in land–sea distribution affect sea level. Sea level is presently rising and the rate of sea level rise may increase due to melting of continental ice sheets that presently cover Greenland, Arctic and Antarctica. Human habitation of low-lying coastlines may be in jeopardy in the near future. Higher sea level will make these coastal areas more susceptible to other hazards, like storms and tsunami.

Storms - The energy reaching the coast can become high during storms, and such high energies make coastal zones highly vulnerable to natural hazards. Great storms such as cyclones or other winter storms can cause erosion of the coastline at much higher rate than normal. During such storms beaches can erode rapidly and heavy wave action can cause rapid undercutting and mass-wasting events of cliffs along the coast, as noted above. High winds blowing over the surface of the water during storms bring more energy to the coastline and can cause more rapid rates of erosion. Erosion rates are higher because during storms wave velocities are higher and thus larger particles can be carried in suspension. This causes sand on beaches to be picked up and moved offshore; leaving behind coarser grained particles like pebbles and cobbles, and reducing the width of the beach.

During storms waves reach higher levels onto the shoreline and can thus remove structures and sediment from areas not normally reached by the incoming waves. Because wave heights increase during a storm, waves crash higher onto cliff faces and rocky coasts. Larger particles are flung against the rock causing rapid rates of erosion. As the waves crash into rocks, air occupying fractures in the rock becomes compressed and thus the air pressure in the fractures is increased. Such pressure increases can cause further fracture of the rock. Also during tropical cyclones, wind driven storm surge and can flood coastal areas and cause much death and destruction.

Tsunami – A tsunami is a giant sea wave generated during certain earthquakes, volcanic eruptions, or landslides. However, submarine earthquakes of high magnitude are the most common cause of tsunamis (Figure 5). The quakes are the result of sudden movement of tectonic plates at subduction zones where one plate is forced under the other. The sudden jump in the movement of the plates sends a tremendous force upward that is transferred to Water (Figure 5). The huge mass of water column is shoved up above sea level generating a great amount of energy which travels horizontally along the sea surface, moving away from the epicentre through the depths at speeds up to 950 km/hour. At the beginning the height of the thus generated tsunami wave may be less than 1m. When the tsunami reaches the coast, friction slows it to about 50 km/h or less. Shallow water compresses the energy forcing the water upward and making the tsunami wave to rise in height (Figure 5). The waves pile up and rush over the land.

Such waves can have wave heights up to 30 m, and have great potential to wipe out coastal cities. Tsunami waves do not resemble normal sea waves, because their wavelength is far longer. Rather than

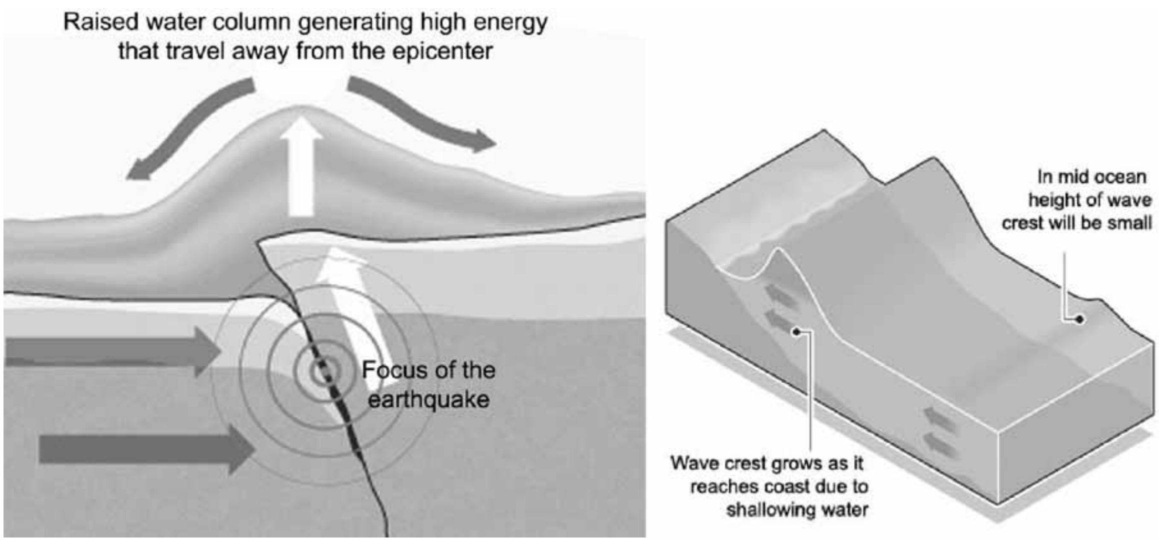

Figure 5. Genesis of Tsunami (left) and growing wave crest as tsunami reaches shore (right)

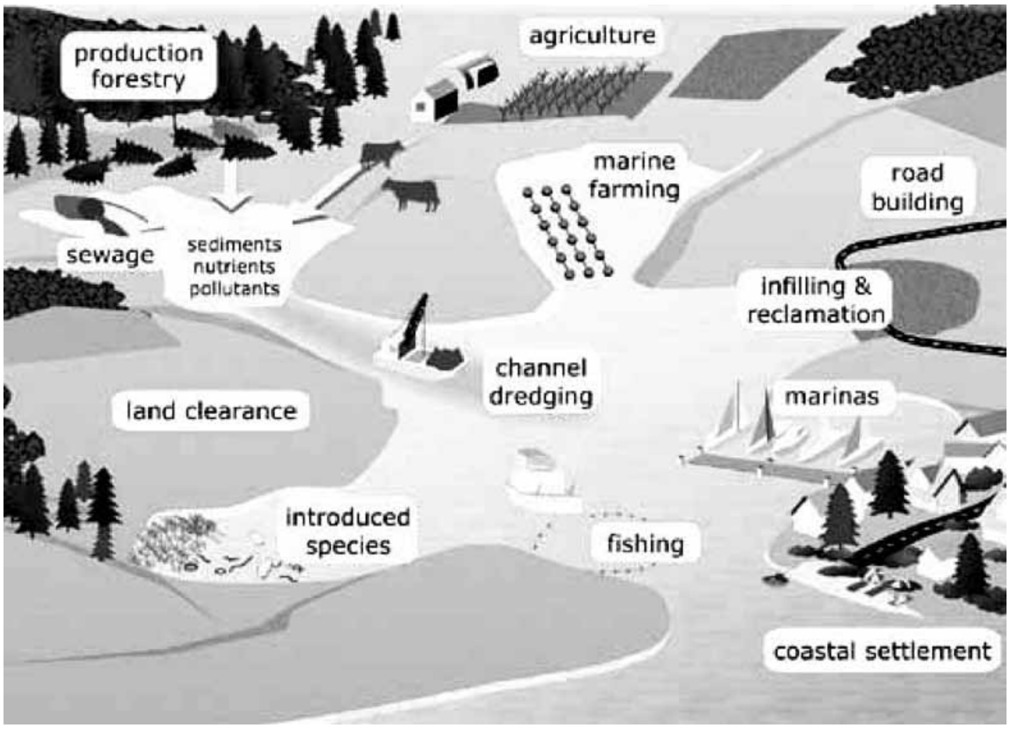

Figure 6. Human activities in coastal zones that make permanent and persistent impact.

appearing as a breaking wave, a tsunami may instead initially resemble a rapidly rising tide, and for this reason they are often referred to as tidal waves. Tsunamis generally consist of a series of waves with periods ranging from minutes to hours, arriving in a so-called "wave train". Wave heights of tens of metres can be generated by large events. Although the impact of tsunamis is limited to coastal areas, their destructive power can be enormous and they can affect entire ocean basins.

Thus, tides, currents, and waves, particularly during storms, bring energy to the coast that might alter the coastal geomorphology. However, when left to itself Mother Nature balances the equilibrium and ecology and environment return to normalcy once again. But the forced alterations by human interventions may result in permanent damage to the ecological and environmental aspects of the coastal zones as mentioned below.

Anthropogenic stresses to coastal zones

Humans and Mother Nature share blame in the destruction of ocean habitats, but not equally. Hurricanes and typhoons, storm surges, tsunamis and the like can cause massive, though usually temporary, disruptions in the life cycles of ocean plants and animals. Human activities, however, are significantly more impactful and persistent (Figure 6).

Wetlands are dredged and filled in to accommodate urban, industrial, and agricultural development. Cities, factories, and farms create waste, pollution, and chemical effluent and runoff that can wreak havoc on reefs, sea grasses, birds, and fish. Inland dams decrease natural nutrient-rich runoff, cut off fish migration routes, and curb freshwater flow, increasing the salinity of coastal waters. Deforestation far from shore creates erosion, sending silt into shallow waters that can block the sunlight coral reefs need to thrive.

Destructive fishing techniques like bottom trawling, dynamiting, and poisoning destroy habitats near shore as well as in the deep sea. Tourism brings millions of boaters, snorkelers, and scuba divers into direct contact with fragile wetland and reef ecosystems. Container ships and tankers can damage habitat with their hulls and anchors. Spills of crude oil and other substances kill thousands of birds and fish and leave a toxic environment that can persist for years. Perhaps the most devastating of all habitat-altering agents, however, is climate change due to global warming. Scientists are still coming to grips with the consequences that excessive atmospheric carbon dioxide and Earth's rapid warming are having on ecosystems. But there is ample evidence indicating that the oceans are bearing the brunt of these changes. As Earth's temperature rises, it is primarily the oceans that absorb the extra heat. Even small temperature changes can have far-reaching effects on the life cycles of marine animals from corals to whales.

In addition, warmer temperatures cause excess melting of ice caps and glaciers, raising sea levels and flooding estuaries. High levels of atmospheric carbon dioxide, caused mainly by the burning of fossil fuels, are absorbed by the oceans, where the gas dissolves into carbonic acid. This elevated acidity inhibits the ability of marine animals, including many plankton organisms, to create shells, disrupting life within the very foundation of the ocean's food web.

MANAGEMENT OF COASTAL ZONES

The purpose of Coastal Zone Management is to maximize the benefits provided by the coastal zone and to minimize the conflicts and harmful effects of activities on social, cultural and environmental resources.

Increased pressure on coastal systems, from environmental to socio-economic causes, threatens the livelihoods of coastal communities. Activities in the coastal zone are inherently related: the interface between marine and terrestrial environments culminates multiple jurisdictions, forms of governance, and resource users (Kay, R.C., & Alder, J. 2005). Because of increased pressure on coastal systems, integrated coastal management and planning has to emerge as a comprehensive approach to involve multiple users within decision-making.

Coastal zone management (CZM) is a part of Integrated Coastal Management (ICM), which is an interdisciplinary approach to problem definition and solutions in the coastal zone.It includes a range of initiatives that promote environmentally sustainable development of coastal areas, and encompasses a range of activities such as community based management of coastal resources, large-scale infrastructure development (ports, industrial and residential parks, etc.), pollution and erosion control, aquaculture, tourism and recreation, oil spill contingency planning, and navigational risk assessment. The crucially important aspect of ICZM is the need for good communication among the participating agencies and the public (Lowry, 1993)

An initial step in coastal zone management is to identify the geographical extent where management is to be implemented: a defined boundary is required. The delineation of this geographical space is mainly based on ecological, physical and socio-economic criteria present, which vary along different parts of the coast. Consequently there are variations in extent and width within different coastal zones. As the coastal zone incorporates both the terrestrial and marine environments there is a need for both a seaward and landward boundary that identifies the coastal zone. From an ecological point of view the inland boundary normally includes those habitats and ecosystems that are directly affected by the marine environment. The inland boundary normally also includes those areas for which management is necessary to control uses that have direct and significant impacts on coastal waters and extends inward to include all coastal resource areas and all major coastal issue areas.

The principles for good coastal planning and management are summarised below:

Sustainable management: The coast should be managed in a way that ensures that the opportunities for future generations to use and appreciate the coast are not diminished.

Identification of limits of acceptable change: Coastal managers should be aware of the physical limits requiring change at their site. Where there is an imperfect understanding, the precautionary principle should be applied.

Maintenance of ecosystem integrity: The coast should be managed to ensure that fundamental physical and natural processes can continue indefinitely.

Consultation: Open and collaborative consultation with all interested parties about the coast is essential for fair and equitable planning and management.

Identification of management objectives: Clearly understood and measurable objectives should be identified for coastal areas. These objectives should govern planning and management decisions.

Minimal intervention: Coastal management should involve doing as much as needed and as little as possible.

Site-specific management approaches: Each coastal site is unique in its features and use, and will require a management approach tailored to those unique characteristics. General techniques and approaches should be translated into what works for a particular coastal area.

Although, in the future, coastal areas will become more urbanized, and the economies of developing countries will undoubtedly diversify to some extent through industrialization, dependence on coastal resources is likely to remain strong. Industrial development often entails the processing of agricultural, fishery and forestry products, together with oil refining and textile manufacture. These diversified economic activities are often also dependent on coastal resources and, as economic diversification increases and makes the component sectors more interdependent, conflicts over natural resources and the environment will tend to develop.

Environmental role

Coastal areas are also important ecologically, as they provide a number of environmental goods and services. The peculiar characteristic of coastal environments is their dynamic nature which results from the transfer of matter, energy and living organisms between land and sea systems, under the influence of primary driving forces that include short-term weather, long-term climate, secular changes in sea level and tides.

Marine, estuary and coastal wetland areas often benefit from flows of nutrients from the land and also from ocean upwelling which brings nutrient-rich water to the surface. They thus tend to have particularly high biological productivity. Moreover, coastal areas frequently contain critical terrestrial and aquatic habitats, particularly in the tropics. Such habitats together comprise unique coastal ecosystems, support a rich biological diversity and frequently contain a valuable assortment of natural resources. Examples of such habitats are estuarine areas, coral reefs, coastal mangrove forests and other wetlands, tidal flats and sea grass beds, which also provide essential nursery and feeding areas for many coastal and oceanic aquatic species.

Physical features of coastal ecosystems, such as reefs and belts of mangrove, are important for the mitigation of the effects of natural disasters, such as storm-tide surges, shoreline retreat or floods. These features also play an essential role in natural processes, such as land accretion, and help to control coastal erosion and other damage arising from wind and wave action.

Even when coastal areas do not provide unique biological ecosystems, their location at the sea/land interface has recreational and aesthetic values which, in many countries, support valuable tourism activities, as well as providing attractive sites for industrial development and human settlements. The recreational and aesthetic values of coastal areas are increasing in developing countries as coastal tourism develops and domestic demand rises with increasing real incomes. Unique and appealing vistas, sandy and rocky beaches, pristine blue water, wetlands and coastal forest, and the associated wildlife, coral reefs and multiple recreational activities supported by these areas are major attractions of coastal areas.

Geoscience in Coastal Zone Management

Integrated Coastal Zone Management (ICZM) involves comprehensive assessment, setting precise objectives, planning of coastal systems and for achieving sustainable development. Strategies for sustainable resource development involve the management of coastal regions, including the design, construction and maintenance of the required development of infrastructure. Geoscientific studies have a multitude of applications in this endeavour and some of them are listed below:

Regional Geoscience:

Regional Geoscience acquires baseline geological and geophysical data at a variety of scales, seeking new concepts of continental margin evolution, including plate boundary processes, spreading ridges, and basin development. The work includes broad regional geophysical compilations for refinement of global, regional and local scale models of margin evolution, seeking linkages between margin development and the basins they contain, contributing to new hydrocarbon and mineralization resource models.

Resources Geoscience:

Resources Geoscience pursues the identification, understanding and assessment of non-renewable resources in Canada's coastal and offshore areas. The present focus is primarily towards offshore oil and gas, with some interest in off shore minerals, and emerging needs for geoscience aspects of biological habitats. Coastal mineral resource potential is beginning to be assessed using state-of-the-art seafloor mapping technology, which is also being applied to benthic fisheries habitat evaluation.

Environmental Geoscience:

Environmental Geoscience seeks understanding of natural geologic processes which affect development of coastal and offshore resources, and evaluates potential or previous impacts on the environment by development. This program provides the geoscience knowledge essential to understand and solve marine and coastal environmental problems, using a combination of mapping and process studies along with capabilities in sedimentology, geochemistry, paleo-environmental reconstructions, coastal dynamics and geotechnical engineering.

Sea floor imagery:

Sea floor imagery provides spatial data of bottom characteristics to complement water depth data. Typically geoscientists use side scan sonars and multibeam backscatter systems to make mosaics of the sea floor. At GSC Atlantic both sea floor imagery mosaics and multibeam bathymetry surveys have been significantly improved by the increased navigational accuracy possible with DGPS positioning technology. Sea floor mosaics which can show the location of man - made objects such as shipwrecks, waste dumps, pipelines and cables also contain valuable information about sediment distributions (Parrott 1995). The imagery also captures the signatures of a wide range of bottom processes such as current erosion and deposition, landslides, gas escape, and faulting - usually identified from specific bottom forms and morphologies.

Geoscience for Coastal and sea floor processes and geologic hazards:

Coastal and sea floor processes are the driving mechanisms in the coastal zone. Energy from waves and tides is transmitted to the seafloor and expended in eroding, transporting and redistributing sediments. In the geological time frame coasts are ephemeral features, forming, transgressing and reforming across the continental margin in response to sea level fluctuation, sediment supply and available energy. Understanding processes of sediment transport is fundamental to engineering design in the coastal zone including ports and harbours, coastal protection, cable and pipeline routing, and in developing predictive models of coastal response.

Seafloor geologic hazards constrain sustainable development in the coastal zone. The siting, construction and maintenance of engineering structures must take account of hazards such as erosion, sedimentation, landslides, gas and ice scour which, unless properly defined, can stop new engineering development.

Costal Zones of India

India has a coastline of 7516 km. It has an Exclusive Economic zone of 2.02 Million Sq. Km. Out of its 1 billion plus population, nearly 20% live in the coastal areas (Srivastava 2010). Many highly populated and industrialised cities like Mumbai, Chennai, Kolkata, Kochi, and Visakhapatnam are located along/near the coastal areas. There are 12 major ports and over 185 minor ports handling shipping to various degrees of intensity (Figure 7). The coastline of the mainland falls under the divisions of 9 States and two Union Territories. The coastline of islands of Andaman, Nicobar and Lakshadweep (Laccadives) group of islands constitute nearly 2000 km.

Along the Indian coastline, the brackish water areas include marshes, backwaters, mangroves, inter – and sub-tidal measures about 14,16,300 hectares. These areas, termed coastal wet lands, act as feeding and nursery grounds for a variety of commercially important fish, prawn and crabs, as a media for inland transportation, fishing etc. Mangroves of Indian Coast are found along the islands, major deltas, estuaries and backwaters of the East Coast on India. They also exist along the oceanic island groups of the Andaman and Nicobar. While the mangroves along the West Coast of India are dense, they are scattered and comparatively small in area. Gangetic Sunderbans, Andaman-Nicobar Islands, Krishna and Godavari deltas and Mahanadi delta areas are some of the best mangrove formations of India.

Indian coastal region is dominated by three seasons, viz. southwest monsoon (June to September), northeast monsoon (October to January) and fair

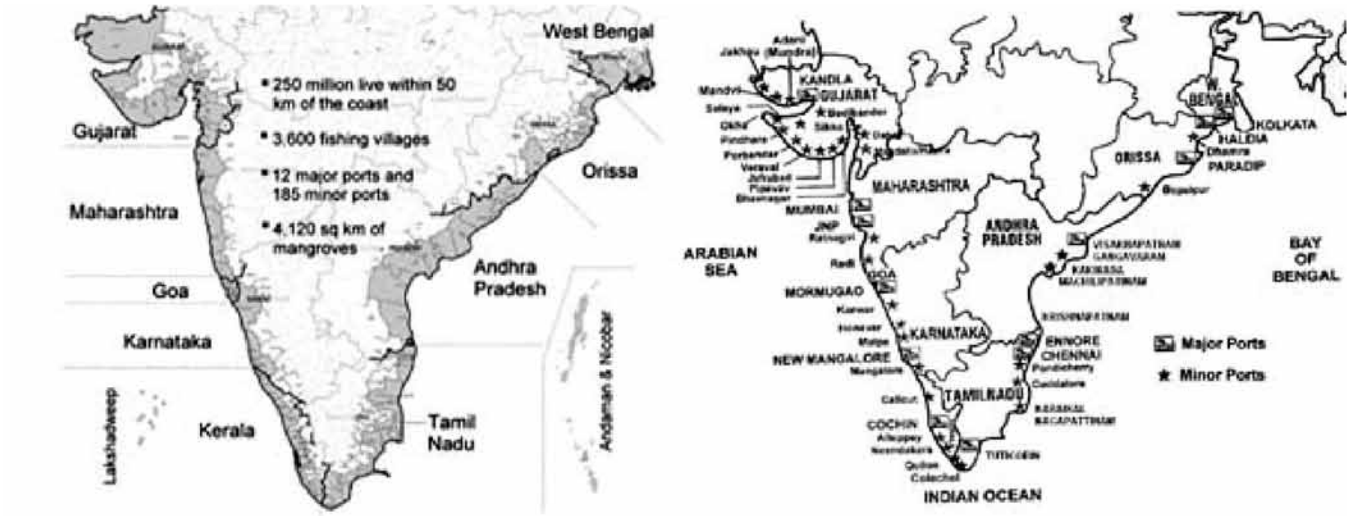

Figure 7. Indian coastal zone (left) and sea ports (right)

weather period (February to May). The continental shelf along the east coast is narrow, whereas along the west coast, the width of the shelf varies from about 340 km in the north to less than about 60 km in the south. Rivers are identified as the major sources of sediment along the Indian coast, among which the Ganges and Brahmaputra contribute a major share of suspended sediments to the Bay of Bengal, and the Indus to the Arabian Sea.

A major environmental concern for coastal zone management of India is coastal erosion due to tropical cyclones. A typical example is the thickly populated coastal zone of Kerala which is facing severe problems due to attack of high waves during the southwest monsoon (Mallik et al 1987). Similarly the southern coast of Tamilnadu faces severe threat of rapid changes in coastal geomorphology due to tropical cyclones and associated storm surges (Mujabar and Chandrasekhar 2011). Similarly Andhra Pradesh coast has frequently been affected by cyclones and inundated by storm surges. Major parts of Krishna and East Godavari districts shoreline are subjected to high rate of erosion. Erosion is clearly noticed in certain areas such as Uppada, Visakhapatnam and Bhimunipatnam. (Anon., 2009). Dynamics of the Indian coastal zones were discussed by many workers (Chandramohan et. al. 1991, 1993a,b, Kumar et al 2000, 2001, 2002, Sundar and Sarma 1992, Sanjeev 1993, Nayak 1980,

The androgenic pressures and the various activities along the Indian coast which require management are enumerated State-wise below:

West Bengal coast

This coast is regularly disturbed by short wave action of tidal currents

a. Erosion
b. Anthropogenic pressure
c. Diffused CRZ line due to continuous erosion/ accretion phenomenon
d. Sea level oscillation due to climatic, geological/ physical factors
e. Global warming and biosphere – atmosphere exchange of trace gases

Orissa coast

- Orissa coast is frequently ravaged by cyclonic storms and associated floods causing colossal loss of life and property almost every year
- Changing Chilika inlet dynamics – likely to affect lakes' ecology
- Changing shoreline causing shift in turtle nesting grounds
- Coastal Land use change and threat to the coastal bio-resources
- Climate change and associated Sea Level Rise, Tsunami
- Livelihood of coastal population

Andhra coast

- Coastal erosion
- Indiscriminate mining of placer sand deposits
- Subsidence of coastal deltaic regions
- Influence of rivers and sea water intrusion into coastal aquifers

- Sub-marine flows
- Influence of Coastal corridor, Exclusive Economic Zone and Coastal Industrial complexes
- Extinction of Mangrove ecosystem.
- Damage to the Wetlands
- Impact of Oil-well drilling.
- Impact of aquaculture
- Influence of salt industry
- Large scale sand mining has resulted in high rate of sediment transportation

Tamilnadu and Puducherry coast
- Pollution of the sea front due to municipal and industrial wastes.
- Ever-increasing demographic pressure with its attendant problems of waste generation and groundwater depletion – the latter causes salinity ingression.
- Pressure on establishing hotels and amusement parks at the water front
- Incomplete implementation of seasonal fishing bans, and overfishing.
- Beach erosion; destruction of mangroves
- Geomorphologic changes to estuaries

Kerala coast
- The problems of the coastal zone are unique due to the high density of population, loss of land due to coastal erosion, mining of beach sand for industrial purposes, drastic
- Morphological and shoreline changes due to shore structures like harbour breakwaters,
- Destruction and reclamation of wetland including mangroves, saline intrusion into the water table, decreasing fish catch, development related degradation of the environment
- Violation of the provisions of CRZ. The coastal community is the only sector that periodically loses dwelling places due to erosion.
- The destruction of natural habitats in the form of reclamation of wetlands.

Karnataka coast
- Occupational pressure
- Coastal erosion
- Water pollution
- Salinity

The intrusion of saline water in wells up to a distance of nearly a kilometre from the coast
- Unsustainable fishing practices
- Substantial increase in the use of trawlers in recent years

Maharashtra coast
- Coastal urban areas such as Mumbai have been severely affected by erosion, partly due to clearance of mangroves and associated vegetation along the shoreline and also due to construction of offshore and coastal infrastructure
- Threats to the mangroves
- Dumping of non-biodegradable solid wastes. Water pollution
- Conversion of mangrove swamps
- Conversion into saltpans
- Conversion into aquaculture plots

Gujarat coast
- Man-made coastal issues triggered due to reclamation of seaward side; effluent discharge into estuary areas; blocking of flow of water in delta regions; illegal mining from rivers; dredging activities resulting in high turbidity conditions.
- Ship-breaking units
- Gujarat has very high number of ports in the country.

. Pollution due to industrial effluent discharge is a major issue in South Gujarat coast
- Sand mining has affected the water table in coastal areas as well as triggered

Saline water intrusion.
- Coastal erosion is also a major problem in South Gujarat

Regulated development of the coast includes protection of fishery, protection of coastal ecosystems, protection of life and property, maintenance the scenic beauty of coast, encouragement to sustainable tourism and ensuring public access to beaches.

Holistic approach to Coastal Zone Management

The unique nature of coastal zones is widely understood to require a concerted, well considered and holistic coordinated integrated management and planning approach (Kay and Alder, 2005). This is most often referred to as an “integrated” management approach. Indeed, “Integrated” as a prefix to coastal management is now so widely adopted as a concept critical in striving for sustainable coastal environments that it has effectively been adopted into the daily language of decision- and policy-makers in many coastal nations. ICM explicitly defines its goal in terms of progress towards more sustainable forms of development seeking a balance between economic development and use of the coastal region, protection and preservation of the coastal areas, minimization of losses of human life and property, and public access at the coastal zones.

National, and State level, for a holistic coastal zone management policy, have to consider broadly the following issues: (i) Overuse of resources (ii) Degradation of ecosystems (iii) Conflicts among stakeholders (iv) Coastal hazards (v) Livelihood security and (vi) Sustainable development.

Due to complexity of activities prevalent along the coastal land and marine environment, an integrated management of these activities in a coordinated manner through appropriated planning exercises would provide a solution to minimize inter-sectorial and cross-sectorial activities. For e.g., construction of ports/ harbours/ breakwaters without considering the suitability of the site may lead to damage to surrounding ecosystem like a brackish water lake or tourism beach or habitat for endangered species. Similarly disposing waste from domestic/industrial areas close to recreation facilities like beach resort or areas of eco-tourism will affect the economy derived from the tourism and related activities.

After years of coastal management planning we are still trying to develop simple, effective and widely applicable models and approaches. Today, the environmental problems in coastal areas have been aggravated by habitat destruction, water contamination, coastal erosion and resources depletion. Moreover, the challenges are further intensified by increasing social and cultural degradation as well as poverty. The root cause of this crisis is a failure of both perspective & governance; Oceans and coasts are the largest public domain and have to be managed holistically for the benefit of local communities, recognizing their socio-economic and cultural heritage values. Involvement of local communities is mandatory in the planning and decision-making process. Sustainability can be achieved when environmental conditions are appropriate. Holistic coastal zone management requires minimizing conflicts, exercising conflict analysis, and appropriately considering suitability. Finding suitable sites for existing and potential use/activity in the marine and coastal environment is one of the most critical challenges facing coastal planning and management. Optimal sites are selected based on environmental suitability analysis and GIS models. Environmental parameters required for potential activity sites were selected and generic protocol was developed. Often a modified version of the activity protocol has to be created and applied based on available and spatially explicit data.

Special attention has to be given to the ecologically sensitive areas such as Mangroves, coral reefs, sand beaches and sand dunes, inland tidal water bodies (i.e. estuaries, lakes, lagoons, creeks), mudflats, marine wildlife protected, coastal fresh water lakes, salt marshes, turtle nesting grounds, crabs habitats, sea grass beds, seaweed beds and nesting grounds of migratory birds etc.

Human involved areas of particular concern are coastal municipalities/corporations (the entire notified area), coastal Panchayats with enough population density.(the entire notified area), ports and harbours, notified tourism areas, mining sites, notified industrial estates, special economic zones, heritage areas, notified archaeological sites under the protected monuments act, defence areas/installations and power plants.

Facilities / activities requiring access to the shorelines are port and harbours, including refuelling facilities, and dredging and reclamation, fish landing sites, lighthouses and light-towers, beach tourism and water sports facilities, saltpans, mining of minerals other than beach sand, rocks, gravel, and sea-shells, hydrocarbon exploration and production and discharge pipelines for treated effluent and sewage, approach roads etc.

CONCLUSIONS AND RECOMMENDATIONS

A coastal zone is the interface between the land and water. These zones are important because a majority of the world's population inhabit such zones. Coastal zones are continually changing because of the dynamic interaction between the oceans and the land. Waves and winds along the coast are both eroding rock and depositing sediment on a continuous basis, and rates of erosion and deposition vary considerably from day to day along such zones. Tides, currents, and waves bring the energy to the coast

Integrated Coastal Zone management (ICZM) is a continuous and dynamic process that unites the government and community, science and management, sectorial and public interests in preparing and implementing an integrated plan for the protection and development of coastal ecosystems and resources.

Environmentally effective coastal zone management requires accurate, up-to-date and comprehensive data on which policy decisions can be based. In brief, scientific data are required on coastal wetlands/land form, land use, coastal processes bathymetry and water quality of near-shore waters. The concept behind the idea of ICZM is sustainability. Sustainability entails a continuous process of decision making, so there is never an end-state. The basic approach should address -adjustment of equilibrium between development and protection of the environment. The term integrated in coastal management context has many horizontal and vertical aspects which reflect the complexity of the task and it proves to be a challenge to implement effectively. Accurate demarcation of the various regulatory zones as per the laid down Government policies/act is the primary requirement for planning and implementing any project. Scientific data collection and study of coastal processes in the inter-tidal zones are the key elements which when integrated into a geographic information system and depicted on large scale topographic maps/charts would provide the base data.

The following recommendations may be taken into account for an effective management of coastal zones:

1. Mangroves are lifeline to coasts as it has potential to minimize damage during natural calamities and topsoil erosion. Therefore emphasis should be given for conservation and restoration.
2. Special attention should be given for conservation of vital & critical habitats such as coral reefs, sea bed grass etc.
3. Reclamation of wetland for agricultural and industrial purposes
4. In high erosion area, buffer zone of 10 km on both sides should be planned for new forestation.
5. Identification of vulnerable areas including eroded areas should be restricted for developmental activities.
6. Proper Planning and implementation of coastal protection work (erosion, flood protection, salt water intrusion, etc.).
7. Mapping and monitoring coastal erosion regularly using high resolution satellite Imagery.
8. Create setback and permitting systems to limit developmental activities in the most vulnerable areas.
9. Retreat from a change climate and shoreline environment.(moving the house further back from the shoreline)
10. Emergency response plan to be made for natural disasters such as cyclones, sea level rise, or anthropogenic activities such as oil spills.
11. The greatest possible use should be made of field data, historical records, palaeo-environmental and archaeological data to improve our understanding of coastal change without placing undue reliance on theoretical modelling techniques;
12. Coastal mapping should be done on large scale (1:2000 scale) with low and high tide area demarcation and special coastal features should be shown as special category.
13. In the map especially sandy beach, spits, beach ridges, mudflat and sand dune should be shown.
14. In order to ensure sustainable development, it necessary to develop accurate, up-to-date and comprehensive scientific databases on habitats, protected areas, water quality and environmental indicators and carry out periodic assessment of the health of the system. The modern scientific tools of remote-sensing, GIS and GPS are extremely valuable in development of databases and to analyse them in the integrated manner and derive management action plans.
15. Appropriate site selection should be marked for industries, aquaculture, recreational activities, etc.
16. It is appropriate to use of natural boundaries and not the administrative ones as the boundary of coastal zone plans

ICZM can benefit a country or region by facilitating sustainable economic growth based on natural resources, conserving natural habitats and species, controlling pollution and the alteration of shoreline and beachfronts, controlling watershed activities that adversely affect coastal zones, controlling excavation, mining and other alteration of coral reefs, water basins, and sea floors, rehabilitating degraded resources and providing a mechanism and tools for rational resources allocation. To accomplish its objectives, ICZM requires several national actions, including a policy commitment to support coastal resources management, an effective coordination mechanism among various government agencies, accumulation and effective dissemination of technical information etc.

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