CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 2

APPENDIX

ADB TA-8652 IND:
CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

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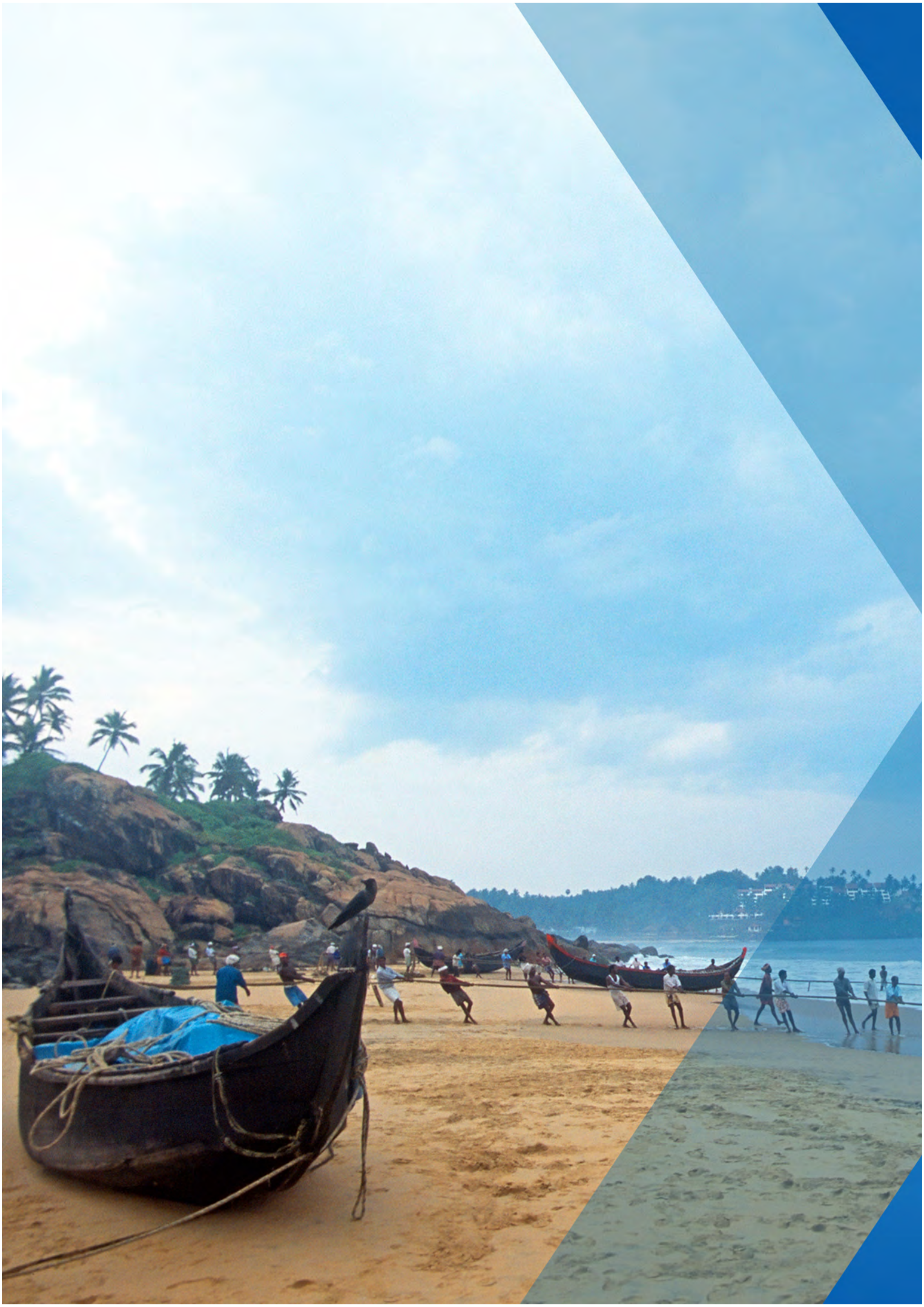
JUNE 2017

FCG ANZDEC Ltd.



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APPENDIX 1
ACRONYMS

ADB TA-8652 IND:
CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

APPENDIX 1
Acronyms

ADB	Asian Development Bank
ADCP	Acoustic Doppler Current Profiler
AVISO	Archiving, Validation, and Interpretation of Satellite Oceanographic Data
BCR	Benefit Cost Ratio
CAC	Citizen's Advisory Committee
CBA	Cost Benefit Analysis
CC	Climate Change
CD	Chart Datum
CEM	Coastal Engineering Manual
CEO	Chief Executive Officer
CERC	Coastal Engineering Centre (of United States Army)
CESS	Centre for Earth Science Studies
CICEF	Central Institute of Coastal Engineering for Fisheries
CIMU	Coastal Infrastructure Management Unit
CMFRI	Central Marine Fisheries and Research Institute
CMIS	Coastal Management Information System
CMU	Coastal Management Unit
CORDEX	Coordinated Regional Climate Downscaling Experiment
CPCB	Central Pollution Control Board
CPD	Continuous Professional Development
CPDAC	Coastal Protection and Development Advisory Committee
CPU	Coastal Planning Unit
Cr	Crores (10 million)
CRCPMP	Climate Resilient Coastal Protection and Management Project
CRZ	Coastal Regulation Zone
CSIR-NIO	Council of Scientific and Industrial Research- National Institute of Oceanography (India)
CSIRO	Council of Scientific and Industrial Research Organization (Australia)
CVCA	Critically Vulnerable Coastal Areas
CWC	Central Water Commission
CWPRS	Central Water and Power Research Station
CZMA	Coastal Zone Management Authority
CZR	Coastal Zone Regulation
DPC	District Planning Committee
DPDC	District Planning and Development Committee
EA	Environmental Assessment
EAC	Environmental Assessment Committee
EACC	East African Coastal Current
EARF	Environmental Assessment and Review Framework
ECC	Equatorial Counter Current
EES	Environmental Effects Statement
EIA	Environmental Impact Assessment
EICC	East India Coastal Current
EJ	Equatorial Jet

EMC	East Madagascar Current
EMP	Environmental Management Plan
ENSO	El Niño and the Southern Oscillation
ESL	Environmental Softness Ladder
FIDIC	International Federation of Engineers
FM	Flood Management
GCM	Global Climate Model; General Circulation Model
GDP	Gross Domestic Product
GEBCO	General Bathymetric Chart of the Oceans
GEF	Global Environment Facility
GIS	Geographic Information System
GMSL	Global Mean Sea Level
GoI	Government of India
GPS	Global Positioning System
GR	General Regulation
GSI	Geological Survey of India
HTL	High Tide Line
IB	Inverse Barometer
ICMAM PD	Integrated Coastal and Marine Area Management Project Directorate
ICRZ	Island Coastal Regulation Zone
ICZM	Integrated Coastal Zone Management
ICZMP	Integrated Coastal Zone Management Plan
IEE	Initial Environmental Examination
IIMP	Integrated Island Management Plan
IIT	Indian Institute of Technology
IITB	Indian Institute of Technology Bombay
IITD	Indian Institute of Technology Delhi
IITM	Indian Institute of Tropical Meteorology
IMP	Island Management Plan
INR	Indian Rupee
IPCC	Intergovernmental Panel on Climate Change
IPCC AR4	IPCC Fourth Assessment Report
IPZ	Islands Protection Zone
IREL	Indian Rare Earths Limited
ISRO	Indian Space Research Organization
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resources Management
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
KREC	Karnataka Regional Engineering College
LCC	Lambert Conical Conformal
LTL	Low Tide Line
MFL	Minimum Floor Level
MHWS	Mean High Water Springs
MIS	Management Information System
MKS	Meter Kilogram Seconds
MLWS	Mean Low Water Springs
MMB	Maharashtra Maritime Board
MoEF&CC	Ministry of Environment and Forests and Climate Change (Government of India)
MoES	Ministry of Earth Sciences
MoWR	Ministry of Water Resources (Government of India)
NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction

NCESS	National Centre for Earth Science Studies
NCPP	National Coastal Protection Program
NCSCM	National Centre for Sustainable Coastal Management
NDBP	National Data Buoy Programme
NDZ	No Development Zone
NGO	Non-Governmental Organization
NGRI	National Geophysical Research Institute
NIO	National Institute of Oceanography
NIOT	National Institute of Ocean Technology
NITK	National Institute of Technology, Karnataka
NIWA	National Institute of Water and Atmosphere, New Zealand
NMC	Northeast Monsoon Current
NOAA	National Oceanic and Atmospheric Administration
NRSC	National Remote Sensing Centre
OBS	Optical Back Scatter
PMDC	Project Management and Design Consultants
PMU	Project Management Unit
PoE	Panel of Experts
PPAR	Project Performance Audit Report
PPP	Public Private Partnership
PPTA	Project Preparation Technical Assistance
PSC	Project Steering Committee
PV	Project Value
PWD	Public Works Department
R&D	Research and Development
RCP	Representative Concentration Pathways
SAC	Space Applications Centre
SC	Somali Current
SCPMIP	Sustainable Coastal Protection and Management Project
SEA	State Executive Agency
SEAC	State Expert Appraisal Committee
SEARF	Supplemental Environmental Assessment and Review Framework
SEC	South Equatorial Current
SEIAA	State Environment Impact Assessment Authority
SIA	State Implementing Agency
SIEE	Summary Initial Environmental Examination
SLR	Sea Level Rise
SMC	Southwest Monsoon Current
SMO	Shoreline Management Organization
SMP	Shoreline Management Plans
SMRC	SAARC Meteorological Research Centre
SPCB	SPCB State Pollution Control Board
SPM	Shore Protection Manual
SRES	Special Report on Emissions Scenarios
SWL	Still Water Level
TA	Technical Assistance
ToR	Terms of Reference
UNDP	United Nations Development Programme
UTC	Coordinated Universal Time
WICC	West India Coastal Current
WMO	World Meteorological Organization
WRIS	Water Resources Information System

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APPENDIX 2

GLOSSARY OF COASTAL TERMS

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APPENDIX 2
Glossary of Coastal Terms

Accretion: The accumulation of sand on a beach which may be either natural or artificial. Natural accretion can occur due to delivery by rivers or longshore transport. Artificial accretion is man-made and may occur adjacent to a port, groyne, breakwater. Accretion also occurs in the lee of offshore reefs and islands. Beach fill by nourishment or bypassing and other such mechanical means will lead to accretion.

Aquifer: A saturated, permeable geologic unit of sediment or rock that can transmit significant quantities of water under hydraulic gradients.
Armor unit: A rock or concrete block designed to form the outer protective layer for a breakwater or seawall.

Atoll: Reef forming islands with a central lagoon. An atoll is a basic type of coral reef formation, which appears annular or ring-shaped (roughly circular or elliptical or horse-shoe shaped) in its plan view. An atoll is often topped by low sand island(s), enclosing a body of water (i.e. the lagoon) and is surrounded by deep water of the open sea, either oceanic or of continental shelf.

Backshore: The upper or inner, usually dry, zone of the shore or beach, lying between the high-water line of mean spring tides and the upper limit of shore-zone processes; it is acted upon by waves or covered by water only during exceptionally severe storms or unusually high tides. It is essentially horizontal or slopes gently landward, and is divided from the foreshore by the crest of the most seaward berm or dune.

Bar: Bars are submerged ridges of detrital sediments (usually sand) which are larger and less regularly spaced than ripple marks. They are formed typically in shallow waters by waves and currents. In many cases, the bars are seasonally pushed landward (in some cases permanently), so that they are merged with the shore or beach or sand dunes or converted into spits.

Barrier beach: A narrow, elongated, intertidal, sloping landform (beach) that is generally parallel with the beach ridge component of a barrier island or spit and facing the sea.

Barrier reef: Reef separated from the coast by a deep channel.

Bathymetry: Water depths measured in order to determine bottom topography.

Beach: The zone of unconsolidated material that extends landward from the low water line to the place where there is a marked change in material or physiographic form, or the line of permanent vegetation. Beach is sometimes referred as shore.

Beach erosion: The loss of beach material by wave action, tidal currents, littoral currents or by deflation often causing damage to the coast.

Beach ridge: Beach ridge is a low essentially continuous mound of beach or beach and dune material (sand, gravel, shingle) heaped up by the action of waves and currents on the backshore of a beach beyond the present limit of storm waves or the reach of ordinary tides and occurring singly as one of a series of approximately parallel deposits. The ridges are roughly parallel to the shoreline and represent successive positions of an advancing shoreline.

Beach scarp: An almost vertical slope along the beach caused by wave-induced beach erosion. It may vary in height from a few centimeters to few meters depending on wave action and composition of the beach.

Bio-shield: A vegetation belt along the coast that protects from wave and tide action, especially during storms. Coastal bio-shields include mangroves, casuarina plantations etc.

Biosphere reserve: Designated resource area featuring multiple use management systems where nature protection and uses for farming, forestry, fisheries, etc. are accommodated.

Boundary layer: Region close to the sea bed or coast where the flow is significantly affected by the interaction with the boundary.

Brackish water: A dilution of fresh water by the sea; brackish water may be defined as containing between 5 and 30 parts per thousand (ppt) of dissolved salt.

Breaker: A wave breaking on a shore, over a reef, etc. Waves break when they feel the sea bed while approaching shallow areas from deep waters. Breakers are either plunging or collapsing or surging. Spilling breakers can be seen in the deep wave generating area.

Breakwater: An artificial structure built into the sea, straight or curved, and designed to impede wave action so as to shelter a harbor or protect a stretch of coastline. The crest will be above the high tide elevation.

Buffer area: A protective, often transitional, area of controlled use-in coastal management, a peripheral zone separating a developed area from a protected natural area.

Bypassing, sand: Hydraulic or mechanical movement of sand from the accreting updrift side to the eroding downdrift side of an inlet, harbor entrance or structure. The hydraulic movement may include natural movement as well as movement caused by pumping.

Caisson: Boxlike structure used in construction work underwater or as a foundation.
Chart datum: See 'Datum'.

Climate: The weather conditions prevailing in an area in general or over a long period.

Climate change: Climate change, also called global warming, refers to the rise in average surface temperatures on Earth. An overwhelming scientific consensus maintains that climate change is due primarily to the human use of fossil fuels, which releases carbon dioxide and other greenhouse gases into the air. Dramatic changes in the climate have been observed after the industrial revolution.

Coast: A strip of land of indefinite width influenced by the marine environment (may be several kilometers) that starts from the landward limit of the beach to the first major change in the terrain features.

Coastal erosion: Erosion of the coast resulting from the erosion of the beach (read with 'Beach erosion' given separately).

Coastal plain: A low, generally broad plain that has as its margin an oceanic shore and its strata horizontal or gently sloping toward the water, and generally represents a strip of recently prograded or emerged sea floor.

Coastal protection: Works or management operations intended to control coastal erosion (usually termed as 'anti-sea erosion works' or 'coastal erosion control measures' in governmental circles).

Coastal zone: The term coastal zone means the coast, coastal waters, wetlands and adjacent shore lands, strongly influenced by the marine environment. Thus, the coastal zone includes the nearshore marine waters, marine islands, beaches, intertidal areas, wetlands and inland area to the limits of the coast.

Coastal zone management: A governmental process for achieving sustainable use of resources of the coastal zone whereby participation by all affected economic sectors, governmental agencies and non-government organizations is involved; unified or integrated coastal zone management when the management actions of the various stakeholders are formally unified and community participation is emphasized.

Contour map: A topographic map on which the shape of the land surface is shown by contour lines, the relative spacing of the lines indicating the relative slope of the surface.

Coral: Corals are marine invertebrates in class Anthozoa of phylum Cnidaria (formerly Coelenterata) typically living in compact colonies of many identical individual "polyps". The group includes the important reef builders that inhabit tropical oceans and secrete calcium carbonate to form a hard skeleton.

Coral reef - atoll: Reef forming islands with a central lagoon. If the lagoon is deep and large, is called oceanic atoll. Atoll with a shallow lagoon is known as shelf atoll. Very small atoll is known as faros atoll.

Coriolis force: It is an inertial force (also called a fictitious force) that acts on objects that are in motion relative to a rotating reference frame. In a reference frame with clockwise rotation, the force acts to the left of the motion of the object. In one with anticlockwise rotation, the force acts to the right.

Critically vulnerable coastal areas: Ecologically sensitive areas which shall be managed with the involvement of the local coastal communities including the fisher folk (CRZ, 2011).

Current, coastal: One of the offshore currents flowing generally parallel to the shoreline in the deeper water beyond and near the surf zone; these may be related to tides, winds, continental shelf waves or ocean water properties.

Current, ebb: The tidal current associated with the receding tide.

Current, flood: The tidal current associated with the rising tide.

Current, littoral: Any current in the littoral zone caused primarily by wave action; e.g., longshore current, rip current.

Current, longshore: The littoral current in the surf zone moving essentially parallel to the shore, usually generated by waves breaking at an angle to the shoreline.

Current, tidal: The alternating horizontal movement of water associated with the rise and fall of the tide caused by the astronomical tide-producing forces.

Cusp: One of a series of low mounds of beach material separated by crescent-shaped troughs spaced at more or less regular intervals along the beach face.

Cyclone: A warm-core, non-frontal synoptic-scale cyclone, originating over tropical or subtropical waters, with organized deep convection and closed surface wind circulation about a well-defined center.

Datum: For marine applications, a base elevation used as a reference from which to reckon heights or depths. This is often referred as chart datum. It is called a tidal datum when defined in terms of tidal phenomena and is based on a 19-year tide cycle (in the USA) - the datum is referenced to a fixed point typically known as a bench mark.

Deep water: Water sufficiently deep not to affect the propagation of surface waves. It is usual to consider water of depths greater than one-half of the surface wavelength as deep water.

Deflation: The removal of loose material from a beach or other land surface by wind. A dune is formed by deflation.

Delta: Delta is a product of rapid deposition of stream-borne sediments into relatively still standing bodies of water. The river supplies and deposits sand, silt and other detrital material more rapidly and then they can be removed by currents. Delta is essentially a land surface through a part of it may be subaqueous. The subaqueous part will be beneath a bay of lagoon or open sea.

Depth of closure: Seaward depth beyond which the variations in the seabed are insignificant or depth beyond which sand level changes between annual surveys become unmeasurably insignificant.

Developed area: Developed area refers to areas within the existing municipal limits or in other existing legally designated urban areas which are substantially built-up and have been provided with drainage and approach roads and other infrastructural facilities, such as water supply and sewerage mains (CRZ, 2011).

Diffraction (of water waves): The phenomenon by which energy is transmitted laterally along a wave crest. When a part of a train of waves is interrupted by a barrier, such as a breakwater, the effect of diffraction is manifested by propagation of waves into the sheltered region within the barrier's geometric shadow.

Downdrift: In direction of the alongshore current.

Dredging: The process of excavation of sediments and other material from aquatic areas for the purpose of maintaining adequate depths in navigation channels and berthing areas, as well as for other purposes.

Dune (coastal): Also known as sand dune, is a ridge or mound of loose, wind-blown (deflation) material, usually sand, on the coast formed just landward of the beach.

Ecotourism: Tourist activity attracted to environmental resources and based, usually, on a conservation theme.

Empirical equation: Equation based solely on observation rather than theory. An empirical relationship requires only confirmatory data irrespective of theoretical basis.

Environmental impact assessment: Detailed prediction of the impact of a development project on environment and natural resources with recommendations as to acceptability of the project, need for minimizing/eliminating/offsetting adverse effects, and a management plan to accomplish these countermeasures; a generic term for all types of impact assessment is environmental assessment.

Environmental management plan: Description of the mitigation measures to minimize the environmental impacts and the administrative aspects of ensuring that mitigation measures are implemented and their effectiveness monitored, after approval of the EIA.

Estuary: The part of a river that is affected by tides. The region near a river mouth in which the fresh water of the river mixes with the salt water of the sea.

Erosion control measures: Methods to control coastal erosion such as the use of seawalls, groynes (hard control measures), reefs, beach nourishment, bio-shields (soft control measures), etc.

Eutrophication: The process of enrichment of water which leads to excessive growth of algae and other aquatic plants from the introduction of an oversupply of nutrients such as nitrates or phosphates.

Flood plain: Flood plains represent the surface being constructed by the river. They run parallel to the river, and are subject to periodic overflow of river water.

Fore dune: A coastal dune or dune ridge oriented parallel to the shoreline, occurring at the landward margin of the beach, along the shoreward face of a beach ridge, or at the landward limit of the highest tide, and more or less stabilized by vegetation.

Foreshore: The intertidal part of a beach or the part of the shorefront lying between the beach head (for upper limit of wave wash at high tide) and the ordinary low water mark that is ordinarily traversed by the uprush and backrush of the waves as the tides rise and fall.

Foreshore facilities: The expression "foreshore facilities" means those activities permissible under the CRZ 2011 notification and they require waterfront for their operations such as ports and harbors, jetties, quays, wharves, erosion control measures, breakwaters, pipelines, lighthouses, navigational safety facilities, coastal police stations and the like.

Geomorphology: That branch of both physiography and geology which deals with the form of the Earth, the general configuration of its surface, and the changes that take place in the evolution of landforms.

Geotextile: Resilient, porous fabric used to retain soil or sand without building up water pressure.

Global climate model: Numerical models (general circulation models or global climate models), representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. While simpler models have also been used to provide globally- or regionally-averaged estimates of the climate response, only global climate models, possibly in conjunction with nested regional models, have the potential to provide geographically and physically consistent estimates of regional climate change which are required in impact analysis.

Global warming: The current increase in temperature of the Earth's surface (both land and water) as well as it's atmosphere. Average temperatures around the world have risen by 0.75°C (1.4°F) over the last 100 years about two thirds of this increase have occurred since 1975. In the past, when the Earth experienced increases in temperature it was the result of natural causes but today it is being caused by the accumulation of greenhouse gases in the atmosphere produced by human activities.

Gross sediment transport rate: The sum of the amounts of littoral drift transported to the right and the left, past a point on the shoreline in a given time period.

Groundwater: The water located beneath the earth's surface in soil pore spaces and in the fractures of rock formations. A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water.

Groyne (groin): A coastal protection structure designed to build a protective beach or to retard erosion of an existing or restored beach by trapping littoral drift. Groynes are usually perpendicular to the shore and extend from a point landward of predicted shoreline recession into the water far enough to accomplish their purpose.

Gulf: A relatively large part of an ocean or sea extending far into the land, partly enclosed by an extensive sweep of the coast, and opened to the sea through a strait; the largest of various forms of inlets of the sea. It is usually larger, more enclosed, and more deeply indented than a bay.

Headland: A high protrusion of the land into the sea, usually cliffed. Glossary - Encyclopedia of Coastal Science / An irregularity of land, especially of considerable height with a steep cliff face, jutting out from the coast into a large body of water (usually the sea or a lake); a bold promontory or a high cape / The high ground flanking a body of water, such as a cove / The steep crag or cliff face of a promontory.

High tide line: The line on the land up to which the highest water line reaches during the spring tide (CRZ 2011). The highs related to the spring tides vary every time and there is a cycle which is estimated to be repeating every 18.6 years. Hence in hydrography and sea surveying, the usually defined high sea level connected with tides is the mean high water springs (MHWS) which is the average of all spring tides over a period of 18.6 years.

High water mark: A line or mark left upon tide flats, beach, or along shore objects indicating the elevation of the intrusion of high water. The mark may be a line of oil or scum on along shore objects, or a more or less continuous deposit of fine shell or debris on the fore shore or berm. This mark is physical evidence of the general height reached by wave run-up at recent high waters. It should not be confused with the mean high water line or mean higher high water line.

Hindcast: To generate wave statistics from historical wind or air pressure data using computer wave models. All physical processes may be hindcast if data or models are available.

Hydrodynamics: A branch of physics that deals with the motion of fluids and the forces acting on solid bodies immersed in fluids and in motion relative to them.

Integrated coastal zone management (ICZM): A dynamic, multidisciplinary and iterative process to promote sustainable management of coastal zones. It covers the full cycle of information collection, planning (in its broadest sense), decision making, management and monitoring of implementation. ICZM uses the informed participation and cooperation of all stakeholders to assess the societal goals in a given coastal area, and to take actions towards meeting these objectives. ICZM seeks, over the long-term, to balance environmental, economic, social, cultural and recreational objectives, all within the limits set by natural dynamics. 'Integrated' in ICZM refers to the integration of objectives and also to the integration of the many instruments needed to meet these objectives. It means integration of all relevant policy areas, sectors, and levels of administration. It means integration of the terrestrial and marine components of the target territory, in both time and space. See also: coastal zone management.

Integrated coastal zone management plan: See 'ICZM'.

Integrated management plan (IMP): Prepared for critically vulnerable coastal areas keeping in view the conservation and management of mangroves, needs of local communities such as, dispensaries, schools, public rain shelter, community toilets, bridges, roads, jetties, water supply, drainage, sewerage and the impact of sea level rise and other natural disasters (CRZ 2011). The IMPs are prepared in line with the other guidelines for preparation of coastal zone management plans.

Intertidal zone: The land area between high tide line and low tide line as per the Coastal Regulation Zone notification.

Jetty: On open seacoast, a structure extending into a body of water, and designed to prevent shoaling of a channel by littoral materials. Stream or tidal flow jetties are built at the mouth of a river or tidal inlet to reduce inlet shoaling and to stabilize the channel. In some countries, they are called training walls.

Land reclamation: See 'reclaimed land'.

Littoral drift: The movement of sand and other material by littoral (longshore) currents in a direction parallel to the beach along the shore; usually wave-driven. The sedimentary material moved in the littoral zone under the influence of waves and currents.

Littoral transport: The movement of littoral drift in the littoral zone by waves and currents, including movement parallel to the shore (longshore transport) and movement perpendicular to the shore (on-offshore transport).

Low tide line: The line on the land up to which the lowest water line reaches during the spring tide. The lows related to the spring tides vary every time and there is a cycle which is estimated to be repeating every 18.6 years. Hence in hydrography and sea surveying, the usually defined high sea level connected with tides is the mean low water springs which is the average of all spring tides over a period of 18.6 years.

Marsh: Grassy wetland areas in standing or slow-moving water, usually treeless vegetation, composed of grass and low shrubs (sedge sods), frequently interspersed with channels or pools of open water. Maritime salt marsh, as distinct from inland salt marsh, is essentially confined to the temperate regions of the world.

Models (modelling): Computer simulations of complex natural processes. Physical models are scaled reproductions of a physical system. A model may also be a simplified representation of an environmental, economic or other processes.

Mudflat, paleo: Mudflats lying above high tide flats and are formed by marine deposition of the past sea level. These mudflats are related to the phenomenon of regression of the sea. They represent the sites of older mudflats when the sea level was several meters higher than the present.

Mudflat, reclaimed: It is a mudflat which is reclaimed by the construction of bunds across creeks. The bunds stop the inflow of sea water.

Mudflat, tidal: They are wide expanse of fine grained soft mud along the shore. They generally consist of deposits of clay, silt, ooze etc. The tidal mudflats are further classified on the basis of tidal influence into three types: i) high tidal mudflats; ii) intertidal mudflats, and iii) sub-tidal mudflats. High-tide mudflats are more or less flat and near high waterline. Deposition here is caused by material brought during the very highest tides. Intertidal slope areas which are unstable are affected by daily tides. The sub-tidal zone is normally exposed during very low tides.

Neap tide: Small tidal range when the sun and moon are opposed. Often taken as equal to the M2-S2 ranges.

Nearshore zone: A subaqueous marine or lacustrine landform area that is generally parallel to the shore and extends seaward and landward from the low water line to beyond the breaker zone including longshore bars. In the nearshore zone, waves steepen, break, and reform during passage to the beach. Sediment transport occurs both along and perpendicular to the shore via wave and current action.

Net sediment transport: The difference between the amounts of sediment transported along a beach to the right and left past a point on the shoreline in a given period.
Non-vegetated wetland: See 'wetland, non-vegetated'.

Ocean circulation: Ocean circulation is a result of ocean currents, which are continuous, directed movement of seawater generated by forces acting upon this mean flow, such as wind, the Coriolis effect, temperature and salinity differences.

Offshore reef: This is a construction-based system which fits into the "soft" solution category of coastal protection measures because it is offshore and underwater. An offshore reef acts on the waves, which are the most common cause of erosion, regulating its energy to act as a beach building force. The crest will be at or less than the high tide elevation.

Overtopping: Passing of water over the top of a structure as a result of wave run-up or surge action.

Paleo-channel: A paleo-channel is an abandoned course of a river. It represents the former levels of the river bed.

Paleo-mudflat: Paleo-mudflats are defined as mudflats lying above high tide flats and are formed by marine deposition of the past sea level (Nayak and Sahai, 1984, 1985). These mudflats are related to the phenomenon of regression of the sea. They represent the sites of older mudflats when the sea level was several meters higher than the present.

Plantations on coast: These plantations include cassuarina, cashew, eucalyptus commercially grown by the government as well as private organizations all along the coast on beach sands and dunes. The plantations especially on the sandy coast are developed extensively for the protection of the coast from high tide surge.

Progradation: Growth (accretion) of sediment deposits on a beach or an estuary.

Prototype: In modelling terms, describes the real world being simulated.

Quaternary Period: A geologic time period that encompasses the most recent 2.6 million years — including the present day. Part of the Cenozoic Era, the period is usually divided into two epochs — the Pleistocene Epoch, which lasted from approximately 2 million years ago to about 12,000 years ago, and the Holocene Epoch, which began about 12,000 years ago. The Quaternary Period has involved dramatic climate changes, with more than 60 periods of glacial expansion interspersed with briefer intervals of warmer temperatures. This period affected food resources and brought about the extinction of many species. The period also saw the rise of a new predator: man.

Reclaimed land: (i) A land area composed of earthy fill material that has been placed and shaped to approximate natural contours, commonly part of land-reclamation efforts after mining operations. (ii) A land area, commonly submerged in its native state, that has been protected by artificial structures (e.g., dikes) and drained for agricultural or other purposes.

Reclaimed mudflat: It is a mudflat which is reclaimed by the construction of bunds across creeks. The bunds stop the inflow of sea water.
Reef: See 'coral reef'.

Refraction: (i) The process by which the direction of a wave moving in shallow water at an angle to the contours is changed: the part of the wave advancing in shallower water moves more slowly than that part still advancing in deeper water, causing the wave crest to bend toward alignment with the underwater contours. (ii) The bending of wave crests by currents.

Regional climate model: A key limitation of global climate models is the fairly coarse horizontal resolution. For the practical planning of local issues such as water resources or flood defenses, countries require information on a much more local scale than global climate models are able to provide. Regional models provide one solution to this problem. Thus, regional climate models work by increasing the resolution of the global climate model in a small, limited area of interest.

Revetment: Sloping structures placed on banks or cliffs in such a way as to absorb the energy of incoming water or a facing of stone, concrete, etc., built to protect a scarp, embankment, or shore structure against erosion by wave action or currents.

Rip-rap: A layer of broken rock, cobbles, boulders, or fragments of sufficient size to resist the erosive forces of flowing water and wave action.

Rip current: A strong surface current flowing seaward from the shore as a return movement of water piled up on the shore by incoming waves and winds. Usually rip currents occur where the longshore currents converge.

Runoff: Water flowing over land into streams, rivers and estuaries derived from rainwater that has not soaked into the ground or been intercepted by leaves, ground depression, etc.
Salient: Widening of the beach as a bulge which forms behind an offshore obstruction like a reef or island.

Salinity ingress: Also seawater intrusion. Mainly in the case of groundwater, the intrusion of seawater due to excess withdrawal of groundwater as compared to its recharge from coastal aquifers resulting in increased salinity of groundwater.

Salt marsh: A flat or gently sloping vegetated wetland in the upper intertidal zone on sheltered parts of the coast (estuaries, inlets, lagoon shores). Often in the form of a depositional terrace, periodically submerged, with halophytic grasses, herbs, and shrubs; dissected by tidal creeks, and may contain enclosed salt pans. Salt marsh is a community of organisms dominated by plants that are tolerant of wet, saline soils, generally found in low-lying coastal habitats which are periodically wet and unusually saline to hyper-saline. The term salt marsh summarizes the saline conditions of the habitat as well as the emergent vegetation which dominates it. Plants which grow in salt marshes are thus tolerant of two conditions: saline and wet.

Sand: Sediment consisting of rock particles with a diameter between 0.0625 and 2.0 mm. Subdivisions are very coarse sand (1–2 mm), coarse sand (0.5–1 mm), medium sand (0.25–0.5 mm), fine sand (0.125–0.25 mm) and very fine sand (0.0625–0.125 mm).

Sand bar: See ‘bar’.

Sand dune: See ‘dune’.

Sandy reef flat: The lee side/inward part/portions of the reef flat where fine coralline sand and broken molluscan shells get deposited are known as the sanded reef flat. However, the deposition may be migratory in nature and may have a seasonal cover of algae or sea grass. The sand is mainly coralline in nature, consisting of fine sand and broken molluscan shells.

Satellite imagery: Visual representation of energy recorded by remote sensing instruments. These images are taken by satellites and may be photographs or various sensors that record electromagnetic energy associated with an environmental phenomenon or feature.

Scrub: Scrubs are low growth or stunted vegetation, growing on poor soil or in semi-arid region.

Sea level: The level at which the sea stands against the coast, conventionally taken as mean sea level, the arithmetic mean of the calm sea surface (excluding waves and oscillations related to winds and atmospheric pressure variations) measured at hourly intervals over at least 18.6 years.

Seawall: A shore-parallel structure placed on the beach near the high tide line to stop land erosion by the sea. The walls are normally made of rocks and may extend from landward of the high tide line to below the low tide line, thereby covering the beach face with rock. (see also submerged seawall).

Sediment cell: A stretch of coastline relatively self-contained as far as movement of sand and other sediments are concerned and where interruptions of such movement will not have a significant effect on neighboring sediment cells.

Sediment pie: Total volume of available sand which is distributed within a sediment cell. Shallow sandy lagoon: Shallow lagoons are less than two meters in depth having carbonate sands and well aerated usually seen in coral islands.

Sheet Pile: Row of interconnected piles designed to retain soil and/or water on one side. Shoal: Region of localized shallower water. Process of getting shallower (and consequential change in wave properties) as shore is approached.

Shoals: A submerged ridge, bank or bar producing a shoal, consisting of or covered by sand, mud, gravel or other unconsolidated material. These can be within rivers, lakes, lagoons and offshore, and in all cases, beneath water and most often recognizable in aerial photographs and satellite images essentially because of their occurrence at shallow depths.

Shore: Synonymous with beach.

Shoreland: This covers the area from the tidal flat inland up to the nearest foothill with some features on the coast as well. Categories like delta, paleo mudflat, coastal dunes, relict alluvium, paleochannel, terrace, ox-bow lake, reclaimed mudflat and strandline etc. are classified in this category. Shoreland include coastal watershed and flood-prone areas. Coastal watersheds are those lands that drain directly into coastal water of 0.5 ppt water salinity. The term flood-prone area means the lowland and relatively flat area adjoining wetland. The area is subject to a 1% or greater chance of flooding in any given year.

Shoreline change: Change over time of the shoreline due to processes of accretion and erosion. These can be analyzed in a geographic information system (GIS) by measuring differences in past and present shoreline locations.

Shoreline management: Generic term for any management option, e.g. no active intervention, limited intervention, advance, realign or hold the existing coastal defense line. shoreline management plan (SMP) provides a large-scale assessment of the risks associated with coastal processes and a framework to reduce these risks to people and the developed, historic and natural environment in a sustainable manner.

Silt: A sediment consisting of particles with a diameter between 1/256 (about 0.004) and 1/16 (0.0625) mm.

Spit: A small point or low tongue or narrow embankment of land commonly consisting of sand or gravel deposited by longshore drifting and having one end attached to the mainland and other protruding into open water, usually the sea, across the entrance of a bay or an estuary, a finger like extension of the beach. Spits have been found to lengthen as well as shorten during the course of years. This may be due to the changes in longshore currents and river flows. Spits are likely to come into existence when the currents are tangential to a headland and do not pursue the irregularities of the shore. The spits are curved at the distal ends which probably indicate changes of current directions or dominant monsoonal drift. Several factors influence the curvature of the spit landward resulting in curved/hooked spits.

Spring tide: Large tides when the sun and moon are supportive. Often taken as equal to the M2+S2 range.

Storm surge: A rising of the sea as a result of wind and atmospheric pressure changes associated with a storm. Usually associated with cyclones, storm surges can travel long distances inland especially in areas of flat topography such as deltas and low elevation coastal zones. The surge is the difference between the actual water level under the influence of a meteorological disturbance (storm tide) and the level which would have been attained in the absence of the meteorological disturbance (i.e. astronomical tide).

Strandline: The term strandline is generally preserved for ancient shorelines i.e. shoreline out of reach of present wave action. As an ancient shoreline, strandline refers collectively to the assemblage of various features characteristics of the former coastal area.

Submerged seawall: A long and narrow wall placed parallel with the shore in the zone between the mid-tide line and low tide line. These often consist of just two or three small geotubes placed along a distended length of the shoreline.

Substrata material: Refers to the underlying layer or materials or substances, in particular a layer of rock or soil or minerals beneath the surface of the ground.

Subtidal: Continuous submergence of substrate in an estuarine or marine ecosystem; these areas are below the mean low tide.

Surf zone: The area between the outermost breaker and the limit of wave uprush.

Sustainable development: Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Swash zone: The sloping part of the beach that is alternately covered and uncovered by the uprush of waves, and where longshore movement of water occurs in a zigzag (upslope-downslope) manner.

Tanks: Artificial impoundments of water used for irrigation.

Terrace: An abandoned flood plain and thus represents former levels of the flood plain. They demarcate episodic formation of valley landscapes. They work on previous levels of valley fill and stream plantation. Climatic hydrologic, eustatic and tectonic changes are involved in the interpretation of terraces.

Territorial limit: As defined by the 1982 United Nations Convention on the Law of the Sea, territorial sea is a belt of coastal waters extending at most 12 nautical miles (22.2 km; 13.8 mi) from the baseline (usually the mean low-water mark) of a coastal state. The territorial limit is taken as 12 nautical miles.

Tidal currents: The horizontal movement of the water resulting from differential tidal elevations.

Tide: The periodic rising (high tide) and falling (low tide) of the water (vertical movement) that results from gravitational attraction of the moon and sun and other astronomical bodies acting upon the rotating earth. In diurnal tidal areas, there is only one high and low tide in a day. In semidiurnal tidal areas, there are two highs and two lows in a day.

Tidal inlet: Any inlet through which water alternately floods landward with the rising tide and ebbs seaward with the falling tide.

Tidal prism: The total amount of water that flows into a harbor or estuary or out again with movement of the tide, excluding any freshwater flow.

Tidal range: The tidal range is the vertical difference between the high tide and the succeeding low tide. Tidal data for coastal areas is published by the national hydrographic service of the country concerned. Tidal data is based on astronomical phenomena and is predictable. Storm force winds blowing from a steady direction for a prolonged time interval combined with low barometric pressure can increase the tidal range, particularly in narrow bays.

Tidal surge: See 'storm surge'.

Tombolo: A bar or spit that connects or "ties" an island to the mainland or to another island.

Tsunami: Long seismic sea waves, generated by a major disturbance within an ocean basin (mainly due to earthquakes, but sometimes explosive volcanic eruptions or submarine landslides). They are of subdued form in deep water, but on entering shallow nearshore areas their height increases greatly, and can exceed 30 meters when they break over the coastline.

Turbulent: Flow (usually fast) characterized by eddies and rapid mixing of sediment and pollutants (c.f. "laminar").

Updrift: Against direction of longshore current.

Vegetated wetland: See 'wetland, vegetated'.

Water bodies: The areas that are persistently water covered like estuaries, lagoons, back waters, lakes and creeks are included in this category.

Waterfront: With reference to CRZ 2011 Notification, activities that require waterfront for their operations include ports and harbors, jetties, quays, wharves, erosion control measures, breakwaters, pipelines, lighthouses, navigational safety facilities, coastal police stations and the like.

Wave: The term wave indicates the short-period (several seconds) undulations observed on the sea surface due to the action of wind. Wind-generated wave at the generating area is called 'sea' and that have travelled outside their generating area is called 'swell'.

Wave built terrace: A gently sloping coastal feature at the seaward or lakeward edge of a wave-cut platform, constructed by sediment brought by rivers or drifted along the shore or across the platform and deposited in the deeper water beyond.

Wave-cut platform: A gently sloping surface produced by wave erosion, extending into the sea or lake from the base of the wave-cut cliff. This feature represents both the wave-cut bench and the abrasion platform.

Wave run-up: Also known as wave uprush is the rush of water up a structure or beach on the breaking of a wave. The amount of run-up is the vertical height above still water level that the rush of water reaches.

Wave set-up: Super elevation of water surface over normal surge elevation due to onshore mass transport of the water by wave action alone.

Wetland: Wetlands are land transitional between terrestrial and aquatic system where the water table is usually at or near the surface of land is covered by shallow water. The land areas that are periodically (at least once a year) exposed and flooded by salt or brackish water through tides and normal storm action and having mangrove swamps and marshes are referred to as coastal wetlands.

Wetland, non-vegetated: They are normally barren areas of rock or having a cover of mud and sand. They are with or without swamps and without any dominant vegetation types and may have sparse cover of vegetation. Non-vegetated wetlands can be sub divided into various types on the basis of nature of material, nature of tidal influence and location.
Wetland, vegetated: Vegetated wetlands are dominated by vegetation. They include mangroves swamps, marsh, algae etc. They can be detected and mapped by seasonal (winter/summer) imagery.

Wind set-up: Super elevation of water surface over normal surge elevation due to onshore mass transport of the water by wind action alone. Set-up can also occur when winds drive currents longshore, due to Coriolis force.

CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 2

APPENDIX 3

EXISTING REGULATIONS FOR THE INDIAN COASTAL ZONE

ADB TA-8652 IND:

CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

APPENDIX 3
Existing Regulations for the Indian Coastal Zone

Introduction

Coastal Regulation Zone (CRZ) in India is subject to special regulations, which aim to administer the coast, in the zone from the territorial water limit which is 12 nautical miles (nm) offshore to the hazard line inland. This appendix analyzes the relevant existing regulations and policies. When developing guidelines, it is necessary to understand what has been regulated already, and how these regulations may be modified or enhanced to address climate change (CC). However, we also need to examine the effectiveness of the regulations and understand when they are helping and when they have been ineffective.

Environmental Protection Act 1986

The Environmental Protection Act 1986 provides regulations for protection and improvement of the environment and for matters connected with the environment. The Act is an umbrella legislation designed to provide a framework for Central Government coordination of various central and state authorities. It was established under previous laws, such as the Water Act and the Air Act.

This appendix considers the Environment Protection Act 1986 and the following Notifications under that Act of Parliament: (i) Coastal Regulation Zone Notification 2011; (ii) Island Regulation Notification 2011 and; (iii) Environmental Impact Assessment (EIA) Notification 2006.

Coastal Regulation Zone Notification 2011

The Coastal Regulation Zone Notification 2011 declares the following areas as coastal regulation zones:

- Land area from high tide line (HTL) to 500 m on the landward side along the sea front;
- Land area from HTL to 100 m inland or the width of the water body (whichever is less) on the landward side along tidally-influenced water bodies;
- Land area falling between the hazard line and 500 m from HTL on the landward side, in case of seafront and between the hazard line and 100 m line in case of tidally-influenced water bodies;
- Land area between HTL and low tide line (LTL) and the water and bed area between LTL and the territorial water limit (12 nm) in case of sea, and the water and bed area between LTL at the bank to the LTL on the opposite side of tidal influenced water body.

HTL is defined here as the highest waterline on the land during the spring tide, without other sea level influences. The LTL is the lowest waterline on the land during the spring tide.
The following are declared as prohibited activities within the CRZ, the exemptions are shown in italics.

(i) Setting up of new industries and expansion of existing industries. *The following is exempted and thereby allowed: those directly related to waterfront or directly needing foreshore facilities; projects of the Department of Atomic Energy; facilities for generating power by non-conventional energy sources and setting up of desalination plants in the areas not classified as CRZ-I (i) based on an impact assessment study including social impacts; development of green field Airport already permitted only at Navi Mumbai; and reconstruction, repair works of dwelling units of local communities including fishermen in accordance with local town and country planning regulations.*

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(ii) Manufacture or handling oil storage or disposal of hazardous substances as specified in the Notification of Ministry of Environment, Forests and Climate Change (MoEF&CC) (No. S.O.594 (E), dated the 28th July 1989, S.O.No.966(E), dated 27 November 1989 and GSR 1037 (E), dated 5 December 1989). *The following is exempted and thereby allowed: transfer of hazardous substances from ships to ports, terminals and refineries and vice versa; and facilities for receipt and storage of petroleum products and liquefied natural gas and facilities for regasification of liquified natural gas in the areas not classified as CRZ- I (i) subject to implementation of safety regulations.*

(iii) Setting up and expansion of fish processing units including warehousing *except hatchery and natural fish drying in permitted areas.*

(iv) Land reclamation and disturbing the natural course of seawater. *The following is exempted and thereby allowed: land required for setting up, construction or modernization or expansion of foreshore facilities like ports, harbors, jetties, wharves, quays, slipways, bridges, sea link, road on stilts, and such as meant for defense and security purpose and for other facilities that are essential for activities permissible under the Notification: measures for control of erosion, based on scientific including EIA studies; maintenance or clearing of waterways, channels and ports, based on EIA studies; and measures to prevent sand bars, installation of tidal regulators, laying of storm water drains or for structures for prevention of salinity ingress and freshwater recharge based on studies carried out by any agency to be specified by MoEF&CC.*

(v) Setting up and expansion of units or mechanism for disposal of wastes and effluents. *The following facilities are exempted and thereby allowed: discharging treated effluents into the water course with approval under the Water (Prevention and Control of Pollution) Act, 1974 (6 of 1974); storm water drains and ancillary structures for pumping; and treatment of waste and effluents arising from hotels, beach resorts and human settlements located in CRZ areas other than CRZ-I and disposal of treated wastes and effluents.*

(vi) Discharge of untreated waste and effluents from industries, cities or towns and other human settlements.

(vii) Dumping of city or town wastes including construction debris, industrial solid wastes, fly ash for the purpose of land filling and the like, and the concerned authority shall implement schemes for phasing out any existing practice, if any, shall be phased out within a period of one year from the date of commencement of this Notification.

(viii) Port and harbor projects in high eroding stretches of the coast, *except those projects classified as strategic and defense related in terms of EIA Notification 2006 identified by MoEF&CC based on scientific studies and in consultation with the State Government or the Union Territory Administration.*

(ix) Reclamation for commercial purposes such as shopping and housing complexes, hotels and entertainment activities.

(x) Mining of sand, rocks and other sub-strata materials except: those rare minerals *not available outside the CRZ; and exploration and exploitation of oil and natural gas.*

(xi) Withdrawal of groundwater and construction related thereto, within 200 m of HTL. *The following exceptions are allowed: in the areas which are inhabited by the local communities and only for their use; and in the area between 200 m to 500 m zone the withdrawal of groundwater shall be permitted only when done manually through ordinary wells for drinking, horticulture, agriculture and fisheries and where no other source of water is available.*

(xii) Construction activities in CRZ-I except those specified in the Notification.

(xiii) Dressing or altering the sand dunes, hills, natural features including landscape changes for beautification, recreation and other such purpose.

(xiv) Facilities required for patrolling and vigilance activities of marine/coastal police stations.

The CRZ is defined by four sub-categories:

- CRZ-I: Areas that are ecologically sensitive and geomorphologically important;
- CRZ-II: Areas that have been developed up to or close to the shoreline;
- CRZ-III: Areas that are relatively undisturbed, coastal zone, usually in the rural areas;
- CRZ-IV: For the water and seabed up to 12 nm from the LTL.

CRZ-I: Ecologically sensitive and geomorphologically important category is bestowed on areas with mangroves, corals and sand dunes. Nearly all beaches have sand dunes and many inlets have mangroves, so there is some conflict in the zoning, which is decided by a ruling of the Central Government's MoEF&CC. No new construction shall be permitted in CRZ-I except:

(i) Projects relating to Department of Atomic Energy;

(ii) Pipelines, conveying systems including transmission lines;

(iii) Facilities that are essential for activities permissible under CRZ-I;

(ix) Installation of weather radar for monitoring of cyclones movement and prediction by Indian Meteorological Department;

(x) Construction of trans harbor sea link and without affecting the tidal flow of water, between LTL and HTL.

(xi) Development of green field airport already approved at only Navi Mumbai

In CRZ-I (B), the areas between LTL and HTL, which are not ecologically sensitive, necessary safety measures will be incorporated while permitting the following, namely:

(i) Exploration and extraction of natural gas;

(ii) Construction of dispensaries, schools, public rain shelter, community toilets, bridges, roads, jetties, water supply, drainage, sewerage which are required for traditional inhabitants living within the biosphere reserves after obtaining approval from concerned Coastal Zone Management Authority (CZMA).

(iii) Necessary safety measures shall be incorporated while permitting such developmental activities in the area falling in the hazard zone;

(ix) Salt harvesting by solar evaporation of seawater;

(x) Desalination plants;

(xi) Storage of non-hazardous cargo such as edible oil, fertilizers and food grain within notified ports;

(xii) Construction of trans harbor sea links, roads on stilts or pillars without affecting the tidal flow of water

CRZ-II: In the CRZ-II areas

(i) Buildings shall be permitted only on the landward side of the existing road, or on the landward side of existing authorized structures;

(ii) Buildings permitted on the landward side of the existing and proposed roads or existing authorized structures shall be subject to the existing local town and country planning regulations including the 'existing' norms of Floor Space Index or Floor Area Ratio: Provided that no permission for construction of buildings shall be given on landward side of any new roads which are constructed on the seaward side of an existing road:

(iii) Reconstruction of authorized building to be permitted subject with the existing Floor Space Index or Floor Area Ratio Norms and without change in present use;

(iv) Facilities for receipt and storage of petroleum products and liquefied natural gas as specified in Annexure-II appended to this notification and facilities for regasification of liquefied natural gas subject to the conditions as mentioned in sub-paragraph (ii) of paragraph 3;

(v) Desalination plants and associated facilities;

(vi) Storage of non-hazardous cargo, such as edible oil, fertilizers and food grain in notified ports;

(vii) Facilities for generating power by non-conventional power sources and associated facilities;

CRZ-III – NDZ: The CRZ-III consists of a No Development Zone (NDZ) and there no construction shall be permitted except for repairs or reconstruction of existing authorized structures not exceeding the existing Floor Space Index, existing plinth area and existing density and for permissible activities under the notification including facilities essential for activities; Construction/reconstruction of dwelling units of traditional coastal communities including fisher folk may be permitted between 100 and 200 m from the HTL along the seafront in accordance with a comprehensive plan prepared by the State Government or the Union territory in consultation with the traditional coastal communities including fisher folk and incorporating the necessary disaster management provision, sanitation and recommended by the concerned State or the Union territory CZMA to National CZMA for approval by MoEF&CC. However, the following activities are permitted in NDZ:

(i) Agriculture, horticulture, gardens, pasture, parks, play field, and forestry;

(ii) Projects relating to Department of Atomic Energy;

(iii) Mining of rare minerals;

(ix) Salt manufacture from seawater;

(x) Facilities for receipt and storage of petroleum products and liquefied natural gas;

(xi) Facilities for regasification of liquefied natural gas subject to conditions;

(xii) Facilities for generating power by non-conventional energy sources;

(xiii) Foreshore facilities for desalination plants and associated facilities;

(iv) Weather radars;

(v) Construction of dispensaries, schools, public rain shelter, community toilets, bridges, roads, provision of facilities for water supply, drainage, sewerage, crematoria, cemeteries and electric sub-station which are required for the local inhabitants may be permitted on a case to case basis by CZMA;

(vi) Construction of units or auxiliary thereto for domestic sewage, treatment and disposal with the prior approval of the concerned Pollution Control Board or Committee;

(vii) Facilities required for local fishing communities such as fish drying yards, auction halls, net mending yards, traditional boat building yards, ice plant, ice crushing units, fish curing facilities and the like.

CRZ-III – In the rest of the CRZ-III areas, i.e. 200 - 500 m

(i) Development of vacant plot in designated areas for construction of hotels or beach resorts for tourists or visitors subject to the conditions as specified in the guidelines;

(ii) Facilities for receipt and storage of petroleum products and liquefied natural gas;

(iii) Facilities for regasification of liquefied natural gas subject to conditions;

(iv) Storage of non-hazardous cargo such as, edible oil, fertilizers, food grain in notified ports;

(v) Foreshore facilities for desalination plants and associated facilities;

(vi) Facilities for generating power by non-conventional energy sources;

(vii) Construction or reconstruction of dwelling units so long it is within the ambit of traditional rights and customary uses such as existing fishing villages and goathans. Building permission for such construction or reconstruction will be subject to local town and country planning rules with overall height of construction not exceeding 9 m with two floors (ground and one floor);

(viii) Construction of public rain shelters, community toilets, water supply drainage, sewerage, roads and bridges by CZMA who may also permit construction of schools and dispensaries for local inhabitants of the area for those panchayats, the major part of which falls within CRZ if no other area is available for construction of such facilities;

(ix) Reconstruction or alteration of existing authorized building subject to sub-paragraph (vii), (viii);

(x) Development of green field airport already permitted only at Navi Mumbai.

CRZ-IV: The activities impugning on the sea and tidal influenced water bodies will be regulated except for traditional fishing and related activities undertaken by local communities as follows:

(i) No untreated sewage, effluents, ballast water, ship washes, fly ash or solid waste from all activities including from aquaculture operations shall be let off or dumped. A comprehensive plan for treatment of sewage generating from the coastal towns and cities shall be formulated within a period of one year in consultation with stakeholders including traditional coastal communities, traditional fisherfolk.

(ii) Pollution from oil and gas exploration and drilling, mining, boat house and shipping;

(iii) There shall be no restriction on the traditional fishing and allied activities undertaken by local communities.

The CRZ also prescribes a Hazard line, which is being demarcated by the Survey of India to regulate certain activities. The Hazard line takes into account tides, waves and sea level rise and shoreline. The land area falling between the hazard line and 500 m from HTL on the landward side is included in CRZ. There is still an uncertainty on how to incorporate regulations within it when they are made available.

Island Regulation Notification 2011

The Island Regulation Notification 2011 is issued by the MoEF&CC to regulate the activities in the ecologically sensitive Islands of Andaman and Nicobar (A and N) and Lakshadweep. It declares the coastal stretches of A and N and Lakshadweep and their water area up to the territorial water limit as the Islands Protection Zone and restricts the areas from the setting up and expansion of any industry, operations or processes and manufacture or handling or storage or disposal of hazardous substances.

As per the Notification, environmental management for the Islands of A and N and Lakshadweep shall be managed as follows:

> The entire island of A and N other than the four islands Middle Andaman, North Andaman, South Andaman and Greater Nicobar and all the islands of Lakshadweep shall be managed as per Integrated Island Management Plans to be prepared by the respective Administration with the support of research institutions.

In view of the large geographical area, the islands of Middle Andaman, North Andaman, South Andaman and Greater Nicobar shall be managed as per the Island Coastal Regulation Zone; with categorization as done for mainland coast.

Environmental Impact Assessment Notification 2006

The MoEF&CC under the Environment (Protection) Act (1986), promulgated EIA notification in 1994 making environment clearance mandatory for expansion or modernization of any activity or for setting up new projects listed in Schedule one of the notification, which have been amended more than 12 times.

In India, EIA was made mandatory in 1994 with the following four objectives:

- Predict environmental impact of projects;
- Find ways and means to reduce adverse impacts;
- Shape the projects to suit local environment;
- Present the predictions and options to the decision-makers.

Until 1994, EIA clearance was the administrative requirement for big projects undertaken by the Government or public sector undertakings. The Notification mandates a public hearing, with further review by a committee of experts in certain cases.

This Notification makes it mandatory for some projects or activities to get prior environmental clearance for implementation. All projects and activities are broadly categorized into two categories - Category A and Category B, based on the spatial extent of potential impacts and potential impacts on human health and natural and man-made resources. Permission shall be obtained from the MoEF&CC on the recommendations of an Expert Appraisal Committee (EAC) for Category A projects, or the State Environment Impact Assessment Authority (SEIAA) on the recommendations of a state or Union Territory Level Expert Appraisal Committee for Category B projects. The activities requiring permission are mining of minerals, offshore and onshore oil and gas exploration, development and production, river valley projects, thermal and nuclear power projects, petro-chemical complexes, chemical fertilizers, synthetic organic chemicals industry, oil and gas transportation pipeline, isolated storage and handling of hazardous chemicals, physical infrastructure projects, etc.

EAC Procedure for Central Government or MoEF&CC: For A category of projects, environmental clearance is needed from the central government or MoEF&CC. The application for the environment clearance is to be submitted to the MoEF&CC. A duly filled form mentioned in EIA notification 2006 (schedule 2) with proper details is submitted to the authority. The authority numbers the received application form and the procedure is done for environmental clearance as mentioned in EIA notification 2006 and amendment in 2009. All details of environmental clearance application, public hearing details for upcoming and terms of reference approved by the State Board is also updated on the web site of MoEF&CC. Composition for EAC by the central government is also updated on the web site. EAC committee is updated every five years. Meetings of minutes are also updated on the web site of the MoEF&CC.

State Expert Appraisal Committee (SEAC) Procedure for State Government: 'B' Category of projects goes to the state authority as mentioned in EIA notification 2006 and a decentralized procedure is undertaken. The Government of India has constituted SEAC and SEIAA committees for this decentralized procedure of environmental clearance.

Modifications Required in the Existing Norms

For proper regulations under the climate change scenario there is a need to make some amendments to the existing CRZ/EIA and other regulatory regimes in India. Based on the Guidelines for Climate Change Adaptation (Volume I) the modifications which take priority as potential regulatory changes are summarized in Table 1:

Table 1. Incorporation of the proposed guidelines in the existing CRZ/EIA regulations

N°	COASTAL PROTECTION AND MANAGEMENT GUIDELINE	RELEVANCE IN CLIMATE CHANGE SCENARIO	ADAPTATION REQUIRED (WHERE?)
1	Develop a structure to have compulsory cooperation / consultation between departments, ministries or agencies which have control over specific aspects of the coast	Though CRZ Notification has several provisions to take care of these interactions, the consultation process is not being meticulously implemented. In the CC scenario the consultation between departments, ministries or agencies need to be ensured through appropriate clauses in the CRZ notification	Yes (CRZ)
2	Clearly define the roles and responsibilities of designers, implementing agency and contractors	At present the roles and responsibilities of different players are not sufficiently defined. Fixing of responsibilities is very essential to bring down failures	Yes (EIA)

3	Make data and designs accessible to the public	This will bring in transparency in the whole process and adds to the acceptability of the proposed intervention; CRCPMP data on climate change projections is uploaded in India-WRIS. MoEF&CC's portal may upload the designs and establish link with the CCIS of India-WRIS	Yes (EIA)
4	Account for both the economic and environmental costs and benefits of coastal management strategies	Accounting for both the economic and environmental costs and benefits of coastal management strategies is essential in the CC scenario	Yes (CRZ & EIA)
5	Use full life-cycle cost analysis, not just construction cost	This shall reflect in the EIA/EMP for coastal protection	Yes (EIA)
6	Coastal protection projects should have a minimum benefit: cost ratio of 1:1 over the full life-cycle	This shall come in the EIA/EMP for coastal protection	Yes (EIA)
7	No construction on the primary sand dune	Dunes are essential to protect the coast, particularly in the CC scenario with rising sea level; the CRZ be strictly enforced	No
8	The HTL should be delineated and incorporated into Coastal Management Plans (CMP)	Incorporation of HTL in CMP is essential to demarcate the CRZ categories	No
9	Sand dunes should be restored and elevated to at least 3 m above the HTL; wherever appropriate new dunes should be created	Dune is the best protection for the coast. Dunes shall be created, reformed and the existing ones be elevated to a height of at least 3 m to protect the coast in the context of the Climate change	Yes (CRZ)
10	No construction within 200 m of the HTL	It is essential to maintain an NDZ of 200 m, which shall act as a buffer zone protecting the coast against the onslaught of hydrodynamic forces	No
11	Dunes should be vegetated only with native dune species and protected with simple fences, with public access pathways no closer than 100 m	Native vegetation is essential to protect the dunes from erosion on one side and allow them to function in tandem with the coastal processes	Yes (CRZ)
12	All new structures should consider risk from current and future hazards including the impacts of climate change	Because of the anticipated sea level rise and extreme climatic events, this guideline is important. CC parameters should be incorporated into the design of all new structures	Yes (EIA)

13	Beach scraping should be undertaken to restore the dunes. If the problem is larger, then sand will need to be pumped shore wards from offshore	Restoring sand dunes is essential to protect the coast in the CC scenario. Beach scraping from accreting beach after retaining an equilibrium beach need to be a permitted activity	Yes (CRZ)
14	No assistance will be given to residents who build on the primary sand dunes and beaches	This is essential to preserve the sand dunes and beaches. It is already accounted for in the CRZ Notification and has to be strictly enforced	Yes (CRZ)
15	No sand should be put onto land even for port projects, except for building sand dunes	Sand should not be used for reclamation or any other similar activity. Reclamation is even now banned under CRZ, except in port projects. The reclamation in port projects should be with sediments other than sand	Yes (CRZ)
16	Dredged sand should be deposited nearshore of downstream beaches in depths no greater than 5 m	Sand which is dredged from sea for navigation or otherwise should go back to the beach. By depositing it in shallower depths off downstream beaches it is guaranteed that this sand will be reworked by the hydrodynamic forces and brought ashore for keeping the sand starved downstream beaches stable	Yes (CRZ)
17	‘No regrets’ measures should be a priority	‘No regrets’ options are sustainable in the long term and should be encouraged in a climate change scenario	Yes (CRZ & EIA)
18	All designs must be site-specific and based on a clear understanding about the coastal processes of the sediment cell	This is to ensure the functional efficiency of the structure and to minimize the impact on the adjoining beaches. This is all the more important in the CC scenario	Yes (EIA)
19	A comprehensive EIA must be provided before any construction approvals are given	A rapid EIA is mandatory under the EIA Notification, but often even this has not been vigorously enforced. In the CC scenario, a comprehensive EIA is required with field measurements and numerical modeling studies	Yes (EIA)
20	Establish appropriate process of monitoring and evaluation of performance of interventions at pre-, during and post development stages	Monitoring and evaluation of performance of structures is essential to assess its reliability modifications required, if any	No

21	Embed climate change adaptations within existing CRZ /EIA Notifications	Though CRZ /EIA Notifications have several provisions which will take care of CC adaptations, these Notifications need to be revised to take care of the whole gambit of CC adaptation	Yes (CRZ & EIA)
22	Coastal protection structures should not obstruct the recreational and fishermen use of beaches	Beach is public property and it has to be ensured that its functional utility is maintained	Yes (EIA)
23	Structures should maintain the natural landscape and habitat function of the coast	This is very important to ensure the aesthetics of the beaches	Yes (EIA)
24	Ensure that the coastal ecosystems are able to adapt to the impacts of climate change (resilient ecosystems)	Adaptation of coastal ecosystems to climate change is very essential for the protection of the coast and coastal community	Yes (EIA)
25	The 'sediment cell' be the unit for the EIA in the place of the present stipulation of 10km radius	On the coast, the 'sediment cell' contains all the sediments which controls erosion or accretion. All impacts of developments are within the 'sediment cell'. Hence instead of the present 10km stipulation 'sediment cell' be unit for EIA for coastal projects	Yes (EIA)
26	The concept of minimum floor level (MFL) be introduced which is the highest sea level that may occur at a coastal site due to climate change impacts	The CRZ considers only horizontal distances and within regulated zone the floor level of structures need to be kept at a safe elevation as a precaution against climate change related impacts.	

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CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 2

APPENDIX 4
STRATEGIC PLANNING OF COASTAL ZONE AND SHORELINE IN INDIA

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CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

APPENDIX 4
Strategic Planning of Coastal Zone and Shoreline in India

Introduction

Strategies and policies that integrate decisions for the Indian coast create a sound basis for balancing resource allocation in the coastal zone. A balance is needed for economic growth, protection against natural hazards, social use, and environmental flows.

In formulating guidelines, much can be learned and adapted from these documents. There had been several attempts by the Government of India to bring order to the development of the coastal zones. The first one was the issuance of 'Environmental guidelines for the development of beaches' in 1983 by the Ministry of Environment and Forests and Climate Change (MoEF&CC) (MoEF&CC, 1983). This was circulated to the States for implementation but failed to gain a comprehensive response. Then, a strict regulatory framework was introduced in the form of the Coastal Regulation Zone (CRZ) notification in 1991 (MoEF&CC, 1991). This regulation was gradually accepted and resulted in the framing of a Coastal Zone Management Plan (CZMP), which serves as the basis for granting approvals to proposed activities.

Although the CZMP focused on environmental conservation and it partially achieved those goals, the selection of coastal protection methods for erosion control was still going on in the traditional way. Coastal protection in India was dominated by the construction of seawalls mainly guided by Central Water and Power Research Station (CWPRS) (CWPRS, 2010).

Two manuals were issued by the National Institute of Oceanography (NIO, 1984) and Karnataka Regional Engineering College (KREC) (KREC, 2002) to codify the approaches to coastal protection. The Guidelines for the preparation of the coastal protection schemes was issued by CWC in 2003 for the National Coastal Protection Project (NCPP).

A serious review of the regulatory regime of MoEF&CC was undertaken (MoEF&CC, 2005), which paved the way for a more balanced approach to the management of coastal zones. A revised CRZ notification was issued by MoEF&CC in 2011, (MoEF&CC, 2011) replacing the old CRZ (1991) and efforts to implement an integrated management approach was commenced. The guidelines for integrated coastal zone management (ICZM) (NCSCM, 2014) and strategies for coastal protection were drafted (NCSCM, 2015). This was accepted and provides a sound platform for the commencement of an integrated approach to coastal protection, using a wider combination of solutions for erosion. A more detailed look into these developments is the topic of this Appendix.

Environmental Guidelines for the Development of Beaches

The Environment Management Guidelines for the development of the beaches were designed by MoEF&CC (1983) to provide environmental impact assessment (EIA) to reduce the risk of environmental harm caused by coastal developments. The main objective was to identify environmental parameters for management and devise a set of indices for assessment of environmental and ecological values, and the potential damage from coastal developments. Here the word 'beach' was used interchangeably with the word 'coast' and hence it had implications for development of the whole coastal area. The States were supposed to prepare coastal management plans for their jurisdiction. Due to lack of enforcement and compliance, no State developed management plans.

Coastal Regulation Zone Notification

To overcome problems associated with the above guidelines, MoEF&CC introduced the CRZ Notification 1991 (MoEF&CC, 1991), which contained mandatory regulations governing any proposed development in the coastal area. The CRZ had a major impact on controlling developmental activities in the coastal areas. The impacts of coastal erosion were also viewed in a different perspective and softer solutions for the ecologically sensitive areas (CRZ-I) and less developed areas (CRZ-III) were considered.

To determine the barriers for the implementation of the CRZ and to have a strategy for coastal management, MoEF&CC brought out a strategy document (MoEF&CC, 2005). This strategy document recommended some changes in the regulatory framework of CRZ. Among the changes recommended to be incorporated there was impacts of climate change and sustainability of the interventions protecting and conserving coastal ecosystems. Some six years later, these recommendations resulted in the revised CRZ Notification 2011 (MoEF&CC, 2011). However, the revised regulations also did not account for climate change probably due to the lack proper guidelines for the same. The larger programs on ICZM, with the support of World Bank and the initiation of innovative coastal protection approaches supported by the Asian Development Bank were the other outcomes. The Global Environment Facility has contributed to the process with the present Technical Assistance for continuing the process of building resilience for the Indian coastal zone.

Environmental Impact Assessment Notification

This Notification (MoEF&CC, 2006) makes it mandatory for some projects or activities to have prior environmental clearance for implementation. All projects and activities are broadly categorized into two categories - Category A and Category B, based on the spatial extent of potential impacts and potential impacts on human health and natural and man-made resources. Permission shall be obtained from the MoEF&CC on the recommendations of an Expert Appraisal Committee for Category A projects. For Category B projects, approval is at State-level through the State Environment Impact Assessment Authority. They take recommendations at the State or Union territory level from a State Expert Appraisal Committee. There is a wide range of activities requiring full EIA. This includes the construction of ports, harbors, coastal protection infrastructure, coastal tourism and others.

Guidelines / Manuals for Coastal Protection

Coastal protection in India traditionally followed the engineering manuals of the United States Army Coastal Engineering Research Centre (Shore Protection Manual, 1984) which was updated periodically. The Coastal Engineering Manual (CEM, 2013) is a much-expanded replacement document for the Shore Protection Manual (1984). The CEM is a useful source which provides technical guidance for application of techniques and methods to the solution of coastal engineering problems.

The Rock Manual (CIRIA, 2007), is another useful document to coastal, river and estuarine managers and engineers, consultants to assist with design, construction, management, specification, quality control, environmental impact assessment, maintenance and material selection. The Rock Manual was originally published in 1991 by Construction Industry Research and Information Association (CIRIA) and CUR (the Netherlands Centre for Civil Engineering Research and Codes) and described the use of rock in coastal and shoreline engineering. The World Association for Waterborne Transport Infrastructure (PIANC) (2003) provides guidelines for designing and constructing berm breakwater.

A pioneering effort to put the engineering practice under one roof was done by NIO (Bruun and Nayak, 1984) prior to accurate climate change models and scenarios were known.

A similar effort with more emphasis on Karnataka was done by KREC (KREC, 2001). For the first time in India, the KREC document gave a detailed account of the soft measures of retreat, nourishment, sand bypassing, sand dune protection / rehabilitation, vegetative measures, etc.

Another set of guidelines was produced within the framework of the "Indian-Netherlands Water and Coastal Management Co-operative Programme 2002-2003". This provided a framework for a number of Indian-Dutch co-operative activities in the field of integrated coastal zone management. The guideline presented the entire spectrum of hard and soft coastal protection measures and highlighted the relationship between integrated management and the various coastal protection methods. It presented erosion in a broader context and discussed how anti-erosion measures can be integrated into a general and sustainable approach to coastal development. It introduced three strategies for erosion: (1) retreat; (2) accommodate, and; (3) protect. The guide describes the measures that can be taken for each strategy, with technical maintenance and protection methods for eroding coasts.

CWPRS is the accredited Government agency to give advice and to design coastal protection works. It brought out a Technical Memorandum on 'Guidelines for Design and Construction of Seawalls' (Kudale and Sharma, 2010). The goal of the document was not to account for climate change impacts or specify the best coastal protection methods to be adopted in a given situation. However, a list of other methods of shore protection was included. These guidelines were based on the experience of CWPRS in the design of coastal protection works, both in practice and in the laboratory. They considered the practical difficulties / deviations encountered during the design and construction of seawalls, with essential precautions to be taken. Deviations that may occur during design and construction were: position of seawall, under-design of armors, toe protection, inadequate or no-provision of filters, overtopping due to underestimation of design wave or the maximum water level, rounded stones, weak pockets, discontinuities in sea wall, armor in single layer and/or pitched. Lastly, the planning of a construction program and maintenance of coastal structures was considered.

Central Water Commission (CWC) through the Coastal Protection and Development Advisory Committee periodically provides guidance to the coastal engineering community about the policies, approaches and guidelines to be followed in the coastal protection works. For the preparation of the NCPP by the States and Union territories CWC had issued guidelines (CWC, 2003). This brings out broad guidelines for coastal protection projects. Rubble mound seawall is the most commonly used protection measure, other structures which moderate the coastal sediment transport processes to reduce the local erosion rate such as offshore breakwaters, groynes and reefs and beach nourishment are covered in the guidelines.

The document recognizes the fact that coastal protection project planning and design being an interdisciplinary task, needs inputs from coastal, geotechnical, hydrology, hydraulics, structural, meteorology, economics, environment, geology, oceanography and other related disciplines. A systematic and integrated approach for planning and developing optimum solutions to the problems of coastal erosion is emphasized. Each segment of the coastline has its own characteristics. Hence it is essential to understand in detail the behavior of the coast in totality and examine various alternatives before arriving at an appropriate solution for the specific site. It recommends thinking globally and acting locally while addressing coastal erosion problems.

Table 1. Guidelines for preparation of coastal protection projects (NCPP, CWC) - typical case of seawalls

COMPONENT	BASIC CRITERIA FOR SEAWALL	SPECIAL CONSIDERATIONS FOR SEAWALL
What is wanted	Storm, tide and/or extreme protection of the shore / beach. Protection of specific valuable areas (highways, buildings, industry, etc.).	Energy absorbing wall or revetment, dyke or dune. Any type of substantial wall with as little adverse effects as possible.
Layout and geometry	As streamlined as possible, it is best to leave and maintain a beach in front of the wall. Influence on adjoining shores.	Erosion may be stopped at the wall but artificial nourishment may be needed to maintain beach in front of the wall. Leeside erosion may result if erosion continues leaning wall as protruding headland or if wall is built too far seaward and is not streamlined in horizontal geometry. Transfer of sand or other nourishment of downdrift shore may be needed.
Combination with other coastal protective measures	Groynes Artificial nourishment	To break longshore current and possibly build up beach in front of wall. To maintain beach in front of wall and/or to check down drift erosion.
Design	Energy absorbing (sloping and/ or mound type. Non-energy absorbing (vertical sheet pile or slab).	Considerate to beach stability due to friction and low reflection. May create local erosion due to less friction against currents and more reflection.

Draft Strategy for Coastal Protection

The Draft National Strategy for Coastal Protection is a document prepared by the National Centre for Sustainable Coastal Management (NCSCM) (NCSCM, 2015) of the MoEF&CC. The objective was to help policy makers and coastal managers to take appropriate decisions with respect to coastal protection. Thus, the target audience includes a broad range of stakeholders such as the government, non-governmental organizations, the private sector, industries and coastal communities. In addition to coastal erosion, climate change is also considered, e.g. sea level rise, storm surge, salt intrusion etc. which will displace people and degrade coastal ecosystems.

The concept of ‘sediment cell’, which is a section of coast where beach sediments are mostly contained within that zone and there is very little transfer of sand to adjacent zones, is advocated in this document. This concept is valuable because it defines the physical boundary and range of potential impacts, which is equal to the size of the cell. The sediment cell is beginning to be used to define the size of the zone which needs to be considered when determining impacts of a proposed development. The strategy paper also documents the techniques and practices for coastal protection under three broad categories: (i) accommodate; (ii) retreat, and; (iii) protect.

An earlier report prepared under the chairmanship of Dr. M.S. Swaminathan (MoEF&CC, 2005) similarly highlighted the need for an integrated approach while dealing with the coastal zone. The Strategies and Guidelines for national implementation of the ICZM were drafted by NCSCM to further facilitate this process (NCSCM, 2014). The document provides another foundation layer to bring an integrated approach to India and provides an important baseline for our guidelines being prepared to deal with climate change.

Shoreline Management Plans

The Shoreline Management Plan (SMP) sets out the strategy for the protection of the coastal communities and the resources for a specified length of the coast. The strategy takes into account the natural coastal processes, human influences, land use and other environmental aspects. A detailed understanding of the problems and needs in the coastal zone, best understanding of the constraints and limitations and support of the user groups and local communities are required for this. SMP defines the nature and magnitude of risks from coastal hazards. The SMP provides a large-scale assessment of the risks associated with shoreline evolution, sea level rise, coastal flooding and erosion against a backdrop associated with the challenges of environmental and economic development and presents a policy framework to address these risks in a sustainable manner.

An SMP will be a large-scale assessment of the risks associated with coastal processes (as described above) and will help to reduce these risks by properly planning the coastal protection and management of the land use. For an SMP to be successful it should be based on a participatory planning and management system at all stages from conceptualization to implementation.

Aim and Objective of SMP

An SMP tries to achieve the following:

- Identify the areas of conservation, preservation and protection and examine the causes of coastal erosion and coastal instability;
- Consider the measures for conservation, preservation and protection and the viability of future coastal protection infrastructure for the most vulnerable and feasible locations using appropriate technologies;
- Consider locations where natural protection measures can be considered such as developing dunes and planting of mangroves and other vegetation for protection;
- Consider wider coastal management issues including social, economic and developmental requirements;
- Ensure that the SMP aligns with the aspirations of the people which can be achieved by stakeholder engagement and improving awareness of coastal issues.

The SMP shall be based on participative planning, professional design and the use of modern technology.

To achieve this, the objectives of an SMP shall be to:

- Identify the best and most sustainable ways to manage coastal resources and risks, including those due to climate change, over the next 100 years;
- Identify social and economic aspects relevant to the coastal zone;
- Indicate how future plans and activities of stakeholders may affect the shoreline and how shoreline management can be relevant to such plans;
- Support the planning system (CRZ, EIA and CC Guidelines) to minimize inappropriate developments in the long-term.

Determination of Shoreline Management Units

The entire coastline will be divided into sediment cells which are defined as a length of coastline relatively self-contained as far as movement of sand and other sediments are concerned, and where interruptions of such movement will not have a significant effect on neighboring sediment cells. The boundary of a sediment cell generally coincides with larger estuaries or prominent headlands. Each sediment cell (as per the detailed demarcation provided by NCSCM) or sub-cell is divided into smaller management units, which are suitably sized for development of shoreline management sub-plans.

Criteria for Sediment Cells:

- **Primary Cells:** Coastal geomorphology (headlands, promontories, bays, etc.), sources of sediments, stores of sediments, interface of rocky-sandy-muddy coast;
- **Secondary Cells:** Changes in littoral front, change in coastal alignment, decadal erosion / accretion, man-made littoral barriers, tidal inlets / river / creek mouths, delta front;
- **Management Units:** Coastal land use, fishing related activities, erosion / accretion / protection measures, proposed development plans, sediment input from rivers, industrial areas, settlements, tourism areas, other coastal activities, polluted areas / salt pans / aquaculture / salt water intrusion, dredging and reclamation, sand / other mining areas, marine protected areas, ecologically sensitive areas, elevated areas, defense areas, archaeological / heritage sites, CRZ boundaries.

Based on the sediment cells and management units identified the landward boundaries are required to be decided. It must be based on the geomorphology, land use, the hazard zoning and CRZ and the administrative jurisdiction of the village or Panchayat. This system of zoning provides a basis for deciding the uses and measures that will protect and enhance the character of distinctly different shoreline areas and for uniformly applying policies and use requirements within these areas (Ramanamurthy et al., 2004).

Development of SMP

Once the zoning and its characterization is completed the strategies or policy options for consideration in each sediment cell / management unit can be worked out. Monitoring the coastal processes and modelling be adopted for predicting the changes to the coast and for testing different alternatives for protection and management. The standard options normally adopted are: do nothing, retreat, accommodation and protection. SMP policies need to be considered for key time related policy 'windows' to consider long-term coastal changes also due to climate change. For this SMP policies will consider existing regulatory policies such as the CRZ and EIA over the short-term with cognizance of management over the next 100 years to accommodate the climate change impacts. The plan and policy for each management unit for the long-term can be developed as recommended in the present Guidelines for Climate Resilient Coastal Protection and Management. Detailed SMPs needs to be prepared through continuous inter-sectoral consultation and public participation for its acceptability.

Table 2. Different stages in the development of an SMP

STAGES	ACTIONS IN EACH STAGE
1	Scope of the SMP: formalizing arrangements for production of the SMP
2	Assessment of the sediment cell and management units and initial stakeholder engagement: undertake a review of coastal processes and behavior to develop baseline scenarios and consider the different policy scenarios over various timescales, and develop knowledge based from stakeholder engagement for each management unit.
3	Policy review and development: assessment of policy scenarios for identification of policies for each sediment cell with details on the protection of the management unit.
4	Stakeholder engagement: consultation with key stakeholders and the public to ensure participation in the development of the policies; approval of the draft and final SMPs.
5	Finalize the plan: finalize SMP taking account of stakeholder responses and overall approval.
6	Implement the Plan: after approval, the SMP needs to be formally adopted by key stakeholders and institutions and incorporated within their planning framework for achieving long-term sustainable coastal management objectives.
7	Post monitoring: After implementation, regular monitoring of coastal morphology and processes should be done for predicting climate change impacts and for providing modifications to the SMP.

Typical Contents of an SMP:

1. Introduction: general description of the coast: assets along the coast, coastal geomorphology, history of shore protection and current status

2. The SMP: aims and objectives of the SMP; process of SMP development - scoping the SMP and collection/collation of coastal environmental data, shoreline assessments and initial stakeholder engagement, draft plan development, stakeholder engagement, finalizing the plan, implementing the plan

3. Introduction to the supporting documents: bathymetric, topographic and sedimentological data; coastal hydrodynamics; littoral environmental characteristics; long-term and short-term shoreline change maps; regional wave modelling report; sediment transport modelling report; beach and nearshore morphological modelling report; State Tourism Policy; State Industrial Policy; State Port Policy; stakeholder engagement report; history of coastal flooding report

4. Institutional setting, stakeholder involvement and influence on the SMP: coastal infrastructure management unit, coastal management information system, setting up shoreline management organizations

5. Policy Development Zones (PDZ) and Management Units (PMU): PDZ and PMU maps for the coast; policy statements for different PDZs and PMUs

6. Action Plan

7. Setting out responsibilities for delivering the Action Plan

References

Appendices

Discussion

India has legislated against coastal degradation but still the coast is undergoing negative environmental impacts. A large portion of the Indian coast is undergoing erosion and a large part of coast is protected with hard measures such as seawalls and groynes (See Appendix 7, Table 1). The beaches in these locations are slowly disappearing making the infrastructure vulnerable. However, where the beaches are better conserved like in Goa (See Appendix 7, Table 1) the erosion is insignificant, and the demand for protection is minimal in that State. Demand by the engineers for protection is greater in the other States.

The global science has shown that some of the 'erosion' is being caused by the structures. For example, Baba and Thomas (1987) noted that toe scour at the foot of seawalls can lead to the collapse of the wall and loss of the beach. Internationally and within India, the seawalls are known to induce an 'end effect', scour at their ends, leading to the need for further extension of seawalls. Griggs et al. (1991) and Dattatri (1994) have clearly indicated that whenever the seawalls are constructed without a beach in front they are expected to fail. CWC (2003) also recommended a beach in front of the seawall. This is discussed in detail in the seawalls Appendix 8. Local fishermen, beach resorts, governmental agencies and many other people build within the CRZ. Much of this infrastructure uses sand mined from rivers and beaches.

The following questions need to be addressed:

- Is erosion a new fact of life that will require billions of Rupees and high-quality planning to cure?
- What are the drivers of extensive erosion – natural or induced?
- How can shoreline management plans and integrated management of the coastal zone be applied also in the context of climate change?

Conclusions

- The existing regulations and practices provide a good basis for developing guidelines for climate change resilience.
- There are no documents which compare the various coastal protection methods being adopted in India, and so understanding the effectiveness of these measures is a priority for sustainable outcomes.
- For shoreline management, a plan needs to be prepared for the whole sediment cell and interventions in each management unit be adopted after a consultative process.
- The new guidelines to accommodate climate change impacts need to be followed in the preparation of SMP.

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APPENDIX 5
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APPENDIX 5
Coastal Scientific Research in India and Important Indian Institutions

Numerous institutes and individuals were asked to provide their scientific papers and this appendix compiles the responses revealing the current state of established research published in peer-reviewed journals on coastal protection and management in India. Coastal research including biological sciences is well established. However, the vast majority of the Indian publications are in conference proceedings and institutional reports, particularly in the area of coastal engineering. This compilation is limited to the papers published in peer reviewed journals although some exceptions have been made by including a few large coastal research compilations from institutes or other sources.

The papers are grouped under the following headings:

Coastal Processes

A. Waves, tides, currents, cyclones and storm surge
B. Sediment and shoreline dynamics
C. Ecology
D. Climate change and sea level rise

Coastal Protection

E. Hard options
F. Soft options

Coastal Management

G. Management

Discussion

The total number of research papers published in India is substantial, but most of them are from medicine, physics/astronomy and engineering disciplines. While some two hundred papers are listed below, coastal research is still far behind the good tally arising from other branches of science and engineering in India.

There is a need to find ways to encourage coastal research and to publish the results. Once published, these papers provide the basis for decision making and future research directions. Information is not lost (as it is in conference, internal and consulting reports) and so the legacy of the scientific research is much more substantial in peer-reviewed publications. The peer-review system also vets the quality of the work.

Appendix 11 on Data Collection and Modeling shows that one of the fundamental impediments to research in India is the lack of high quality and modern research equipment for study of coastal processes. Many studies have been undertaken to measure waves, but practically very little has been done for measurements of longshore currents, longshore and cross-shore sediment transport and beach dynamics. The highly important surf zone is mostly missing. An upskilling of coastal researchers needs to move forward in harmony with budget for the purchase and training using modern equipment and techniques. Indian beaches have many unique qualities and are subject to monsoonal weather patterns, which means that research from other countries cannot be always transferred to the Indian context.

Key gaps identified in the series of publications below provide a research direction for the future. These are:

- The influence of structures: impacts of coastal structures on their environment and the positive/negative benefits of the structures;
- Beach sediment dynamics: longshore and cross-shore movement of beach sand using modern measurement techniques;
- Seawalls and groynes: the effects and sedimentary dynamics in front of and adjacent to seawalls and groynes at local scales;
- Numerical modelling: development and calibration of models at smaller scales like the front of a seawall. Most models are larger regional scales calibrated against current meters and wave measurements;
- Surf-zone dynamics;
- Offshore (inner shelf) sediment dynamics;
- Intra and inter-sediment cell dynamics;
- Estuarine and inlet sediment dynamics;
- Geology and Geomorphology of the coast;
- Dredging and mining related sediment dynamics;
- Climate change impacts on the coastal ocean parameters;
- Sea level rise and monsoonal flooding impacts on the coast;
- Alternate sustainable and climate resilient coastal protection methods, and;
- Sand dunes: detailed inventory, dynamics, regeneration and conservation.

This list is not exhaustive and many individual scientists may have many ideas for future research.

Coastal Processes – Waves, Tides, Currents, Cyclones and Storm Surge

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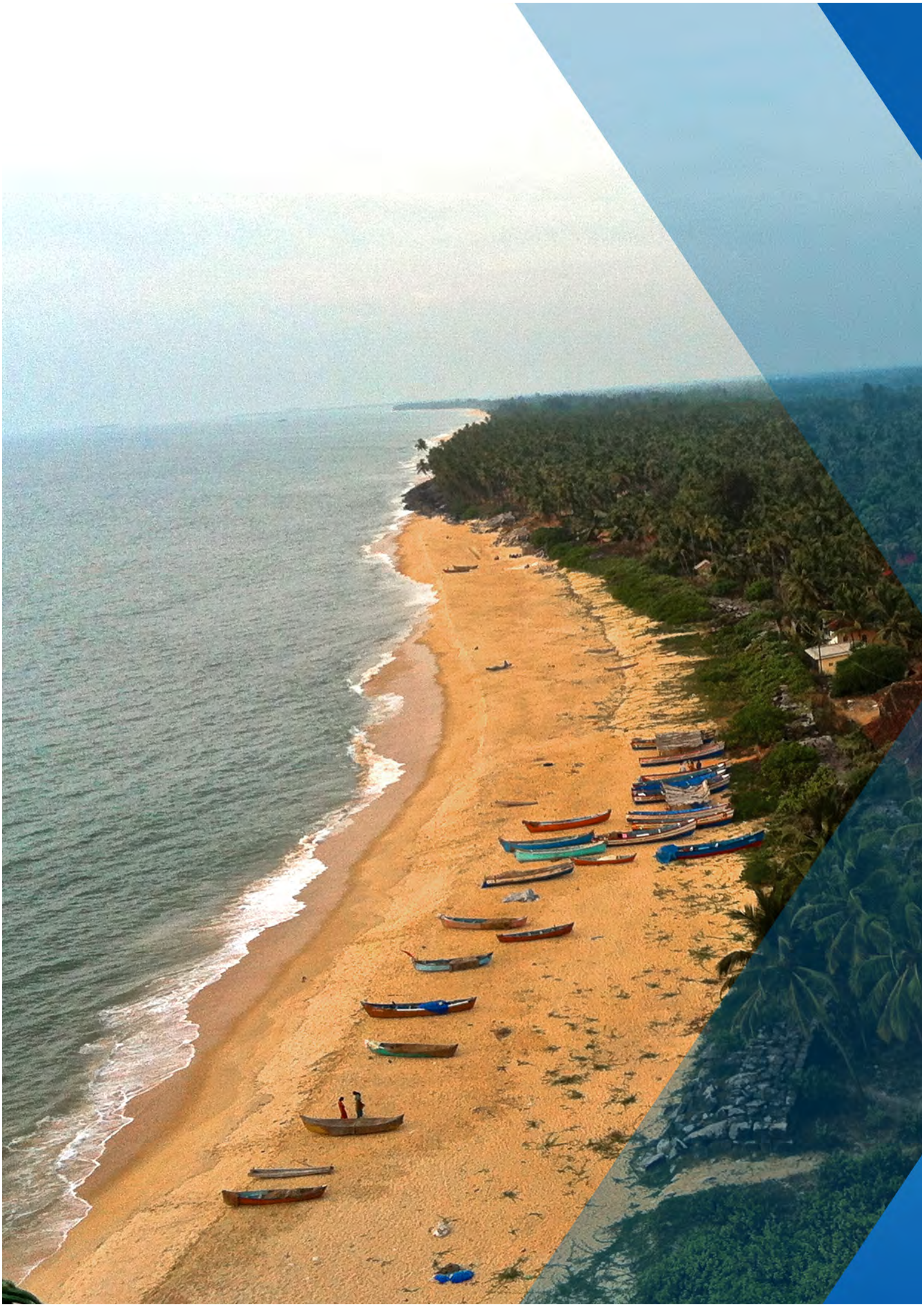
Important Institutions Involved in Coastal protection and Management in India

1. Ministry of Water Resources, River Development & Ganga Rejuvenation, Government of India [http://wrmin.nic.in/]
2. Ministry of Environment, Forests and Climate Change, Government of India [http://envfor.nic.in/]
3. Ministry of Earth Sciences, Government of India [http://www.moes.gov.in/]
4. Central Water Commission, Government of India [http://www.cwc.nic.in/]
5. Central Water & Power Research Station, Ministry of Water Resources, River Development & Ganga Rejuvenation, Government of India [http://cwprs.gov.in/]
6. Integrated Coastal and Marine Area Management Project Directorate, Ministry of Earth Sciences, Government of India [http://www.icmam.gov.in/]
7. National Centre for Sustainable Coastal Management, Ministry of Environment, Forests and Climate Change, Government of India [http://www.ncscm.res.in]
8. National Centre for Earth Science Studies, Ministry of Earth Sciences, Government of India [http://www.ncess.gov.in]
9. National Institute of Ocean Technology, Ministry of Earth Sciences, Government of India [https://www.niot.res.in/]
10. National Institute of Oceanography, Council of Scientific & Industrial Research, Government of India [http://www.nio.org/]
11. Department of Ocean Engineering, Indian Institute of Technology Madras [http://www.doe.iitm.ac.in/]
12. Centre for Atmospheric Sciences, Indian Institute of Technology Delhi [http://cas.iitd.ac.in/]
13. Department of Civil Engineering, Indian Institute of Technology Bombay [http://www.civil.iitb.ac.in/]
14. Department of Ocean Engineering & Naval Architecture, Indian Institute of Technology Kharagpur [http://www.naval.iitkgp.ernet.in/]



CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 2

APPENDIX 6

COASTAL PROCESSES

ADB TA-8652 IND:

CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

APPENDIX 6
Coastal Processes

Coastal processes determine the responses of the coast to waves, currents, tides, storms and sea level rise. There are myriad physical processes in the sea. The key forces which shape our coasts are waves and currents.

How are waves created?

TWhen wind blows across the sea surface, the friction between the air and water initiates a series of small ripples. These bumps on the sea give the wind something to push against, and soon the ripples grow into waves. The waves grow higher, longer and faster, reaching maximum size when they nearly match the speed of the wind.

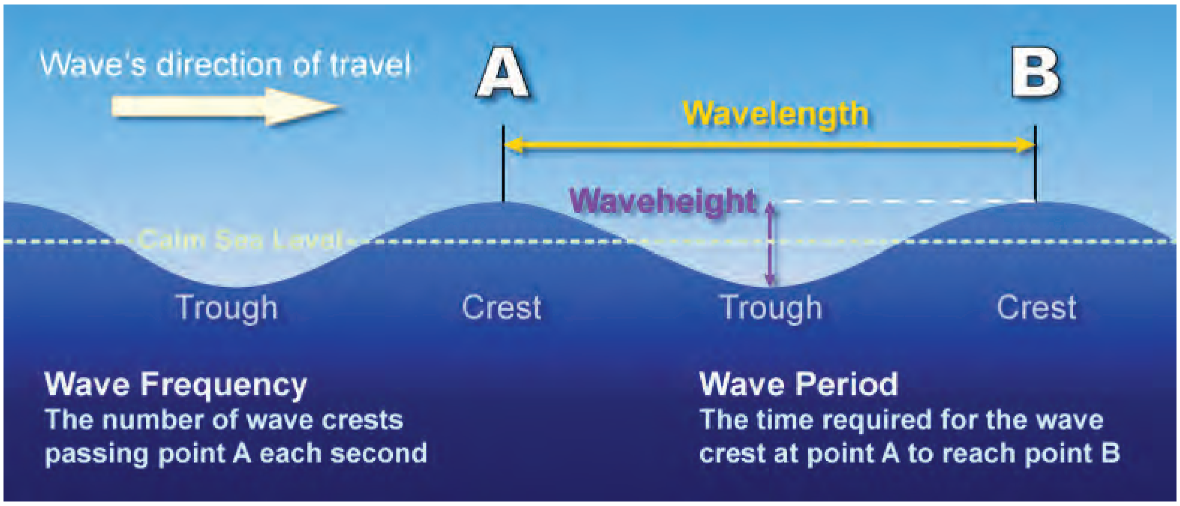
The longer and further the wind blows, the bigger and faster the 'sea waves' become. The largest waves on Earth occur where strong winds blow steadily across miles of open sea. Examples are the long empty stretch around Antarctica and the Southern Ocean which generates swells coming to India.

In deep water, a group of wind-driven waves, called a wave train, develops into a series of harmonious, rounded 'swells'. The train keeps moving even after it leaves behind the wind that formed it. In the open sea, wave trains soon encounter other sets of waves traveling in different directions and with different speeds, heights, and wavelengths. Interference between wave trains can produce a confused, highly irregular sea.

In the open ocean, individual water molecules move in circles as a wave passes with no net movement: energy is only thing that waves transmit across the sea.

The highest surface part of a wave is called the crest, and the lowest part is the trough (Figure 1). The vertical distance between the crest and the trough is the wave height. The horizontal distance between two adjacent crests or troughs is known as the wavelength. The time taken for a wave to travel one wavelength is called the period.

Figure 1. Propagating ocean surface wave



Source: NOAA (2017)

Long period waves move faster than short period waves. As the storm swell moves across the oceans, the long waves move ahead of the stragglers. Swells also form into groups of larger waves or "sets". We see these large wave sets (also called 'wave groups') arriving at beaches every five to ten minutes.

When waves move into shallow water they start to "feel the bottom"—the deepest circling water molecules come in contact with the seafloor. The wavelength decreases and the waves in the train start to bunch up. The wave length (L) is related to the depth of water (h) and wave period (Tp) by

$$L = L_0 \tanh\left(\frac{2\pi h}{L}\right) \quad \text{or} \quad L = T_p \sqrt{\frac{gh}{F_a}} \qquad (1)$$

L_0 is the deep water wave length

$$L_0 = \frac{gT_p^2}{2\pi} \qquad (2)$$

where (=9.81 ms^{-2}) is the acceleration due to gravity. From this equation, the wave length corresponding to the wave period in the given depth of water can be worked out by iteration.

In MKS units, the deep water wave length (L_o) is given by

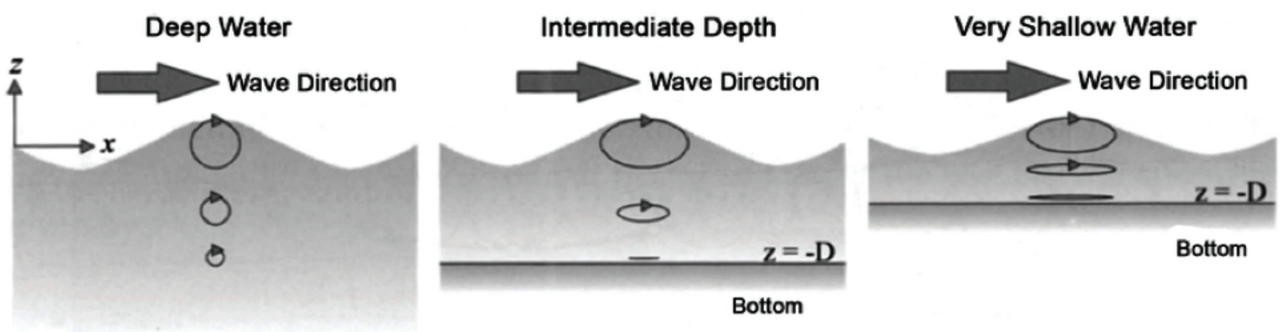
$$L_o = 1.56\ T^2 \qquad (3)$$

The waves are classified as deep water or shallow water waves according to relative depth (d / L) as follows:

1 / 2 < d / L deep water waves
1 / 20 < d / L < 1 / 2 intermediate
D / L < 1 / 20 shallow water waves (4)

In deep water, the trajectories of water particles are circular and effect of the waves does not reach the seabed whereas in shallow water, the trajectories are elliptical in nature and the effect due to waves is felt at the bed (Figure 2).

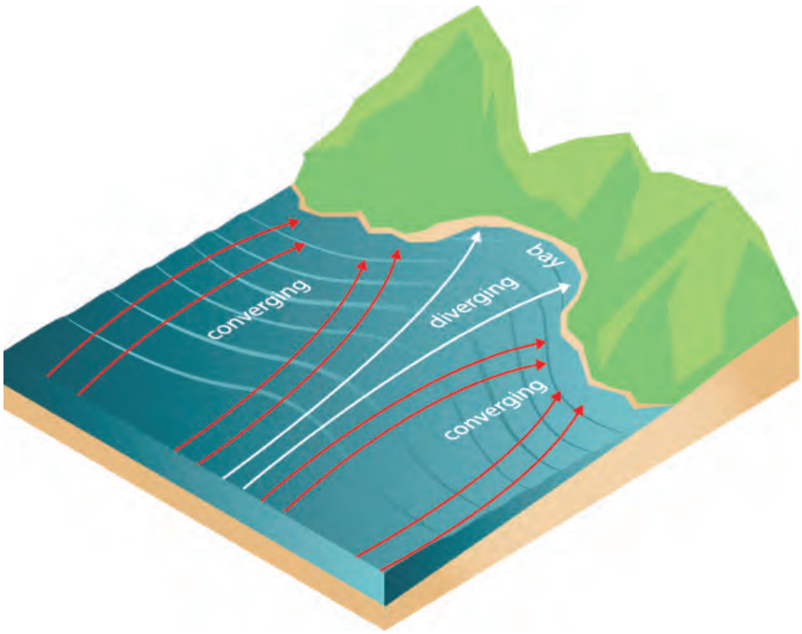
Figure 2. Water particle trajectories in progressive water waves



Source: NOAA (2017)

If a wave is coming towards land at an angle, or the shoreline is uneven, some parts of a wave will feel bottom before other parts and slow down first. This causes the wave to bend, or refract, so that waves turn towards the shore or wrap around islands or headlands (Figure 3). The wave begins to lean forward as the crest rushes ahead of the base and eventually the wave topples over and breaks.

Figure 3. Wave refraction-convergence and divergence



Source: University of Hawaii (2017)

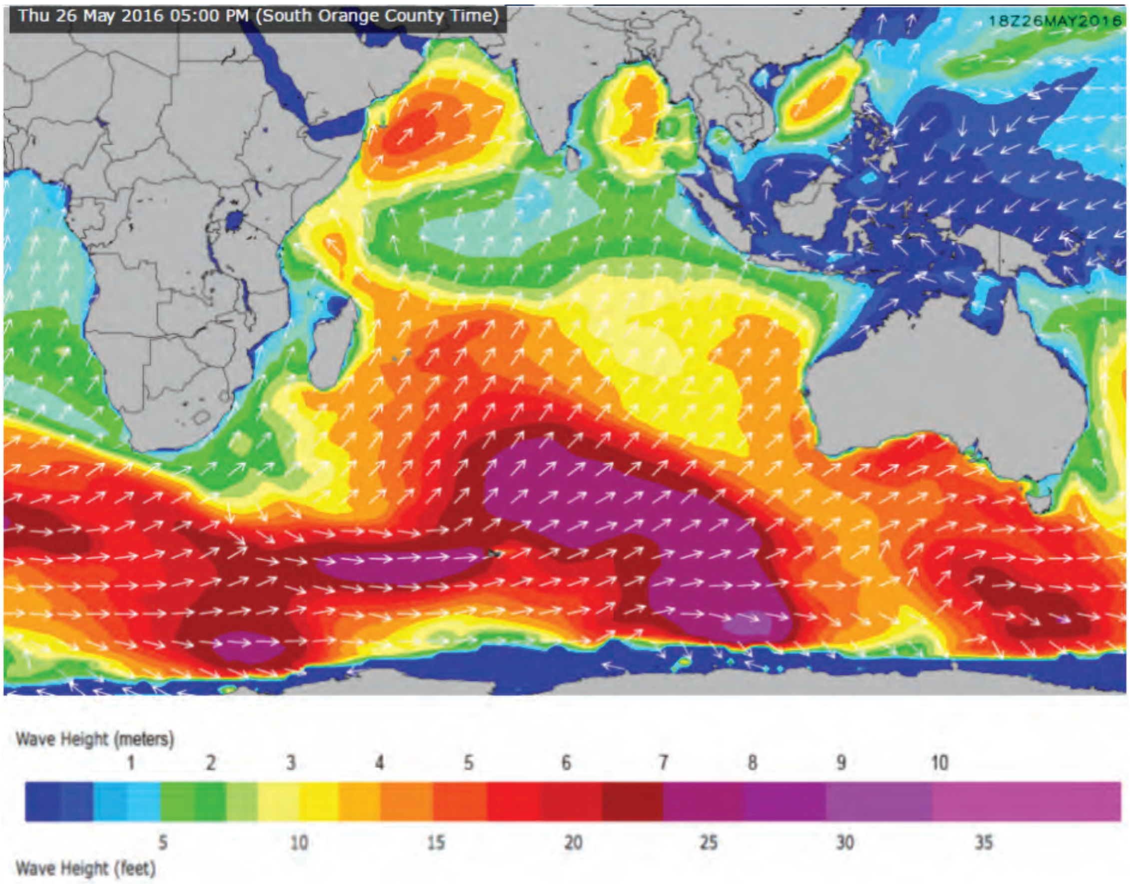
Where do Waves in India Come From?

Waves reaching India come from two different sources. The first source is the Southern Ocean where big storms occur (Figure 4). The waves travel thousands of kilometers to reach the Indian shore. They arrive in India with directions from the southerly quarter. These waves normally have long periods.

The second major source is the monsoon storms. These storms are close to the Indian shore and produce "messy" seas with short period and irregular waves. On the east coast, the monsoon waves come from north of east. On the west coast, they come from the north of west.

India is tropical with two main seasons. The non-monsoon season has offshore winds and waves come as "swell" from the south. During the monsoon season the coasts are impacted by the "sea" waves. To understand the effect of climate change on the Indian coast we have to study both systems and their influence. The wave direction is important in the refraction and diffraction of the waves and along the Indian coast the offshore wave direction is normally different by up to 45° between the monsoon and non-monsoon periods. Other waves come from cyclones, especially on the east coast when cyclones travel across northern India in the Bay of Bengal (Figure 5).

Figure 4. Indian Ocean and Southern Ocean wave height



Arrows indicate the direction of wave propagation.
Source: www.surfline.com/surfdata/chart_viewer/?chart=iowave&id=2950

How are Tides Generated?

Tides, which are typically observed along most of the coast around the world are, periodic in nature with high and low waters once (diurnal) or twice a day (semi-diurnal); the latter is dominant in India. Tides are created by the pull of the sun and moon on the oceans. There are many constituents due to variations in the orbits. Global bathymetry plays a very important role as the tidal waves interact with the continents causing interference patterns that can create very small tides in some locations and very large tides in others. The tides on the coast of India increase substantially to the north.

Tides are responsible for moving large amounts of sediments perpendicular to the coast and tidal range governs the width of the littoral zone. Tides influence the distribution and morphology of tidal flats, coastal deltas, barrier island, spits etc. It is also responsible for salt and fresh water mixing in estuaries and may play an important role in the mixing of ocean currents.

The flow of water (tidal flow) from land towards sea is from high tide to low tide and is called the ebb tide, while landward tidal flow from low to high tide is called the flood tide. Time of no flow between ebb and flood tide is called slack water (period). If we observe the tide for a longer period, then we observe that the tidal range varies with time. There are periods with large tidal ranges and periods with small tidal ranges. The period with large tidal range is called the spring tide while the period with smaller tidal ranges is called the neap tide. The time between two periods of spring tides is about 15 days.

How are Currents Generated?

Large-scale currents along the coast can be generated by many factors. The common factors are tides, waves, winds, ocean circulation and coastal-trapped waves.

The ocean circulation is driven by global weather patterns and temperature gradients. Coastal-trapped waves arise due to storms which locally alter the water level. The wave then travels along the coast, trapped at the shore by the Coriolis Effect. The most important force at the beach is the waves. When waves arrive at an angle to the shore, they generate a current along the beach which is known as a "longshore current" (see Appendix 16). These currents move sand along the shore (littoral drift or longshore transport). The waves also cause the water levels to change around the surf zone, known as "set-up". Gradients in the water levels lead to the formation of rip currents, particularly against an obstruction like a headland, port or groyne.

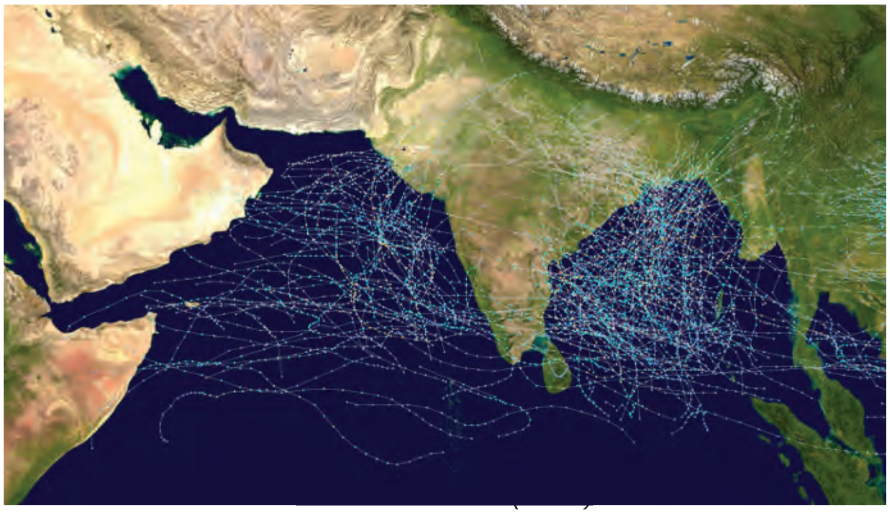
Other currents are generated by winds. Wind-driven currents occur when the sea surface is moved downwind by the stress at the air-sea interface. Longshore winds are the most important for beaches as they can drive currents up or down the coast which, in the presence of waves, exacerbates the longshore transport. Less important currents for beaches are tidal currents, coastal-trapped waves and oceanic circulation.

Inside the harbors and estuaries, the currents are mostly caused by tides or river flows. In combination, these form sand bars and help to flush sands from the rivers into the sea. Mangroves create friction on the banks of an estuary which reduces the currents. They commonly collect muds which can eventually lead to natural reclamation of the estuary as the muds build up above the high tide line.

Climate Change and Extreme Events

Many studies (e.g. IPCC 2013) have shown that climate change may lead to changes in the frequency and intensity of the meteorological drivers of sea level change and to riverine flooding. While projections of tropical cyclones in the north Indian Ocean region are uncertain, the available studies suggest that there may be an increase in the number of tropical cyclones in the more intense categories. Clearly, any increase in the magnitude of cyclones will make shorelines more susceptible to modification by waves and storm surges as well as pose a risk to cities and coastal communities. There are several incidents in India in the past; tropical cyclones can generate heavy rainfall, very strong winds and big storm surges when they make landfall, leading to considerable damage to coastal environments and built assets (e.g. 1999 Odisha Cyclone).

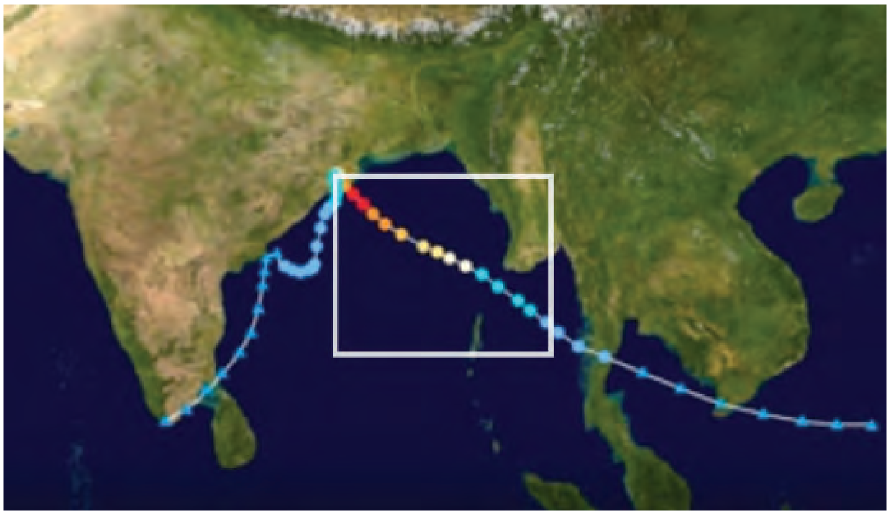
Figure 5. Cumulative track map of all North Indian Ocean cyclones (1970-2005)



Case Study – Odisha Super Cyclone (October 1999)

In the recorded history of cyclones for the State of Odisha, the Super Cyclone of 29-30 October 1999 was undoubtedly the most intense (Kalsi, 2006), which devastated the entire infrastructure in its core area on 29 October 1999 (Figure 6). The cyclone attained its peak intensity (lowest pressure 912 hPa) at 0300 UTC of 29 October 1999. The central pressure in this case was almost same as in the case of Nagapattinam cyclone of November 1977 where it was 911 hPa.

Figure 6. The 1999 Orissa cyclone



Pressure: 912 hpa

Highest winds (1-minute sustaunes): 290 km/h

Fatalities: 15,000

Damage: $4.5 billion (1999 USD)

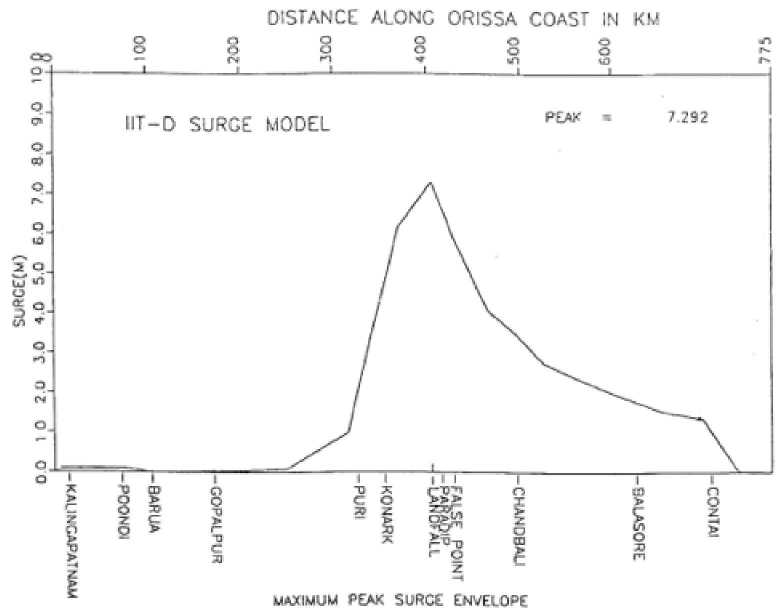
The Orissa cyclone, one of the most powerful and deadliest cyclones to hit India in recent history caused a massive 15,000 deaths. It formed from a cluster of thunderstorms off eastern Philippines before steadily organizing and peaking on December 28, with a pressure of 912hpa.
Source: https://www.youtube.com/watch?v=JKsaT4qdSRA

The buoy deployed off Paradip under the National Data Buoy Program of Department of Ocean Development recorded a significant wave height of 8.2 m. The wind speed recorders at Paradip became unserviceable after recording 80 kt winds around 0200 UTC on October 29. A maximum wind of southwesterly 97 kt was reported at about 0700 UTC on 29 October from Puri.

Unfortunately for the super cyclonic storm of Odisha, there is no recorded surge information available. The task force instituted by the Ministry of Urban Development for the assessment of the damages encountered in this super cyclone, estimated a storm surge of 7.5 m, which apparently contains the astronomical tide of about 0.8 m at the time of landfall. According to the State Government of Odisha total sea elevation was about 20 feet (6.5 m). Figure 7 reproduces the peak surge (m) envelope with Indian Institute of Technology (IIT) Delhi location specific fine grid model used by Kalsi (2006).

After crossing the coast, the system moved very slowly a little further to the northwest, weakened and lay centered in the evening of 29 October near Cuttack as a very severe cyclonic storm. Very heavy rains with strong winds lashed coastal Odisha for 2 days. It weakened slowly, took a clockwise turn and appeared as a depression near Chandbali on 31 October morning. Thereafter its remnants drifted south westwards as a low pressure that dissipated off south Odisha coast on 1 November 1999.

Figure 7. Peak surge (m) envelop with IIT Delhi location specific fine grid model (Radius of maximum wind as 40km)



Source: Kalsi, 2006

Tsunami

Tsunami waves are the largest and most energetic on Earth. Tsunami waves are barely noticeable in the open sea – their height is just 1 m or less, and successive wave crests are miles apart. These waves travel very fast, racing across an ocean at the speed of a jet.

Tsunamis are caused by geological events that push a mass of water. Underwater landslides, volcanic eruptions, even asteroids falling into the sea from space, can create a tsunami.

But most are caused by earthquakes which move a large piece of seafloor up or down. The displaced water rushes away from the disturbance in waves that spread in all directions. When tsunamis reach the coast, they behave like normal breaking wind waves. But when all of that enormous energy is compressed into shallow water, the wave grows to massive heights, as much as 40 m or more.

As the wave rises, water is sucked into the crest from ahead of the wave, and the shoreline seabed can become suddenly exposed, like an exceptionally low tide. The tsunami breaks with enormous force and the water from the collapsed wave can sweep far inland. A tsunami is usually a series of waves which arrive over several minutes to almost two hours.

Beach Responses

Beaches have been in existence for millions of years, and so they have intrinsic stability. But will they survive climate change? And what factors may prevent them from surviving, particularly human interventions that may disrupt natural systems. Beaches can simply change their alignment to re-distribute sand into different locations. Or they may work to build up the sand dune. Alternatively, they may simply erode as sand supply dwindles or moves elsewhere.

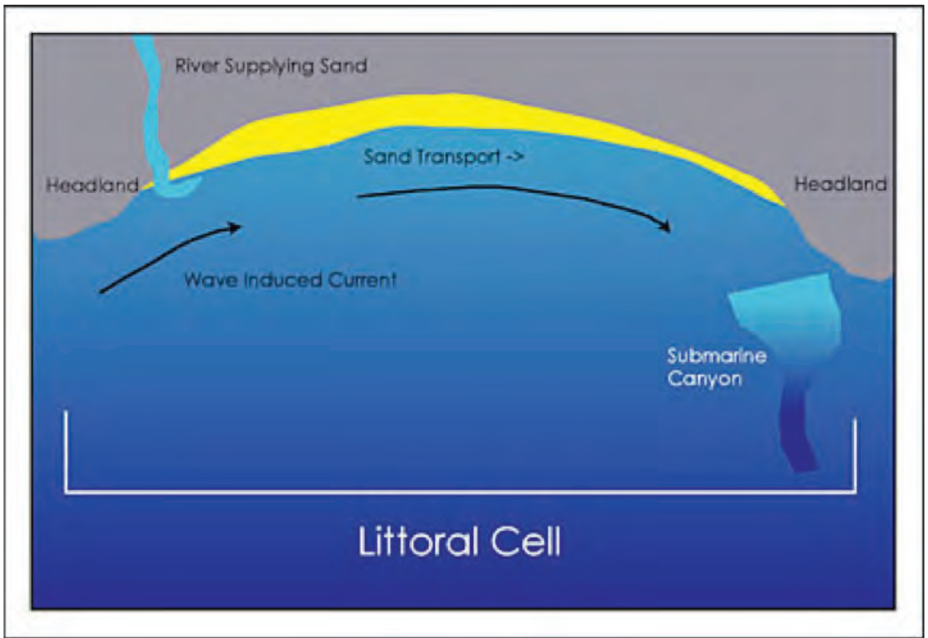
The problem of beach adjustment under climate change is complex and subtle. A stormier or altered wave climate with higher water levels defines the real impact of climate change on the coast.

Sediment Cell

A sediment cell (also known as littoral cell) is defined as a length of coastline which is relatively self-contained (Figure 8). Common examples are beaches between large headlands. The volume of sand is essentially fixed, notwithstanding new deliveries from rivers.

Many scientists assume that works within a sediment cell will have no measurable influence on locations outside the cell. Thus, the sediment cell is a convenient method to sub-divide the coast into zones which are essentially independent with no sediment exchanges between the cells.

Figure 8. Littoral cell



Source: Beachapedia (2015)

The sediment cells can be broadly divided into primary, secondary and tertiary. The primary cells can be based on coastal geomorphology, sources of sediments, stores of sediments, interface of rocky-sandy-muddy coast and other major features which divide the coast.

Table 1. Types of coastlines of different maritime states in India

State	Sandy beach (%)	Rocky coast (%)	Muddy flats (%)	Marshy coast (%)	Total length* (km)	Length of coast affected by erosion** (km)
Gujarat	28	21	29	22	1214.7	36.4
Maharashtra	17	37	46	–	652.6	263.0
Goa	44	21	35	–	151.0	10.5
Karnataka	75	11	14	–	280.0	249.6
Kerala	80	5	15	–	569.7	480.0
Tamil Nadu	57	5	38	–	906.9	36.2
Andhra Pradesh	38	3	52	7	973.7	9.2
Orissa	57	–	33	10	476.4	107.6
West Bengal	–	–	51	49	157.5	49.0
Daman and Diu					9.5	–
Pondicherry					30.6	6.4
Total mainland	43	11	36	10	5422.6	1247.9
Lakshadweep					132.0	132.0
Andaman and Nicobar					1962.0	–
Total					7516.6	1379.9

*According to the Naval Hydrographic Office.
**Information collected from respective states.

Source: Kumar et al. (2006)

The secondary cells can be demarcated by changes in littoral front, change in coastal alignment, decadal erosion / accretion, man-made littoral barriers, tidal inlets / river mouths, and other features that partially sub-divide the sediment transport. The tertiary cells are actually management units, normally based on land use and other coastal activities which affect the sediment movement up and down the coast.

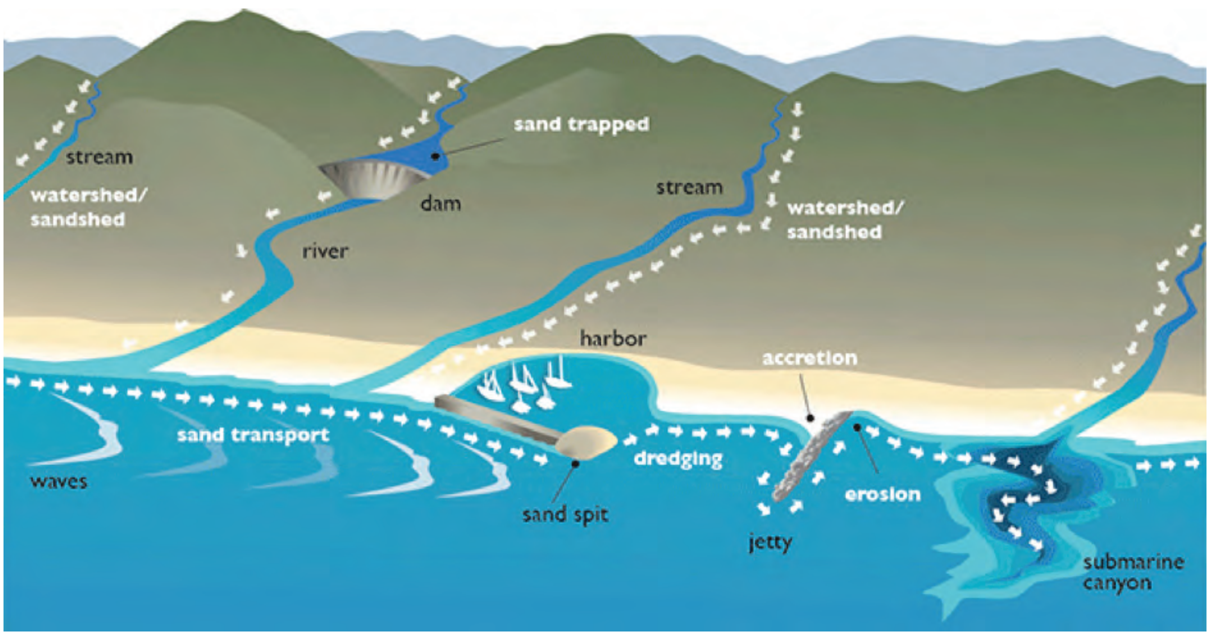
Sediment Pie

The “sediment pie” is the total volume of sand available on a beach within a sediment cell, i.e. the volume currently on the beach plus any new sand brought to the beach by waves and currents or a river (Figure 9). Much of the sand on global beaches came to the shore several thousand years ago (during the Holocene period). Supply from offshore is small now. Legal and illegal sand mining on the beaches is causing a major reduction. Large dams on many rivers have blocked deliveries to the coast (see Appendix 7). People are encroaching on the beach with buildings and other infrastructure, which buries a large volume of sand and disturbs the coastal processes.

Thus, the sediment pie is getting smaller. The sediment pie rules are:

- Sand is precious;
- There is a limited volume of sand available;
- If one coastal structure captures sand, then less sand will go to the downstream locations;
- Dredging of sand to be sold or put to reclamation reduces the volume in the pie;
- Not much new sand is coming to the beaches, and;
- Changing the natural beach processes that nature put in place when the earth was formed is an error.

Figure 9. Sediment transport pathways



Source: Sea Grant (2014)

In the longshore direction, beaches with a sediment cell are connected along their full length. They are very responsive to the local wave climate. Longshore currents link each part of the beach and carry sand along the shore. As the season changes, the longshore currents in India usually change in synchrony with the wave climate. Net movement at the beach is to the north in the dry season and to the south in the monsoons. Of course, there are exceptions for beaches which might be sheltered by headlands or have unusual orientations.

Stable ('Happy') Beach

A stable or "happy" beach has a neutral alignment relative to the wave climate. Waves come from many directions and they push sand along the shore. But if the total push one way is equal to the total push the other way when averaged over a year, then the beach has neutral sediment movement. Happy beaches are much less likely to be subject to erosion, unless the sand is trapped by structures or removed by human activities. Commonly such beaches reside between natural headlands or on beaches with orientations that are perpendicular to the average wave power reaching the beach.

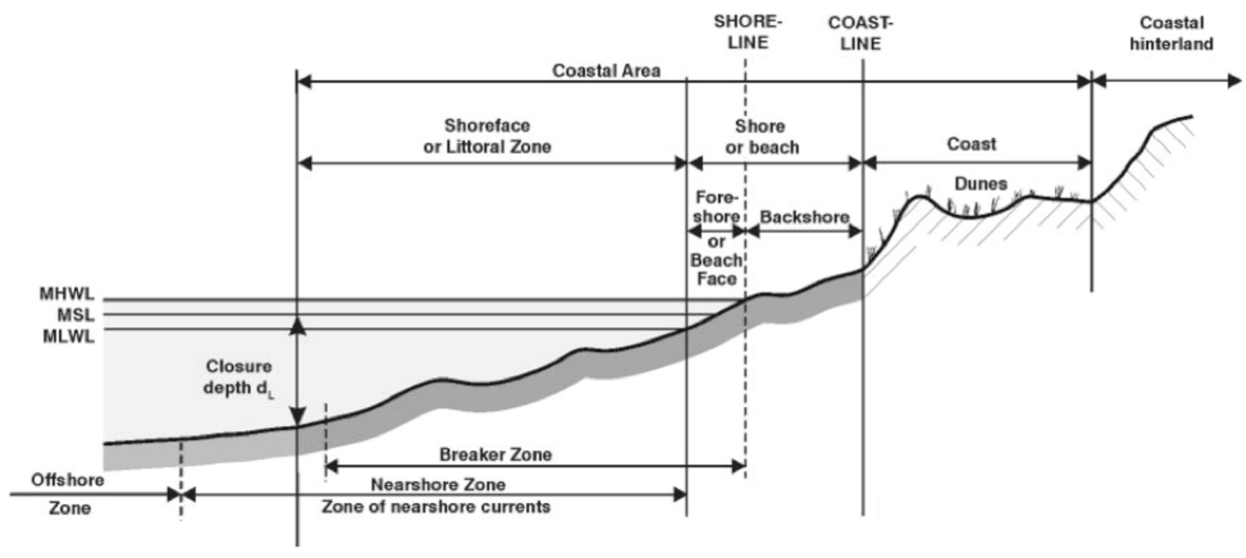
Unstable ('Hungry') Beach

A hungry beach is out of alignment with the waves. When waves come from many different directions the sand moves up and down the coast. But the hungry beach has more sand going one way than the other. This means that the net sediment movement along the shore is up or down the coast.

To be stable, Hungry beaches need a constant sediment supply, i.e. they need food. The food has traditionally come from large rivers and we still see evidence of large river deltas bulging out from the shore in India. The hungry beach is out of balance if the sand supply is reduced (e.g. dams on rivers, sand mining or large structures which obstruct their supply). Sand can be quickly washed away from a hungry beach, if the sand inputs are less than the outputs along a section of shoreline.

Beach Evolution Cross-Shore: The 'Dune-Bar Connection'

Figure 10. Geomorphic features of the coast and the active dune-bar system



Source: USACE (1984)

In the cross-shore direction, beaches are like the tip of the iceberg. Much of the beach is underwater, beyond the sand we love to enjoy. There are several key morphological features (Figure 10): sand dune, upper platform or berm, beach face, subtidal beach, bar, and offshore zone.

Nature has evolved a simple system to keep beaches stable:

- **Step 1:** When big storms arrive (mostly during the monsoons in India) the waves cut into the berm and carry the sand offshore to the underwater sand bar where waves are breaking

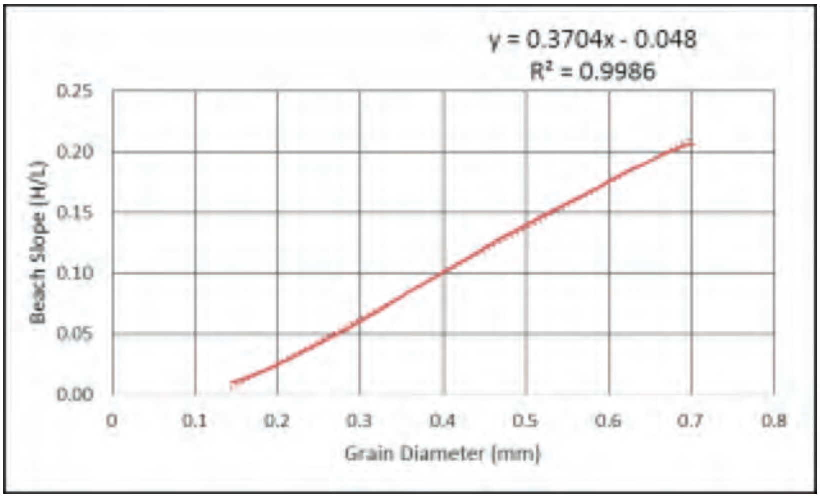
- **Step 2.** The sand bar at the breakpoint gets higher. This causes the breaking waves to lose more energy when breaking which reduces the wave height at the shore
- **Step 3.** Eventually when the sand bar is very shallow, the erosion of the beach face and berm stops
- **Step 4.** The sand on the bar is not lost. During calm conditions under clean (longer period) swells, the sand is moved slowly back to the berm and winds or waves under very high sea levels can move the sediment to the berm or sand dune
- **Step 5.** The sand lost from the berm and dune during the storm is now back again.

In India, these processes mostly occur seasonally as the wave climate changes from erosive during the monsoon to accretionary in the dry season. Of course, this process is disrupted by a seawall, as the wall sits between the bar and the berm or dune.

Over-topping of Waves

Over-topping is a natural part of the beach system. Big waves can set-up the water level and the swash of the broken wave on the beach face goes over the top of the berm. Over-topping helps to build up the berm and sand dune. When waves over-top they bring sand shorewards which builds up the beach (see Appendix 16).

Figure 11. Beach slope versus sand grain size. The slope increases as the sand becomes coarser



Source: Modified from Reeve et al. (2004)

People living in this zone are not fond of this natural process as the over-topping can lead to minor flooding in their houses. But the beach is actually behaving naturally by using this simple process to re-build the beach and berm. Rock seawalls, for example, interrupt over-topping and the beach is normally lost (see Appendix 8).

Under climate change with higher water levels this highly important over-topping process will act to make the beaches higher and will protect the villages behind. But people need to allow this process to occur. We acknowledge that people view this process as flooding.

Coastal Interventions

Sometimes people build their houses on the top of the sand dune. Sometimes governments put roads along the foreshore, buildings on the beach, rock seawalls on the dune, walls across the beach to train rivers and / or build ports which project offshore on an open sandy shoreline. Sometimes, swamps dry up and are reclaimed and river flows are diverted to stop flooding which changes sand delivery to the coast.

These affect the sediment supply to downstream zones. Great care is needed. The engineer needs to be aware of the sediment cell, sediment pie and the state of the beach to ensure that the total volume of sand remaining is sufficient to sustain the beach.

Design Water Level

Many factors affect sea levels. Offshore key factors are:

- Tides;
- Large-scale ocean circulation;
- Oceanic gyres;
- Coastal currents;
- Coriolis deflection of currents;
- Local wind set-up;
- Cyclones;
- Barometric pressure, and;
- Sea level rise due to climate change.

Inshore the factors include:

- Wave height;
- Wave period;
- Wave direction;
- Surf zone width;
- Beach gradient;
- Sand grain size;
- Sand bars;
- Surf zone set-up;
- Surf beat;
- Swash and run-up;
- Surf zone currents; and
- Rainfall.

These parameters and factors determine the level of the sea at the coast, and the ultimate re-sculpting or retreat of the coast in response to waves and storms. The design water levels are considered in detail in Appendix 17.

Climate Change Scenarios

Q1 What if storms get stronger and more frequent?

The "dune-bar connection" relies on storms to take sand to the bar while clean swell during calm conditions brings the sand back to the dune. If storms get stronger and more frequent and the balance between offshore and onshore sand migration is changed, then the beach will erode.

Q2 What if the monsoon gets longer / shorter or weaker / more intense?

The average orientation of beaches in India depends on both the monsoon and the non-monsoon wave conditions. Any shift in the ratio of the duration, orientation or intensity of the monsoon (relative to the non-monsoon) will have big impacts. On long beaches, rotation can lead to hundreds of meters of accretion at one end and the same amount of erosion at the other end.

Q3 What if the wave period changes?

Wave periods are mostly shorter in the monsoon. Wave period is a key factor determining if net sand movement is onshore (long wave periods) or offshore (short wave periods). A shift in the period could have dire consequences.

Q4 What if sand supply changes?

Locations experiencing drought under climate change will have smaller flows in the rivers. This will lead to a corresponding reduction in sand supply to the coast. Wetter zones might have improved supply, but floods need to be accommodated. Continued sand mining will have dire consequences.

Q5 What if humans build rock walls along the entire coast?

Case studies show that while the rock seawalls prevent shoreline retreat, the erosion continues underwater. Rock walls along the coast would fundamentally change the beach system and lead to further beach erosion. We show in the Appendix 8 that rock walls are unsuitable for coastal protection under increased water levels due to climate change.

Q6 What if cyclones move further south?

Most beaches are close to equilibrium with their environment. But a sudden shift in the location of cyclone landfall puts the beaches out of alignment with their environment. Such dramatic shifts would be one of the most important impacts, particularly along the east coast of India around the Chennai district and further north.

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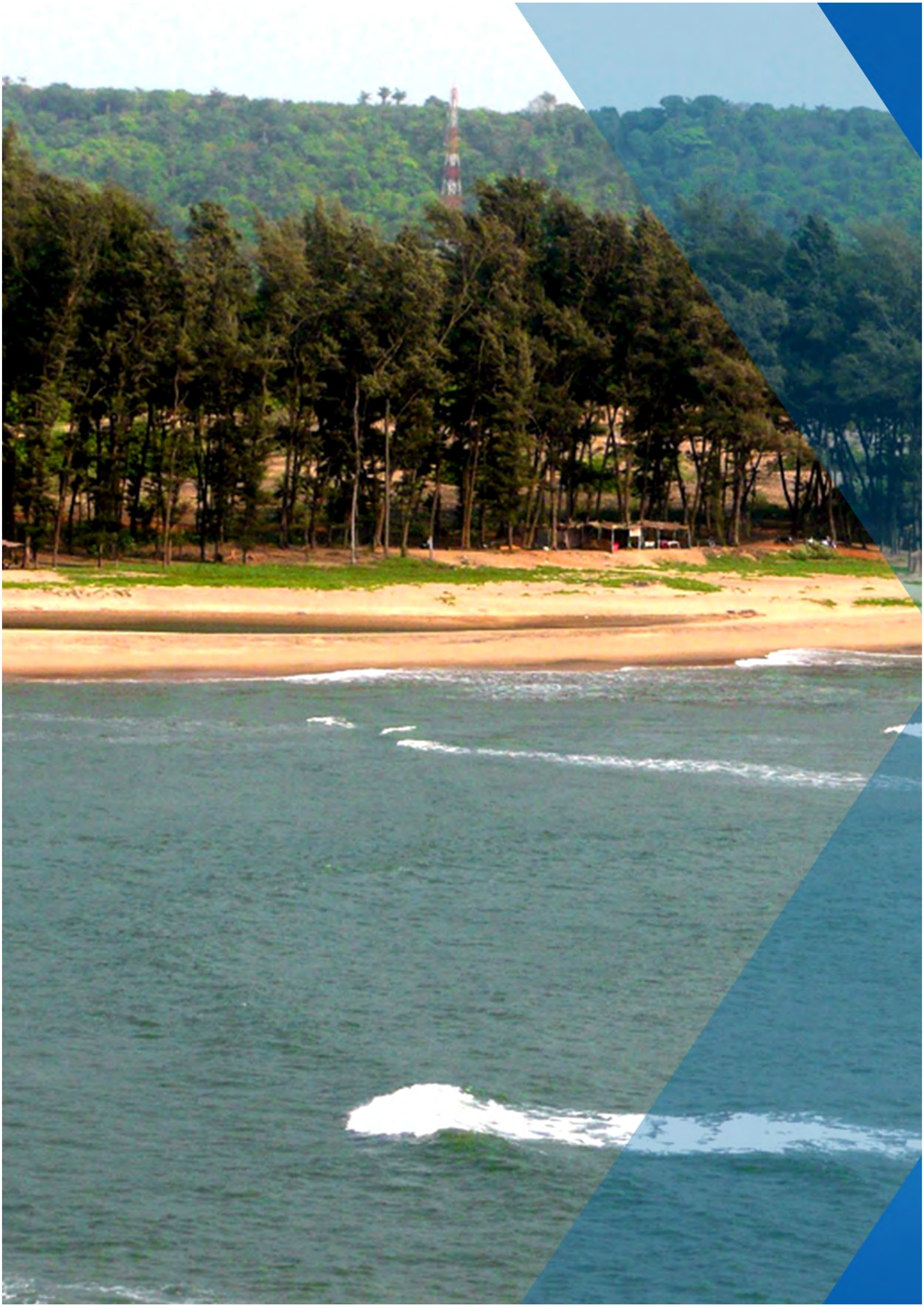


CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 2

APPENDIX 7

DESIGN OF SAND-BASED CLIMATE RESILIENT SOLUTIONS

ADB TA-8652 IND:
CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

APPENDIX 7
Design of Sand-Based Climate Resilient Solutions

Introduction

While a few projects have adopted sand-based solutions in India (Table 1), the overwhelming preference for coastal protection structures has been seawalls and groynes. International best practice has favored a wider variety of solutions. In this Appendix, the category of "sand-based solutions" is considered:

- **Dune care:** Nurturing existing or artificial sand dunes, focusing on methods to enhance the dunes by planting and the use of fencing to prevent trampling;
- **Nourishment:** Introduction of new sand to the beach system;
- **Bypassing:** Sand trapped near a structure or river is moved past the blockage, and;
- **Back-passing:** Sand which travels along a beach is moved back to its starting point.

Putting new sand on the beach is a strong method to protect beaches and is the most beneficial on the environmental softness ladder (i.e. the softest solution).

While the terms "soft" and "hard" are used in coastal engineering to describe the "solution" being developed, the definition is sometimes confused by the construction materials being used. The terms are reiterated here from the Main Guidelines for the complete understanding of this Appendix. Soft coastal solutions are those that do not damage or grossly interfere with the beach, and which allow natural bypassing of sand, such as nourishment or a submerged offshore reef. Soft solutions might be used to enhance marine ecosystems or public amenity. On the other hand, hard coastal solutions are those that disrupt the beach and environment. They normally include structures like seawalls, groynes, port walls, wharves, and high breakwaters. They usually have a large visual impact and physical presence.

In relation to the material being adopted for construction, soft materials could include nourishment, sand-filled geocontainers etc. Notably, a geotube inflated with sand is very hard, but it is normally put in the "soft" construction material category. Hard construction materials are substances like natural rock or concrete.

Under these definitions, a soft solution can be constructed from hard materials, e.g. an offshore reef made of rocks. Conversely, a hard solution can be made from soft materials, e.g. a seawall made of geocontainers. The Guidelines focus throughout on the coastal protection solution, rather than the selection of building materials, and so the term "soft" refers only to the solution being adopted.

This Appendix deals with soft sand-based solutions, which are now widely favored in many countries, but they remain to be practiced in India. Geocontainers are a construction material, rather than a coastal protection solution, and so they are not considered to be relevant to this Appendix.

Table 1. Status of Shore Protection using nourishment or sand-filled geocontainers

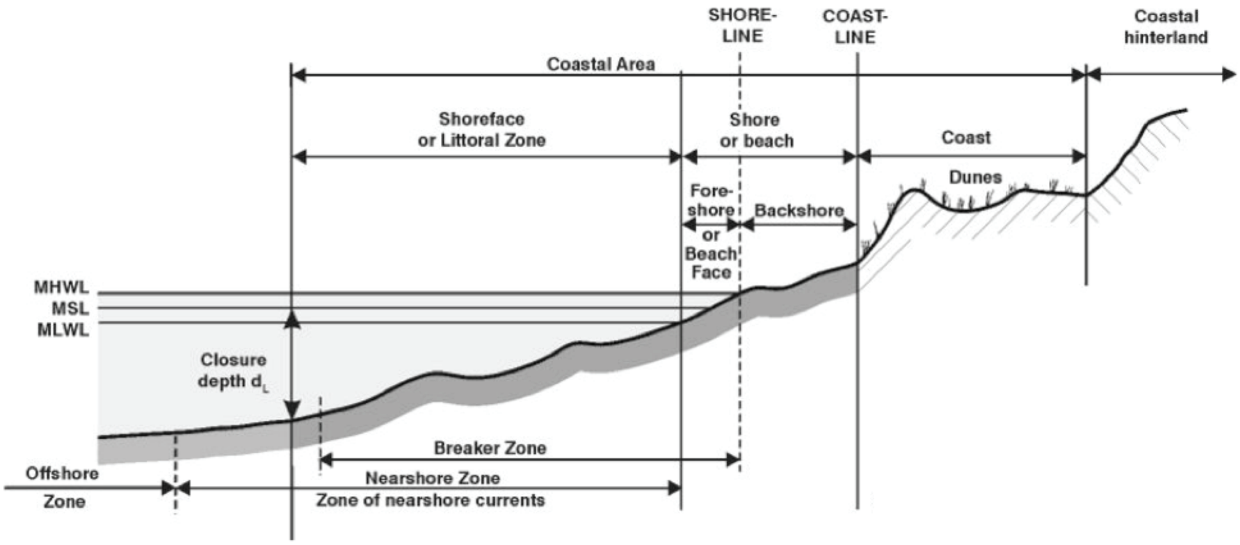
SI N°	COASTAL STATE	STATUS OF COASTAL PROTECTION	SAND-BASED SOLUTIONS FOR COASTAL PROTECTION ADOPTED
1	West Bengal	Generally, seawall and revetment; groynes near Subarnarekha and Digha inlet; 3,464 m sea walls and revetments at Digha	A seawall has been constructed using sand-filled geotubes for a stretch of about 800 m between Shankarpur and Mandarmani to protect dunes; social forestry near Subarnarekha inlet on the dunes.
2	Orissa	Generally, seawall and revetment.	Social forestry activities in Bitharkanika and Gahirmatha coasts; dune management by social forestry
3	Andhra Pradesh	Generally, seawall and revetment	Nourishment of the RK Beach, Visakhapatnam is regularly being done with dredged material from new sand trap of Visakhapatnam Port (now discontinued)
4	Tamil Nadu	Generally, seawall and revetment; groynes at many locations like Ennore, Royapuram, Kanyakumari	Dune management by social forestry in Tirunelveli and Tuticorin districts. Mangrove management at the Nagapatnam-Vedaranyam coast. Shore parallel geotubes planned at Cuddallore
5	Puducherry	Generally, seawall and revetment; groynes at North Puducherry	Beach restoration program for Puducherry initiated
6	Kerala	Generally, seawall; groynes at some locations	The first multipurpose offshore artificial reef of the country with geotextile containers filled with sand was implemented at Kovalam in 2010; dune management by social forestry in north Kerala.
7	Karnataka	Generally, seawall and revetment	Four nearshore berms using geotextile bags and two offshore rock / tetrapod reefs combined with beach nourishment are being implemented at Ullal under SCPMIP; dune management by social forestry. Beach nourishment at Kirimanjeswara.
8	Goa, Daman & Diu	Generally, seawalls and revetment; perched submerged breakwaters at Daman.	Nearshore parallel geotubes and beach nourishment for a length of 800m at Candolim in 2010, not successful; dune management at Utroda-Majorda; beach nourishment at Coco.
9	Maharashtra	Generally, seawalls and revetments; groynes at a few locations.	Sand-filled geotextile tubes were deployed at Devbagh, Malvan as temporary protection for 150 m long coast; nearshore geotextile tube submerged seawall and beach nourishment provided for 900m long coast at INS Hamala, Mumbai in 2010; offshore geotextile submerged seawall together with beach nourishment was provided for 400m long coast at Dahanu; submerged reef and beach nourishment being implemented at Mirya Bay, Ratnagiri under the SCPMIP; Social forestry and mangrove rehabilitation in Malvan coast proposed under a GEF-UNDP project.

10	Gujarat	Generally, seawalls and revetments along the south Gujarat coast and at Dwaraka.	A task force appointed by Gujarat Government has taken up preparation of a Master Plan for coastal protection for the State; dune management by social forestry
11	Andaman & Nicobar Islands	Generally, revetments	Mangrove afforestation in pockets
12	Lakshadweep	Mainly tetrapod embankments	Dune management in Chetlat island

Morphology of Indian Beaches and Dunes

The coast has several geomorphological zones (Figure 1). From offshore, the sub-tidal beach within the nearshore zone is located in deeper water beyond the surf zone. The surf zone interacts with the sub-aerial beach through the swash zone and onto the berm of the beach. Landwards of the berm, a series of dunes may have formed. These terms are more fully described in Appendix 6. In this section, the focus is on the sand dune segment.

Figure 1. The geomorphic features of the coast



Source: USACE (1984)

A dune is a mound or ridge of sediment with its axis, or crest, parallel to the shoreline. Many relict dunes in India may have been established by winds and wave over-topping during periods of higher sea levels. However, in the normal conditions the dunes form when strong winds bring beach sand shorewards from the upper beach and berm (Figure 2). Vegetation on the dune helps to capture the wind-blown sand and the dune may grow in volume after each successive wind event.

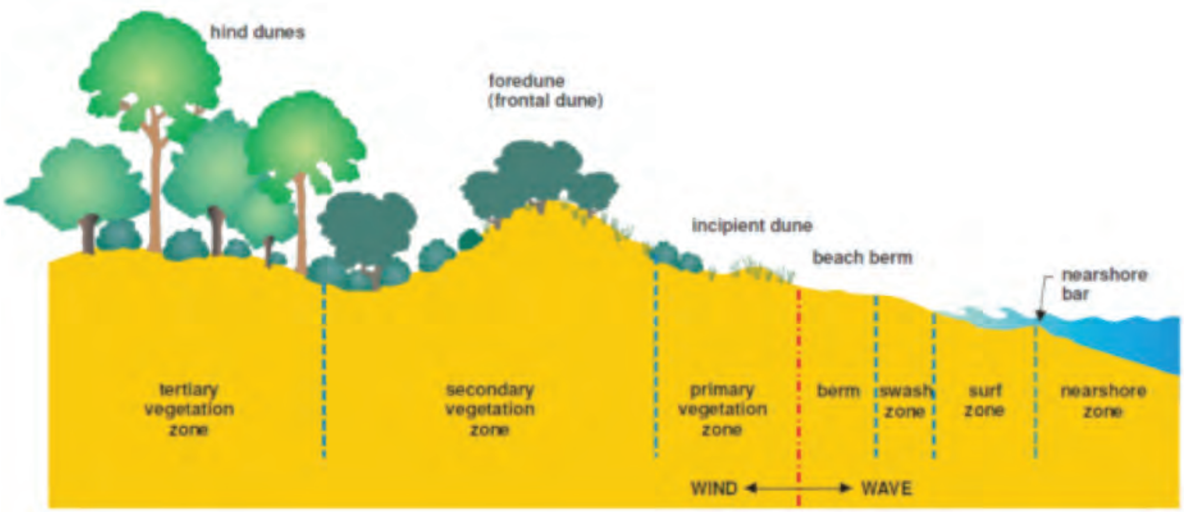
In principle, the dune / berm combination may erode during severe storm events (Figure 1). The sand is moved offshore onto the sub-tidal bar. Once the storm abates, long-crested swell slowly brings the sand back to the beach. Sometimes this process is restricted to the berm only, but sometimes the storm is large enough to engage the dune as well.

Thus, the dune provides two key services. First, the high crest can prevent or reduce over-topping by big waves in storms. Secondly, the dune provides a sediment reservoir which may be redistributed in large storms, thus reducing further impact of the waves, and subsequently returned to the dune in calm weather. As waves reach a dune and its sediments move and shift, the wave energy is absorbed, protecting landward areas from the full brunt of the storm. But there needs to be enough sediment available in the beach environment to facilitate this.

Dunes in India take on a remarkable range of sizes (even up to 10 m in height in south Tamil Nadu coast) and shapes, depending on the amount of sand available, the size of the sand, beach width, time available to build and the prevailing wind directions. The beach is the sole source of sand for coastal dunes. In India, many beaches have a small frontal dune because the winds are not strong enough to bring sufficient sand shoreward. The natural dunes usually have an elevation which is 1 to 5 m above the high tide line.

Dunes naturally migrate landwards under sea level rise (Scottish Natural Heritage, 2000) and so they are an ideal coastal protection solution for Indian beaches under climate change. The landward migration may be halted if enough sand is added to the beach to allow the dunes to grow upwards with sea level rise, using the nourishment sand.

Figure 2. Typical features of a dynamic beach system



Source: NSW Department of Land and Water Conservation (2001)

Dune Care

While many regulations exist in the coastal regulation zone, the coast is struggling to remain natural (natural refers to the maintenance of the pre- and existing ecosystem services) and many beaches are eroding. Throughout India, most coastal states have a significant length of their shoreline (even up to 50%) that require protection. This can only worsen under conditions of higher sea levels, bigger and more frequent storms, and an increase in population along the coast. The regulatory and management challenges are therefore substantial.

Dune care involves nurturing existing or artificial sand dunes, focusing on methods to enhance the dunes by planting and the use of fencing to prevent trampling. Dune care does not involve sand nourishment to create a new or larger dune, although a dune care program is recommended for artificial dunes. The goal is to simply improve the vegetation to create a more stable dune and to revitalize the natural systems that existed before dunes were trampled, built upon or damaged by man in general.

Vegetation is vital for survival of dunes, both with respect to the binding of sediment by root systems and in facilitating the build-up of dune sediment by wind. All dune improvement project sites must be vegetated (only with the vegetation native to the dunes) to maintain stability. Dune care has been used very successfully in New Zealand, South Africa and other countries worldwide.

The term 'vegetation', as used here, encompasses all the different plant species that grow from the high waterline to the back of the beach through the dunes. The different climatic and environmental conditions in different areas of the dune influence the species growing in different regions of the dune ecosystem through the process of vegetation succession. In India, a total of 338 species belonging to 69 families of flora have been identified.

Dunes have three general vegetation zones based on soil salinity, elevation, sand texture, wind velocity, temperature and human interference. In addition, these zones can intergrade and sharp distinctions between zones are usually absent. The foreshore and face of the fore dune supports creeping sand-binders such as *Ipomoea pes caprae* and *Spinifex littoreus* along with *Cyperus rotundus* in the upper portion (Figure 3).

Figure 3. Some common vegetation on the beach sand dune systems in India

Ipomoea pescaprae

Spinifex littoreus

Sesuvium portulacastrum

Chrysopogon zizanioides

Cynodon dactylon

Launaea sarmentosa

Saccharum sp

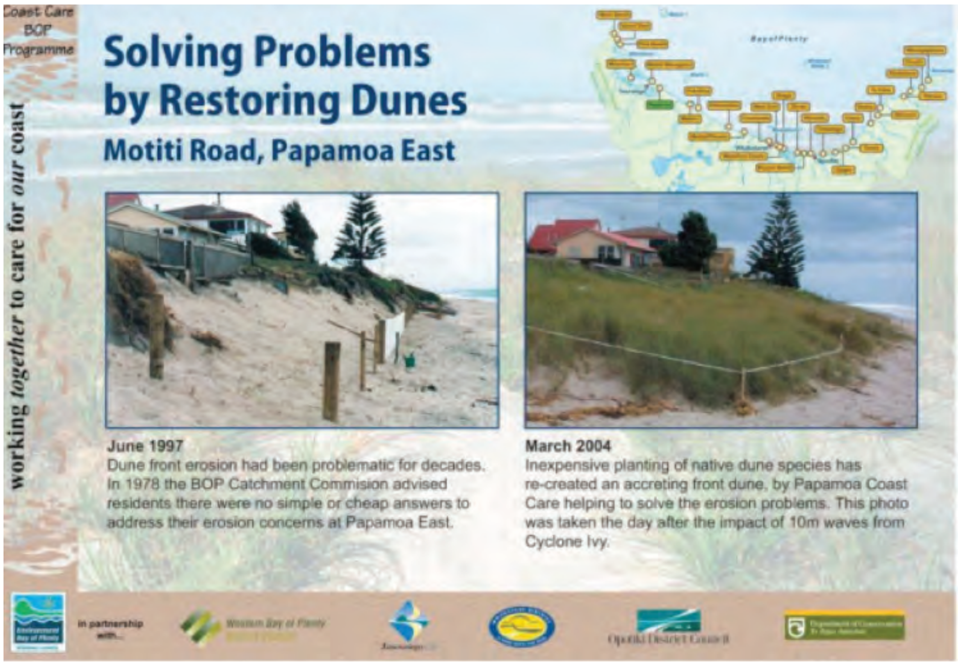
Canavalia maritima

Cassia tora

Source: Photos taken by consultant D. Oswin Stanley (2017)

Over the fore dune crest and back dune, which is also exposed to winds and salt spray, shrubs and a few sand-binding creepers and herbaceous plants such as *Aerva sp, Calotropis sp, Crotalaria spp, Cissus sp, Sida acuta, Vitex negundo, Lantana sp, Clerodendrum inerme, Ipomoea pes caprae, Opuntia sp, Scaevola taccada; Salvadora persica, Pandanus tectorius, Terminalia catappa, Calophyllum innophyllum, Thespesia populnea, Pongamia pinnata,* and *Cocos nucifera* are the most common vegetation found. The inner back dune is vegetated by a number of trees and shrubs like Palmyrah (*Borassus* flabellifer), Cashew (*Anacarduium oxydentrum*), *Pandanus sp., Calophyllum inophyllum* etc, which occur either in pure stands or as mixed vegetation. Local tree species like Tamarindus indica, *Erythrina indica,* and *Hibiscus tiliaceous* can survive in dune systems but are mostly restricted to landward slopes of rear dunes.

Figure 4. New Zealand dune care program



Source: Greg Jenks, Coast Care Bay of Plenty Programme, Environment Bay of Plenty, New Zealand

Figure 5. Example of simple and larger walkways with fencing to prevent trampling of dunes

Source: Russell (2017)

To prevent the public from damaging the dune, most dune care projects use sand fencing around the newly planted area. In Figure 4, a very simple fence has been built for demarcation of the planted area. New Zealanders are unlikely to cross the fence due to the public education programs about dune care and the need to preserve the dune for future generations and beach protection. At the same time, public walkways are constructed for public access (Figure 5). Many of the walkways have a wooden trail which prevents the loose sand from being damaged (Figure 5).

"Sand-trapping" fences have been used also to trap wind-blown sand or to simply stabilize the existing sand while plants are growing (Figure 6). The fences are usually temporary, as they may be broken by wind, sand build-up, the public etc. Thus, in most cases, a simpler fence to mark the dune area is preferred. Sand-trapping fences should not be placed where a dune of adequate size already exists, where they would trap sand in unnatural configurations, or where they cannot be buried, such as in vegetated portions of the dune or too close to the water. Sand-trapping fences around the first dune ridge function as the core around which the natural dune can evolve (Nordstrom et al., 2000; Grafals-Soto and Nordstrom, 2009).

Biodegradable fences can be used to create an initial dune ridge while avoiding the long-term hazard to fauna and diminishing the human footprint in the landscape (Miller et al., 2001). Most importantly, the dune project area must be protected from fishing boats, vehicles, pedestrians and grazing animals.

Figure 6. Sand fencing used to help trap sand and stabilize dunes

Source: CZM (2003)

Nourishment

Nourishment involves bringing new sand to the beach and nearshore zone. The principle being adopted is that the "beach provides the best form of coastal protection". A well-nourished beach will provide protection from storms and keep the whole coast healthy. Indeed, the beaches and dunes have been providing coastal protection since the dawn of time. The sand is a precious resource which provides protection, public amenity and a natural looking shoreline. Nourishment is highly recommended as the best method to deal with future climate change. In some cases, a hybrid solution may be adopted with nourishment plus some structures such as offshore reefs / islands or groynes. This is discussed in more detail in Appendix 10.

The designer of a nourishment project must deal with three key decisions:

1. **Source:** Where will the sand come from?
2. **Sink:** Where will it be placed and what are the volumes?
3. **Durability:** How long will the sediment remain on the beach?

In relation to the sink, there are four zones that may be nourished. In some cases, the beach is relatively healthy but the dune may be inadequate. Thus, sand may be placed to build-up an existing dune or to create an artificial dune. If the beach is also eroded, then sand may be placed both on the dune and on the beach above the berm. In the third case, the whole dune, beach and underwater profile is nourished. The fourth option involves placement on the offshore bar and allowing the natural wave action to redistribute the sand and bring it up onto the beach.

We summarize and name these options as:

1. **Dune nourishment:** Placing all of the sand as a dune backing on the beach;
2. **Dry beach nourishment:** Using the nourished sand to build a wider and higher berm above the waterline;
3. **Profile nourishment:** Distributing the added sand over the entire beach profile, and;
4. **Nearshore bar nourishment:** Placing the sand in the shallow offshore as an artificial bar.

In relation to the source, the most common options for bringing new sand to the beach are:

1. **Sand positioning:** Sand taken from the lower beach around low tide, normally with heavy machinery is brought up above the high tide line;
2. **Sand pumping:** Sand pumped shoreward from offshore of the breakers or navigational channels;
3. **Off-sire sand:** Sand is brought from an external source, normally by truck, and;
4. Sand is bypassed or back-passed (see sections below).

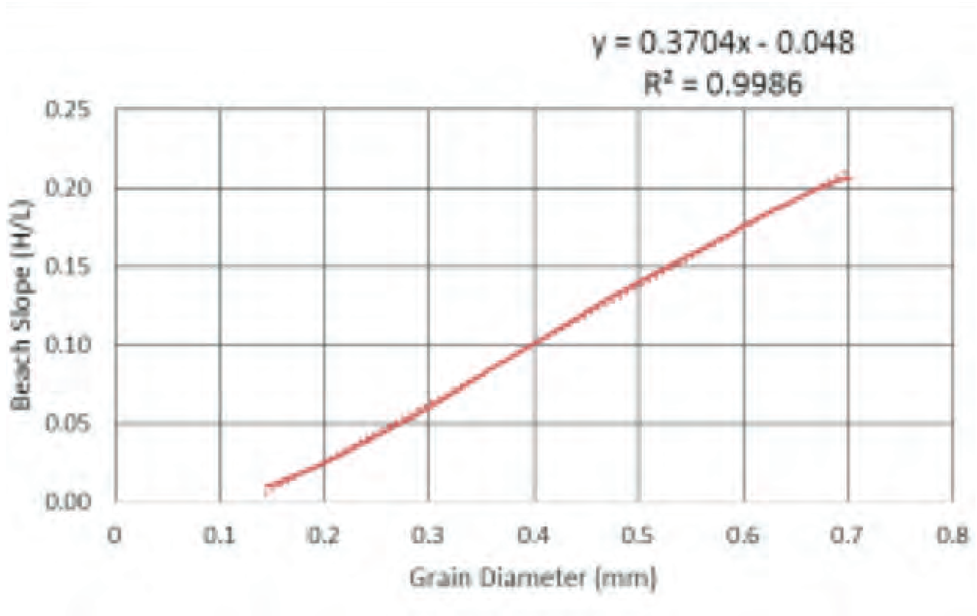
The selected design depends on the location of the source material and the method of delivery to the beach. If the borrow area is on land and the sand is transported by trucks to the beach, placement on the berm or in a dune is generally the most economical.

Nourishment is particularly effective in protecting upland development against storm waves. The dry beach method results in an immediate increase in beach width available for recreation. Once the sand is placed on the beach, waves and currents redistribute the material offshore and alongshore until a stable profile configuration is achieved. The nourished beach may take weeks to several months to reach the new equilibrium condition depending on local conditions. During this process, the beach will narrow as sand slumps down underwater and so an allowance for this process needs to be included in the nourishment design.

The durability of the nourishment will depend primarily on the size of the sediment cell versus the volume of sand to be placed. A small volume in a large cell will "disappear" relatively quickly due to redistribution within the cell by longshore and cross-shore currents. The best solution is to bring enough sand to re-nourish the entire sediment cell. Notably, sand has not actually disappeared; it has just been distributed more evenly throughout the cell and so any new sand provides some benefit throughout the full sediment cell. The benefit may be small if the cell is large and the new volumes are small.

Nourishment projects require the use of compatible sediments. Sediments that are too fine will erode quickly, reducing project effectiveness. Sediments that are too large may not move and shift as intended and could increase erosion and other problems. Coarse sands will create a steeper beach (Figure 7) and this can lead to heavy wave breaking and public safety may be reduced. Consequently, the percentage of sand, gravel, and fines in the selected sediment should match, or be slightly coarser than, the existing beach and dune sediments.

Figure 7. Beach slope versus sand grain size



Source: Modified from Reeve et al. (2004)

Using sediments with slightly larger grain sizes can provide improved erosion control and storm damage protection. More energy is needed to move this larger material, absorbing wave energy more effectively and eroding less readily. In addition, when a dune is over-topped during a storm, the larger sediments shift landward and provide direct protection from storm waves.

Thus, decisions about the range of sediment sizes should be based on specific site conditions determined from grain size analyses and the desired level of shoreline protection.

The color and texture of the sediment for a nourishment project can affect the aesthetics of the site. However, because this impact is temporary and does not interfere with the way the shoreline system functions, color may be optional. Sediment with high concentrations of heavy mineral appears black when compared to the typical white-to-yellow color of Indian west and east coast. The color changes are ephemeral (Prakash and Verghese, 1987).

In relation to texture, some compatible sediment sources contain a percentage of fine silt which can deter recreational beach users. Although the silt naturally blows or washes away with time, sediment with lower silt content is preferred. In these cases, many international projects have placed such sediment on the offshore bar, which allows the waves to sort the sands and the fines to wash out. But the temporary mud plume may be considered unsuitable for the site. If the sediment has a high shell content, then it may be best placed on the offshore bar for natural wave sorting.

Dune Enhancement and Artificial Dunes

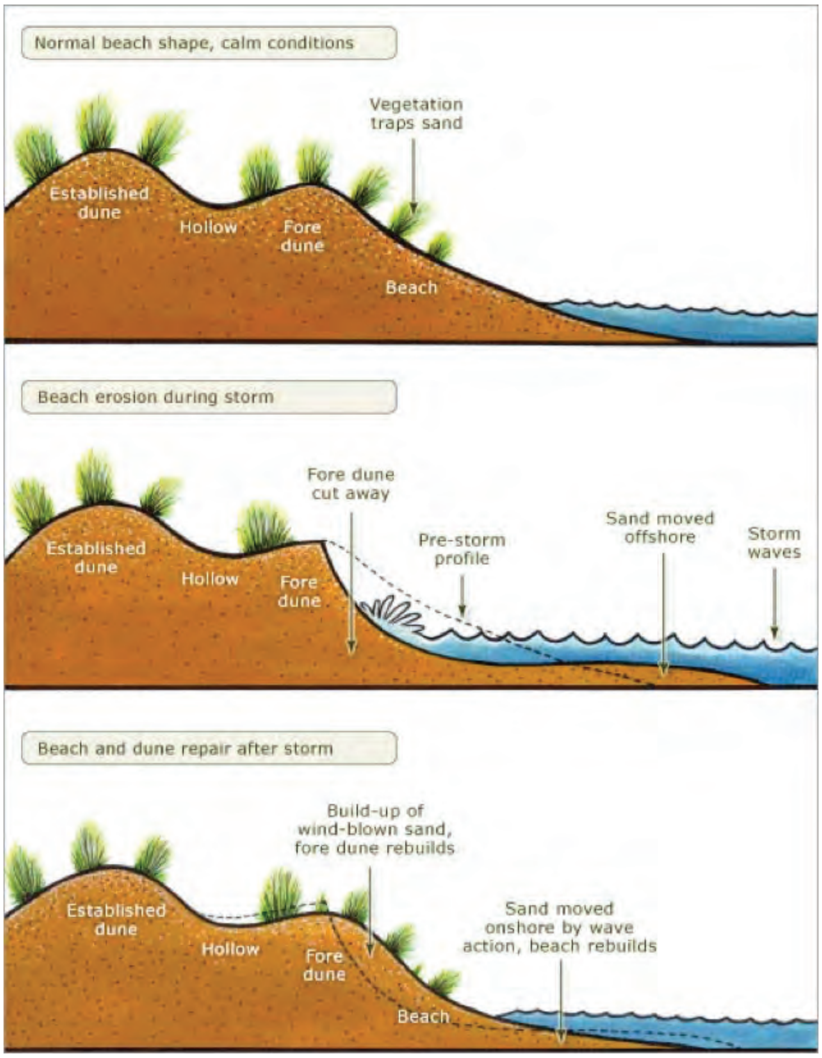
An artificial dune is a shoreline protection option where a new mound of compatible sediment is built along in the backshore of the beach. Degraded dunes can be strengthened by increasing their height and stability or new artificial dunes can be created.

Artificial and nourished dunes, not only increase the direct level of protection to inland areas by acting as a physical buffer, the added sediment from dune projects supports the protective capacity of the entire beach system (i.e., dune, beach, and nearshore area).

Appropriate Locations for Dune Enhancement

Dune projects are appropriate for almost any area with a dry beach at high tide, sufficient space to maintain some dry beach even after the new dune sediments are added to the site and good onshore wind is present to slowly support the dune formation. Figure 8 shows that: fore dunes are formed when vegetation traps wind-blown sand (upper panel); the front face of a fore dune is eroded when storm waves crash onto the dunes and wash away plants and sand (middle panel), and; the dunes form again as vegetation is re-established on an exposed site and begins to trap sand (lower panel). In areas with no beach at high tide, the protection provided by dune projects is relatively short-lived because the added sediments are readily eroded and redistributed to the nearshore by waves, tides and storms. In these situations, increasing the width of the beach through beach nourishment may be a preferred shoreline protection option. For projects on narrow beaches where the seaward part of a dune would be reached by extreme high tides or minor storms, the dune will likely erode quickly and require frequent maintenance to retain the level of protection the project was designed to provide. While sand dunes can provide efficient protection against beach erosion, "false" security from storm waves should not lead to inappropriate coastal development which is constructed too far forward.

Figure 8. Beaches and fore dunes are in a constant state of change in response to waves and wind



Source: Wassilieff (2006)

Dune Dimension and Slope

The height, length, and width of a dune relative to the size of the predicted storm waves and storm surge determines the level of protection the dune can provide. The recommended size for an artificial or nourished dune will depend on the desired level of protection, the predicted wave conditions and storm surge for the area, and site constraints (such as beach width and proximity to sensitive resource areas). In general, the dune crest should be at least 3 m above the local high tide line. This would need to be larger in cyclone prone regions (Appendix 13).

The slope selected for the project will be based on the existing beach and dune slope, the width of the dry beach, and the grain size of the dune sediments. Steep dunes are unstable and may erode rapidly and cause problematic scarps. To avoid this problem, the seaward slope of the dune should be less than 3:1 (base:height).

Volume of Material

The volume of sediment needed for a dune project can be determined by finding the difference in volume between the final design against the natural beach profiles measured on the site. Volumes are normally expressed as m^3 / m of beach length.

Maintenance Requirements

To maintain the dunes as an effective physical buffer, detailed studies will determine if sediment must be added regularly to keep the dune's height, width, and volume at appropriate levels. Dunes may also degrade if the public is given access to the dune or if a dune care program is not put in place. As with most aspects of natural resource management, follow-up management is critical to ensure the success of a dune project.

The amount and frequency of sediment nourishment for a dune project will therefore depend on the proximity of the dune to the reach of high tide, the frequency and severity of storms, the initial design of the dune (e.g., grain size, volume, height, and slope), and how established is the vegetation. Storm wave uprush may eliminate the seaward portion of the dune and create an erosional scarp, but post-storm beach accretion creates a new source of sand to be brought back to the beach, re-establishing the dune sediment budget.

Plants may need to be replaced (at the appropriate time of year) if they are removed by storms or die. Losses are more common in the early stages of a planting scheme.

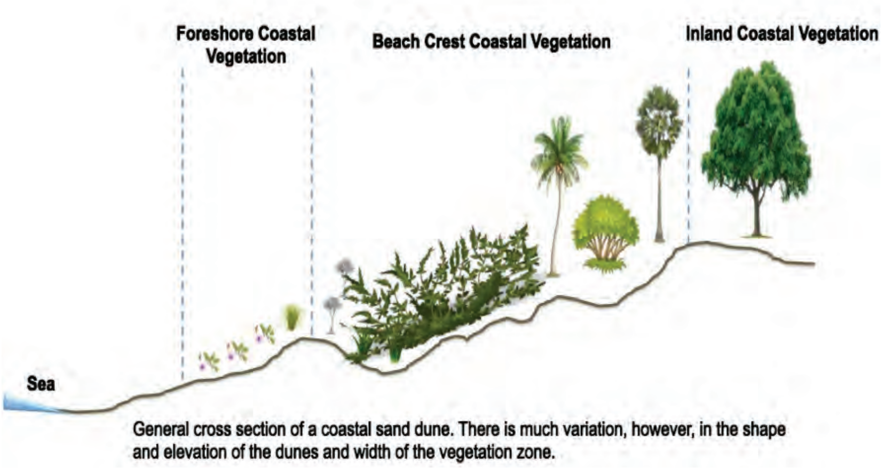
As the volumes involved in a dune project are relatively low, some projects will use monitoring to determine the re-nourishment requirements. However, this can lead to failures of the project if an allowance for re-nourishment is not made early and funds procured.

Planting and Management of Vegetation on Dunes

Each dune site must be considered independently, with approaches tailored to the specific site. Planting shall imitate the natural conditions and should be undertaken after long-term monitoring of the beach dune system and nearshore coastal processes and after ensuring that a reasonable physical and natural environment has been established. Post planting monitoring should be undertaken at least bi-annually to assess the beach dune evolution and the success of the vegetation plan.

The vegetation plan (Figure 9) should be developed after a thorough evaluation of the site and observing a natural model or referencing to an adjacent reference area during different seasons. The vegetation plan shall specify the species, spacing, diversity and density. Involving the local community and the local expertise of the community living in the area and agencies working is essential in the site assessment, development of vegetation plan, nursery development, planting, protection, monitoring and management and trading of the produce if any would be appropriate. Trainings related to every aspect of ecosystem restoration should be provided to the community, non-governmental organizations and other stakeholders.

Figure 9. General distribution of vegetation on the coastal sand dunes in India



Source: Oswin Stanley (2017)

Dune assessment establishes a baseline so that changes in vegetation cover and species composition can be monitored over time. The restored dune and beach sand need to be sustainably managed by regular monitoring procedures decided specific to the site. "community dune care groups" may undertake monitoring of dune condition and vegetation cover periodically.

Project Costs

In general, the greater the quantity of sediment that is used in the project, the greater the construction costs, the lower the maintenance costs, and the greater the level of protection provided for the site. The considerations that most influence the cost of dune projects are the severity of erosion, the width and elevation of the beach, the volume and availability of sediment source, the size and location of the proposed dune. For comparison with other coastal protection options (e.g. for seawall, INR 5 -10 crores per km), dune projects typically have relatively low construction cost (INR 0.25 – 1 crore per km), depending on the sand availability and maintenance costs.

Community Consultation and Participation

Unlike the hard options, the dune project once established can be more easily managed by the local community with some amount of technical guidance (Figure 10). Strong community and local government (e.g. Panchayat) interest and involvement can generate a sense of local ownership that is invaluable in successfully completing and maintaining a dune project. It is especially important to have residents on side. To this end, dune restoration or nourishment planning must address the needs and expectations of all users, including residents, fishers and visitors.

Both existing users of the site and potential stakeholders need to be identified and their views respected. The earlier this occurs the more likely the project will attract sustained community support. Ideally, efforts will extend beyond basic consultation to having users help formulate and implement the project plan. The success of these efforts relies upon an effective community consultation exercise.

In the case of recreational beaches, visitor needs and expectations should also be understood. Their expectations in terms of access and facilities and the recreational experiences that they are seeking may also differ from those of residents. In short, any dune management project should include a carefully planned procedure to achieve and maintain strong awareness and support within the broader community.

Figure 10. Community involvement in dune care programs, Bay of Plenty, New Zealand

Source: Jenks (2003)

Project Monitoring and Evaluation

Monitoring and maintaining a dune site may be needed for several years after completion of site works. Monitoring is important in assessing:

- Whether dune restoration / nourishment goals have been achieved;
- What kind of follow-up actions are required, and;
- How plans can be modified to achieve better future projects.

Evaluations should be conducted for several years after dune building begins, so that stakeholders can appreciate the coastal protection benefits, the time required for a resilient species-appropriate vegetation cover to become established and have realistic expectations of dune restoration outcomes.

Dune Case Study: Miaramar Beach, Goa, India

The first ever experiment to regenerate sand dunes in India was conducted at Miramar Beach, Goa in 2007 (Mascarenhas and Murali, 2010). The dunes flattened by trampling were recreated by fencing (one meter high) and allowing the growth of native vegetation. It was noticed that the dunes started taking a shape in three months of active monsoon.

However, since there was no mechanism to sustain the fences and the developed dunes, the experiment, after demonstrating the efficacy, failed. Some stretches, however remained intact for a long time. In the southern part of the same coast where trampling is absent and with proper management of the native dune vegetation by the Department of Forests extensive stretches of dunes are still intact (Figure 11 and Figure 12). Dune management also should consider avoiding littering on the dune by visitors. Tipping of domestic waste needs to be prohibited for the preservation of the dune ecosystems, however this does not stop litter being dumped by tourists. Attempts to prevent littering can be in the form of signs and warnings to alert the public of the fragile state of the ecosystem and the damage caused by improper waste disposal.

Figure 11. Google imagery of Miramar Beach dune project area, Goa, India

Source: Google Earth (2017)

Figure 11. Google imagery of Miramar Beach dune project area, Goa, India

Source: D'Silva (2013)

Dune Case Study: Kalpakkam, Tamil Nadu, India

Kalpakkam township located about 75 km south of Chennai, was affected by the December 2004 Tsunami. A coastal protective system designed by the Ocean Engineering Centre, Indian Institute of Technology (IIT) Madras, which involved a combination of soft and hard solutions to withstand tsunami and wind generated waves, was implemented along the four kilometers long coast during 2006 (Figure 13). The system consisted of a:

- 4.5m high retaining wall with rubble front;
- 2 m high sand dune;
- 10 m wide channel and;
- Green belt.

In order to reduce the cost of construction, existing sand on the 35 m wide beach was remolded to develop the sand dune and the channel. The expected functions of the system included:

- In case of a tsunami, a part of incident energy is lost while encountering the first line of defense, i.e. the dune (as it acts as a speed breaker allowing the incoming flow to climb up the sand dune, fall in the channel and get redirected parallel to the coast). Rest of the energy is dissipated on the rubble front allowing the retaining wall to experience minimum impact due to tsunami. green belt adds to the dissipation of the energy of the incoming tsunami;
- In case of an extreme situation when 35 m wide beach is lost and the rubble fronted retaining wall is exposed directly to the wind generated waves, part of the rubble stack will slide into the sea and offer protection to the exposed beach face and the rest protects the retaining wall.

However, a portion of the sand dune (not protected by vegetation) lost its form due to wind action and the channel was filled by sand with the material moved from the dune suggesting the need for their maintenance (Mani, 2007, 2014).

Figure 13. Sand dune and seawall at Kalpakkam, Tamil Nadu

Source: Mani (2006)

Dune Case Study: Digha, West Bengal, India

Dune retreat at Digha, West Bengal is at an average 17 m per year (Das 2015). The causes of dune retreat according to Das (2015) are:

- Cyclonic storms;
- Construction of a sea wall;
- Construction of hotels and resorts on the dune, and;
- Sand mining.

This site was subjected to so many negative construction impacts that dune development was not found to be a suitable solution (Figure 14 and Figure 15). According to Bhattacharya, et al. (2003), after the construction of a sea wall, the dune retreat rate reached 16 to 18 m per year, compared to 11 m per year in the 1980s before the construction of the wall.

This case study shows how dunes in India have been lost through mismanagement of the coast, and the solutions put in place exacerbated the problem.

Figure 14. Erosion scarp on the frontal dune and temporary protection at Digha, West Bengal. The old dunes are seen behind the coastal works

Source: Chakraborty (2012)

Figure 15. Construction on the dune, Digha, West Bengal

Source: Chakraborty (2012)

Profile Nourishment

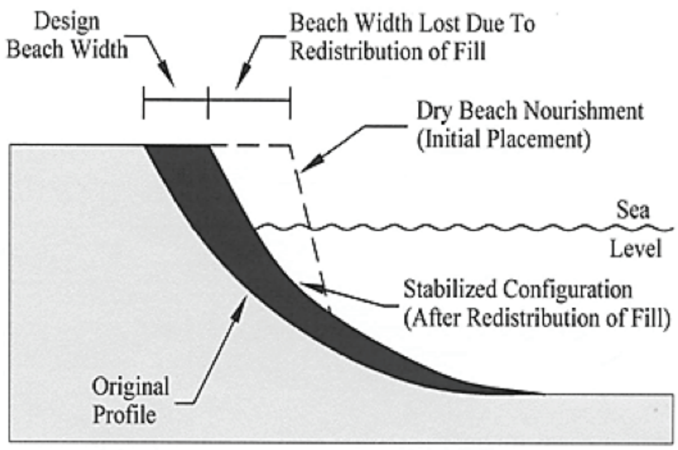
Profile nourishment involves placing the sand across the entire beach cross-section, both above and below water. Figure 16 shows beach nourishment at Miami Beach, United States which restored a declining tourist industry and paid for itself in revenue. Because the equilibrium condition develops immediately, there is little offshore redistribution of sand and changes in the dry beach width are minimal. We recommend that profile nourishment should be accompanied by artificial dune creation.

While the profile is adjusting to reach an equilibrium condition, the public may perceive the narrowing of the initial dry beach width as a sign of failure of the project. Therefore, public education at the onset of the project is beneficial so that the public understands that some initial alongshore and offshore sediment movement and erosion of the berm are expected. Also, the public needs to recognize that the sand remains in the littoral zone within the envelope of beach profile changes, the sand has not actually been "lost" (Figure 17). Although the profile adjustment will in most cases result in shoreline recession, the material will be still present in the active beach profile; much of it will be in the offshore bar and on the berm.

Figure 16. Beach nourishment restored a beach front to Miami Beach, United States

Source: Feydey (2005)

Figure 17. Schematic representation dry beach nourishment



Source: USACE (1992)

Beach Nourishment Design

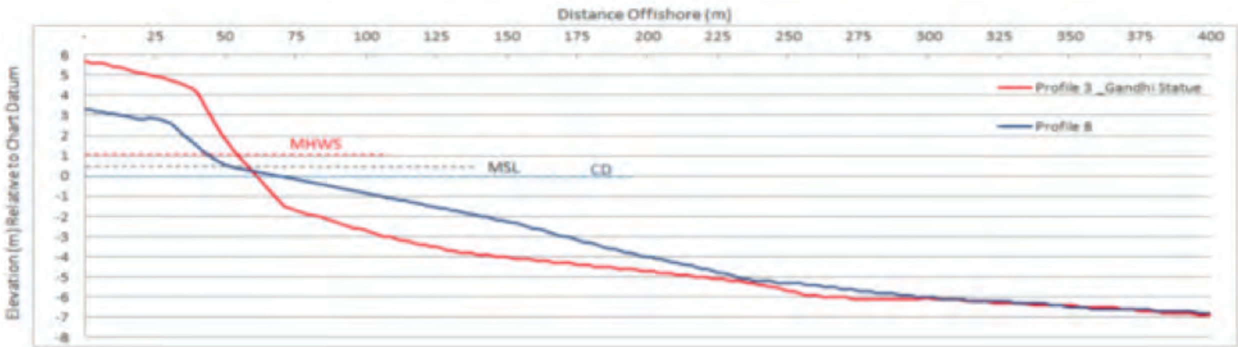
The designed beach profile should approximate the natural beach. There are three commonly-adopted methods to calculate the required volumes, i.e.:

- By surveying a nearby, healthy beach to find the profile;
- By applying the Dean formula, or;
- Seaward transfer of the existing beach profile to achieve the required beach width.

Healthy beach profile method: To estimate the natural profile, the first approach is to study nearby existing contiguous beaches which are not eroding. For this, detailed bathymetric survey(s) are needed on the eroding beach and the nearby beach. The difference in the profiles can be used to find the required nourishment volumes. The surveys should include the dune (or permanent or hard structures on the landward end) out to the depth of closure (the seaward limit of significant sediment movement). Offshore bathymetry data beyond the depth of closure may be required for wave transformation modelling and / or identification of offshore sand source for beach nourishment, but is not normally considered when calculating nourishment volumes.

An example is shown in Figure 18 where the healthy and eroding profiles have been surveyed and compared. Notably, the healthy profile has a concave up shape, while the eroding profile is concave down, but both profiles meet at the depth of closure around 6 m depth. The volume required to restore the profile was 350 m^3 / m of beach.

Figure 18. Measured cross-shore profiles on the eroding coast in front of a rock wall and further south on a healthy natural beach (Puducherry)



Source: Black and Mathew (2015)

Dean method: Dean (1991) developed a method for beach nourishment design based on the equilibrium beach profile model, whereby volumes of fill would be estimated by comparing the equilibrium profile of the borrow material with that of the native material. The relationship for the equilibrium profile given in Dean (1991) is:

$$y(x) = A\,x^{2/3}$$

where y is the depth in meters at a distance of x meters offshore. The parameter A is a scale parameter that depends on the sediment grain size. A can be expressed (Dean, 1991) as:

$$A = 0.21\,D^{0.48}$$

where D is the sediment grain size in mm. The Dean profile is concave down (Figure 19).

The use of the Dean (2002) concept also provides a direct method for estimating nourishment quantities for various wave and sand source conditions. Dean's method is based on assuming that both natural and nourished beach profiles conform to the characteristic parabolic equation given above. These concepts are generally accepted in the industry, although no allowance is made for the formation of an offshore bar.

Depending on the relative values of the coefficient A for the native and beach fill material, the nourished profile will intersect the native profile either landward or seaward of the closure depth *(h_c)* (Hallermeier, 1978) depending on the relative slopes and the amount of dry beach width *(B_d)* that is being reclaimed (Figure 19).

Profile intersection occurs when:

$$B_d\left(\frac{A_n}{A_b}\right)^{\frac{3}{2}} \leq 1 - \left(\frac{A_n}{A_b}\right)$$

Where A_n and A_b are the native and borrow sand scale parameter. For an intersecting profile, the fill material sediment grain size, D_b > native sediment grain size D_n and therefore, $A_b > A_n$. Conversely, for a non-intersecting profile, the fill material sediment grain size, D_b < native sediment grain size Dn and therefore, $A_b < A_n$.

Therefore, for an intersecting profile, the volume of beach material per meter length of beach required to create an increased dry beach width is:

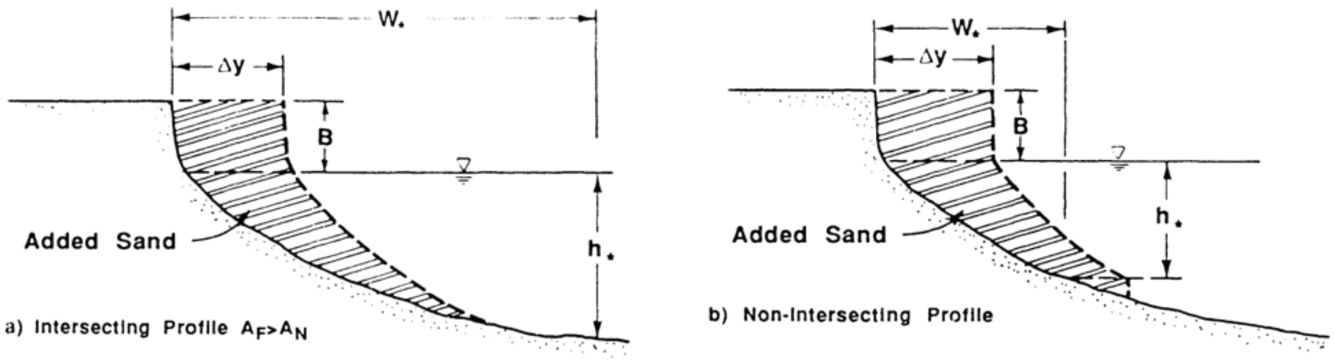
$$V_b = B_d R_C + \frac{A_n\, B_d^{\frac{5}{3}}}{\left(1 - \left(\frac{A_n}{A_b}\right)^{\frac{3}{2}}\right)^{\frac{2}{3}}}$$

And for a non-intersecting profile:

$$V_b = B_d R_c + 3h_c^{\frac{5}{2}}\,\frac{\left(\left(\frac{B_d}{h_c}\right)^{\frac{3}{2}} + \left(\frac{1}{A_b}\right)^{\frac{3}{2}}\right)^{\frac{5}{3}} A_n - \left(\frac{1}{A_b}\right)^{\frac{3}{2}}}{5}$$

The equilibrium profile methods do not account for a sediment deficit in the pre-project beach profile, which is common along eroded shorelines where beach nourishment projects are typically considered. This means that surveys of the profiles are essential. The methods also only account for volume below the berm elevation. Volume contained in the dune and upper beach must be added to the estimate. These methods are recommended for quick calculations, and to compliment calculations based on differences between the natural stable beach profile with the eroding profile.

Figure 19. Intersecting and non-intersecting profiles



Source: Dean (1991)

Beach width method: On sandy beaches the design profile may be obtained by simply shifting the existing profile seaward. The existing beach is transferred seaward by the amount of beach widening that is required (USACE, 1992) (Figure 20). Some care needs to be taken to ensure the new profile joins at depth with the existing profile and this is normally done by applying a Dean shape to the seabed.

Design Versus Construction Profiles

In general, the "healthy beach" method is recommended for finding the design volumes. The design profile is the cross-section that the equilibrated beach is expected to take after equilibrium is reached.

The construction profile is the cross-section that the contractor is required to achieve. Normally, the constructed beach contains enough sediment so that the design profile can be achieved after adjustment. In addition, the construction profile may be simpler and easier to build than the design shape for convenience and cost. Both the design fill and the advanced-fill quantities are normally included.

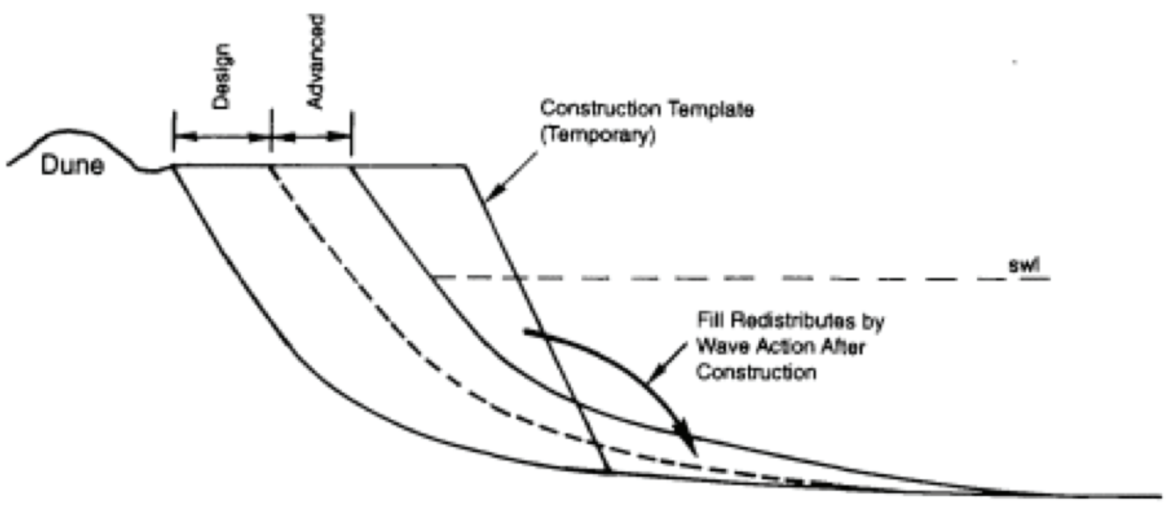
The construction cross-section is usually significantly wider than the design profile because of the steeper slopes and t's often steeper than the design cross-section because of budget limitations. Sand can be placed high on the beach, allowing wave and current action to adjust the construction cross-section to a flatter equilibrium slope; this usually occurs within the first few months to a year. Residents need to understand that the sand is not lost; the sand is simply slumping down underwater to fill the scoured profile (Figure 20).

Table 2. Initial construction densities on selected U.S. projects

Beach/Project	State	Yer	Volume (m^3)	Length (m)	Density (m^3/m)	Type
Coney Island	New York	1923	1,300,500	2,896	449	High
Mammoth to Long Branch	New Jersey	1999	3,289,500,0	5,310,8	619	High
Shark River to Manasquan Inlet	New Jersey	1999	2,371,500,0	4,989,0	475	High
Ocean City Phases I and II	Maryland	1988-1991	4,403,520	11,265	391	Intermediate
Wrightsville Beach	North Carolina	1965	1,751,636,9	4,267,20	410	High
Myrtle Beach	SouthCarolina	1986	652,385	13000	50	Low
Hilton Head Island	SouthCarolina	1990	1,800,000	10,500	167	Low
Tybee Island	Georgia	1975	1,700,000	4,100	418	High
Miami Beach	Florida Atlantic	1978 - 1982	9,200	17,000	543	High
Delray Beach	Florida Atlantic	1973	1,250,000	4,270	293	Intermediate
Longboat Key	Florida Gulf	1993	2,400,000	15,000	170	Low
Panama City	Florida Gulf	1999	6,800,000	28,000	244	Intermediate
Gulf Shores	Alabama	2001	1,600,000	5,000	330	Intermediate
Harrison County	Mississippi	1952	5,300,000	40,000	130	Low
East Island	Louisiana	1999 - 2000	2,007,809	3,246	618,5	High
Trinity Island	Louisiana	1999 - 2000	1,352,417	3,810	355,0	Intermediate
Sonth Padre Island	Texas	1994	1,221,000	6,750	181	Low
El Segundo to Santa Monica Pier	California	1946 - 1948	10,700,000	9,500	1,119	High
Torrey Pines	California	2001	250,000	500	500	High
Redondo Beach	California	1964	1,070,000	2337	450	High

Source: Campbell and Benedet (2006)

Figure 20. The construction template



Source: USACE (1992)

Nearshore Bar Nourishment

Nearshore bar nourishment involves the placement of beach fill material in a sand bar just offshore of the surf zone. To be successful, the placement must be within the active portion of the beach profile, typically around half the closure depth. The guidelines suggest that sand must be placed in depths less than 5 m, but this depth may be less in locations with small waves. The appropriate depth is less than 2.5 times the significant wave height averaged over the non-monsoon period (up to a maximum of 5 m).

The bar is dynamically connected to the beach, and so waves will bring the sand shoreward. It is always preferable to do bar nourishment at the start of the non-monsoon when long period waves are present to bring the sand inshore.

Nearshore bar nourishment is most likely to occur when sand is dredged, e.g. port channels or offshore sources.

Sources of Sand for Beach Nourishment

The source of sand is one of the critical elements of beach nourishment design. The quality of the sand controls the aesthetics, the cost, and the physical and ecological performance. As noted above, the perfect sand for beach nourishment would be sand that is exactly same or slightly coarser than the native beach sand. The match should include grain size and distribution.

However, in practice, the choice of material for a nourishment project may be controlled by availability and cost, with only an application of the “rule of thumb” that the median diameter of the borrowed material be equal to or somewhat coarser than the median diameter of the native sediment on the beach (Komar, 1998).

Dredged sand from harbors and inlets can be a sediment source if the dredged sand is uncontaminated and has a small fraction of fine grain sizes (such as silt and clay). In many cases, dredged sand in ports originally came from the beach and should be returned, rather than deposited in the deep water offshore (or on land) where it is permanently lost from the littoral zone. If the sand is muddy, then it may be deposited offshore on the bar, which allows the waves and currents to winnow out the muds, leaving the pure beach sand. However, the mud plume may be environmentally damaging in some locations.

Offshore sand deposits are another major source of sand for beach nourishment. Sand from these relict deposits is typically dredged and placed on the dry beach. The primary advantages of this approach include low cost, high placement rates on the receiving beach, and minimal disturbance onshore while the project is underway.

Investigations by Geological Survey of India have identified offshore sand deposits at many places off the Indian coast which are like the native beach sands (Sukumaran et al. 2010; Dinesh et al. 2014). Offshore sand deposits are yet to be utilized in India for beach nourishment.

In some beach nourishment projects, ebb tidal shoals have been mined as they are usually clean sands with grain sizes that match the beach sands. However, we need to be very careful when mining ebb tidal shoals for beach nourishment as these shoals usually shelter and feed the nearby beaches. Changing the natural shoal shape can lead to beach erosion. Indeed, this sand is normally transported out of the estuary naturally during high rainfall events, unless the estuary has been modified internally with deeper channels.

The sediment trapped behind the dams represents another source of sand for beach nourishment. The loss of sediment reaching the coast due to the damming of rivers is a well-documented phenomenon (Willis and Griggs, 2003). The use of this sediment accomplishes two objectives: re-establishment of the reservoir capacity and nourishment of the beaches.

Length of Beach to be Nourished

Nourishment projects should fill the whole sediment cell, if possible, due to alongshore spreading (Komar, 1998; Douglass, 2006). If a short section of beach is nourished, the sand will simply disperse through the whole sediment cell. The rate of alongshore spreading of the placed sand is a dominant engineering measure of the success of a project and is fundamental to determining success relative to economic measures as well. Numerical models are available for detailed analysis of the longshore dispersion of nourished sand placed on the beach.distribution.

Transport of Borrowed Sediment to Nourishment Site

Generally, there are two methods of transport and placement of borrow material for a beach nourishment: hydraulic and dry methods. Hydraulic methods are generally used for material obtained from marine-based sources and dry methods for material obtained from land based sources though the hydraulic method may be employed for land based sources, depending on the site conditions. If the borrow sand is stockpiled on land, the sand is trucked to the nourishment site and placement on the dry beach is obviously the most economical and efficient method. The sand delivered to the shore then needs to be groomed using earth moving equipment to the desired construction profile.

Monitoring

Following construction, the beach nourishment needs to be monitored to evaluate the project performance and to regularly assess the condition of the nourishment. These include shoreline and berm positions, total volume, and the response of the beach to a storm. Beach profile surveys, beach sediment sampling, shoreline surveys, satellite imageries, and wave and water level monitoring would provide an accurate and objective measure of the nourishment project's response. Without physical monitoring data, it is difficult to estimate how well the project is performing in comparison to the design. Most monitoring programs involve an early phase of more intensive data collection of beach profiles, sediment and marine ecology to evaluate project performance. After the project performance is established, data collection may be scaled back.

A full pre-project (baseline) bathymetric survey should be undertaken, followed by a post-nourishment survey. Surveys are then performed twice a year, typically at the end of monsoon (September for the west coast of India) and summer (February or March) to determine the full excursion of seasonal changes in the sub-aerial beach width and volume.

Re-Nourishment Requirements

In general, maintenance requirements for a nourishment project can be determined by calculating the sediment deficit in the full sediment cell. This is then compared to the volume of sand being placed on the beach to determine the percent effectiveness of the nourishment project. If the percentage is low, then the designer must determine the durability of the nourishment at the local site using computer modelling and assess the value of the project accordingly.

Nourished beaches typically require periodic re-nourishment, until the full sediment cell is filled. It was noted in Appendix 6 that beaches with small net sediment transport or short sediment cells are the most durable. Remember that sand is not being lost from the sediment cell and so each re-nourishment helps to bring the full sediment cell back to a healthy state. This will occur faster if the initial project spreads sand over more of the full cell.

Beach nourishment projects worldwide suggest that typical re-nourishment intervals range between two and ten years. However, if the weather conditions following the nourishment are generally stormier than average conditions, the time for re-nourishment may be shorter than the expected ten years. To lower the risk of a shortened re-nourishment interval, increased advanced-fill quantities beyond those actually required is an option if sufficient quantity of sand is available.

Sand retention devices may be used to prolong the effectiveness of beach nourishment. For example, according to Gold Coast City Council, the submerged reef at Gold Coast Australia (Black, 1999) has reduced their re-nourishment requirement from every ten years to at least every 30 years (John McGrath, Gold Coast City Council).

Relative Benefits and Impacts Compared to Other Options

The major benefit of nourishment projects is that unlike seawalls or other "hard" coastal protection structures, dunes and beaches dissipate wave energy during storm conditions rather than reflecting waves. The design of a hard structure affects how much wave energy is reflected; for example, vertical walls reflect more wave energy than sloping rock revetments. These reflected waves erode beaches in front of and next to a hard structure, eventually undermining and reducing the effectiveness of the structure and leading to expensive maintenance. This erosion also results in a loss of dry beach at high tide, reducing the beach's value for storm damage protection, recreation, and habitat. As shown in Appendix 9, hard structures also impede the natural flow of sand, which can cause erosion in downstream areas of the beach system. Dune projects, however, increase protection to landward areas while allowing the system's natural process of erosion and accretion to continue. In addition, because of their more natural appearance, dunes can be more aesthetically pleasing than hard structures (Figure 21).

In general, the impacts of nourishment projects are relatively minor when compared to hard structures and ultimately, the replacement of sand on the beaches will lead to stability in the future under climate change.

Figure 21. Well-established sand dunes in Karnataka and Tamil Nadu

Source: Padmanabhan (2014) and Arivanatham (2015)

Bypassing

Sand bypassing is the practice of transporting accumulated sand from the up-coast side of a sediment barrier. The construction of breakwaters and other shore normal structures can interrupt the longshore sediment transport and cause erosion of the downdrift coast. Sediment bypassing involves moving sediments from the areas of accumulation to the eroding area, e.g. across a port or entrance training walls. By maintaining the supply of sediment along the shore, sediment bypassing ensures that excessive downdrift erosion is avoided by nourishing the downdrift beaches.

Figure 21. Well-established sand dunes in Karnataka and Tamil Nadu

Source: Deepak (2014)

Figure 23. Beach nourishment through a rainbow pontoon at Visakhapatanam Port

Source: Deepak (2014)

Sand bypassing redistributes sand within the littoral system. This method does not represent a true source of sand because no new material is added to the system. Sediment bypassing associated with dredging operations at the entrance to ports (e.g. Visakhapatanam, India, Figure 22 and Figure 23) and inlets (e.g. Tweed River, Australia, Figure 24 to Figure 27) proved to be an effective means of nourishing downdrift beaches. However, sand bypassing has been rarely utilized in India, except at Visakhapatanam Port (and at Pondicherry for a short period), although there are many coasts where bypassing is needed.

Bypassing is sustainable and makes best use of material already in the littoral system as well as reducing un-wanted build-up. In the case of properly designed port breakwaters, bypassing also reduces deposition of material in navigation channels. Methods used to undertake bypassing include the installation of specially designed fixed plant, floating plant (dredgers) or land based equipment.

Sand bypassing considerations include: determination of the amount of sand actually in transport along shorelines and plant capacity - the hourly rate at which a plant can transfer arriving sand.

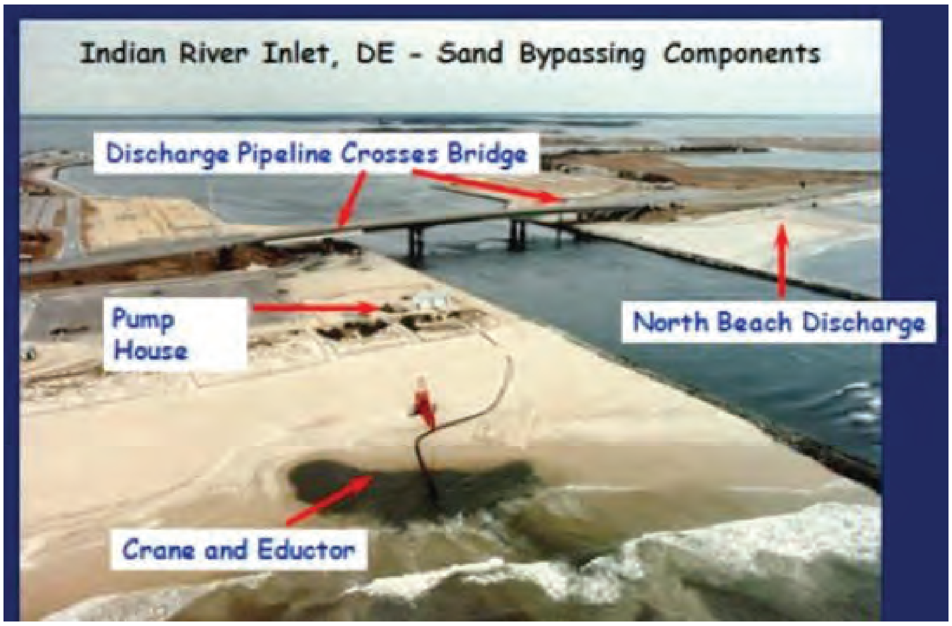
Many of Indian beaches have already been damaged unknowingly by interrupting the movement of sand along and to the coast. In addition, a large quantity of sand has been removed from the ship channels and dumped offshore or on land. Much of the man-made erosion can be stopped or at least minimized with sand bypassing methods – restoring the movement of sand along the beach past a structure.

Figure 24. The Tweed River Entrance Sand Bypassing Project (TRESBP), Australia

This project aimed to intercept coastal sand moving towards the entrance of the Tweed River in northern NSW and southern Queensland, Australia, and move it up the coast to meet the project objectives of: (i) to establish and maintain a clear navigation channel at the entrance to the Tweed River, and; (ii) to achieve a continuing supply of sand to the placement areas at a rate consistent with natural drift rates.

Source: Water Research Laboratory (2017)

Figure 25. Sand bypassing: artificial movement of sand across entrance channels



Source: USACE (1991)

Figure 26. Tweed River (Gold Coast, Australia) sand bypass system has pumped sand from the Tweed River mouth to beaches to the north to ensure the river mouth is safe for shipping, and to stabilize coastal erosion north of the river

Source: Naccache (2015)

Figure 27. Tweed River sand bypassing has resulted in a large build-up of sand seawards around 100 – 200 m, and created a world-class sandbar surf break

Source: Naccache (2015)

Back-passing

Sand back-passing involves the mechanical transport of material from a wide stable beach to an up-coast sediment-starved beach within a sediment cell. In effect, currents bring the sand, while pumps return it upstream. This method often is utilized in locations where the sand from an eroding reach moves alongshore and is deposited in a more sheltered area. Back-passing essentially "recycles" the sand back to the eroding beach and allows artificial adjustment to seasonal effects.

Figure 28. Sand back-passing, Noosa, Australia

Like sand bypassing, back-passing operations (Figure 28) redistribute sand within the littoral system and this method does not represent a true source of sand because no new material is added to the system. Sand back-passing has been rarely utilized in India. Sand back-passing is sustainable and makes best use of material already in the littoral system or onshore.

Considerations for sand back-passing include: ownership of the sediment source, beach uses, littoral drift patterns, environmental effects, would the removal of sediment from the accumulated area cause erosion at the site from which sand is being recycled. As the source sand for back-passing is from the same sediment cell, comparatively low environmental effects are likely, and thereby ecological or visual effects are also minimal.

Stakeholder consultation is essential as removal of sand may conflict with the aims of other stakeholders. If the sand volumes are moderate and the haul distances are short, the back-passing can provide a cost-effective method for beach maintenance. However, back-passing may be less efficient on wide sandy beaches, where large sand volumes will be required.

Back-passing Case Study: Noosa, Queensland, Australia

The city of Noosa (Australia) was built on a sand-spit between a headland and river entrance. These sand spits are low lying and typically unstable as the river entrance migrates in storms and calms. The history of Noosa Beach offers insights into how procedures for coastal protection and public attitudes have changed over the last five decades.

Initially no protection was provided to the houses, but regular over-topping led to the construction of a low rock wall with short groynes in 1967 (Figure 29). By 1972, the entire beach was lost in front of the rock seawall (Figure 30). The local community was complaining about the loss of the beach.

By the early 2000s, Noosa had commenced a back-passing operation whereby sand was shifted from the estuary to the beaches (Figure 31). The sand is swept back from the beach to the estuary under natural wave and current action. Tourism numbers coming to the beach rose substantially and the foreshore real estate is now one of the most expensive in Australia. A groyne was placed in the center of the beach to slow the losses of back-passing sand (Figure 31). Groynes can be effective when accompanied by nourishment in zones of strong net littoral drift.

Figure 29. Noosa, Australia with low rock seawall and short groynes (1967)

Source: Stockwell (2016)

Figure 30. Noosa's rock seawall. All the beach was lost (1972)

Source: International Coastal Management (2016)

Figure 31. Noosa beach groynes

Source: Google Earth

Ultimately, the selection of the best method will depend on the field and computer studies which identify the causes of the problem. The most common cause of erosion in India is the imposition of structures causing downstream sediment deficiencies, or the reduction of sand on the beaches due to dredging and mining. In these cases, new sand must be added to the beach or the cause must be eliminated. Even so, the lost sand may still need to be replaced to widen the beach and allow space for the natural processes to become re-established.

In many cases, the cause is just degradation of the dune, public trampling and general slumping of the upper beach. Dune care involves nurturing the dune with planting and stopping the public from damaging the dune. It does not involve the placement of new sand. However, there are many cases where the degradation of the dune leads to enhanced erosion. And conversely, the rehabilitation of the dune has led to stability of beaches that were formerly eroding. Potential dune care sites should be identified in the CMP's of each state as it is an inexpensive method to adopt with community participation.

Dune care will not protect a coastline which is eroding due to sediment starvation from upstream. The erosion will simply cut through the dune and the beach will be lost as seen at Thalapaddy, Karnataka (Figure 32). The root cause of the erosion at Thalapaddy needs to be overcome, rather than relying on the dune.

Nourishment will be successful in cases when the cause of the sediment deficiency is cured (e.g. bypassing of sediment is initiated past a disruptive port). However, nourishment is also highly effective when the full sediment cell is treated or when the net longshore transport rates are small.

Critics may claim that nourishment has "disappeared" but they may not realize that some of the sand has slumped underwater to re-create the sub-aerial profile. In other cases, the sand may be lost longshore due to strong longshore drift. The designer must be aware of the size of the sediment cell, the sediment deficiency in the full cell, the longshore transport rates and the causes of the erosion.

If studies are carefully done, nourishment is expected to help most beaches in India if the amount of sand added is sufficient to sustain the full sediment cell, either in the first nourishment or with a systematic re-nourishment program that eventually fills the sediment cell. Nourishment projects will only fail if insufficient sand is added or the designer is unaware of the sediment dynamics. As noted already, nourishment is less viable if sand upstream is being blocked by a structure, without being bypassed, on a beach with strong net longshore transport.

In long sediment cells, structures may be needed to sub-divide the cell. However, these structures will not solve the problem in many cases if they rely on capture of natural sand supplies and they may have a substantial impact downstream. Most structure projects in India, particularly groynes and offshore reefs / islands, need to be accompanied by a nourishment program.

Figure 32. Beach erosion at Thalapaddy, Southern Karnataka

Source: International Coastal Management (2016)

Conclusions

Sand-based solutions are adaptable to climate change and have the least environmental impact. They acknowledge that the "best form of coastal protection, is the beach". Sand losses due to mining and the impacts of coastal structures have led to sand shortages on many Indian beaches. The sand-based solutions with nourishment overcome these deficiencies and bring the beach dune system back to a healthy state.

Nourishment will typically fill the full sediment cell. Design volumes must allow for sand redistribution both offshore underwater and beyond the nourishment site. In the long-term, this sand is not lost, and it will protect the full sediment cell.

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CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 2

APPENDIX 8

SEAWALL LIMITATIONS IN A CLIMATE CHANGE SCENARIO

ADB TA-8652 IND:

CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

APPENDIX 8
Seawall Limitations in a Climate Change Scenario

The seawall, one of the most known means of coastal protection in India, is a construction-based solution and ranks as the hardest solution on the 'Environmental Softness Ladder' (Volume I). In this Appendix the design, strengths and weaknesses of seawall as a climate resilient coastal protection measure are considered with case studies.

Engineering Design of Seawalls

The basic design and construction methods are generally available in coastal engineering manuals (United States Army CERC, 1984; Bruun and Nayak, 1980; USACE, 2006). The 'Technical Memorandum on Guidelines for Design Construction of Seawalls' (2010) of the Central Water and Power Research Station (CWPRS) provides essential guidelines for Indian practice, with the precautions to be taken during design and construction of seawalls. These guidelines are based on the experience of CWPRS in India, both in practice and in the laboratory. The Memorandum lists the various methods of shore protection and highlights design considerations and the usual steps needed to design an adequate and efficient rubble mound seawall / revetment. Deviations in design and construction may occur, such as position of seawall, under-design of armors, toe protection, inadequate or no-provision of filters, overtopping due to underestimation of design wave or the maximum water level, rounded stones, weak pockets, discontinuities in sea wall, armor in single layer and / or pitched. Use of chains of concrete blocks, gabions (stone-filled cages) or flexible bags or nets, nylon or coir bags filled with sand / gravel, concrete pipes, octagonal concrete blocks arranged in gabions and geotubes in the armor layer have been adopted by CWPRS in different parts of the coastline. Finally, the planning of a construction program and maintenance are considered in the Memorandum.

The Technical Memorandum of CWPRS does not, however, consider the decision-making in relation to selection of a seawall as the preferred coastal protection solution. The Memorandum also does not account for climate change impacts or specify the best climate resilient coastal protection method to be adopted in a given situation. Volume I of the present Climate Resilient Coastal Protection and Management Guidelines provides these decision-making tools.

The Central Water Commission (CWC) (2015) (see Appendix 4) recommended seawalls to be "as streamlined as possible" with nourishment to maintain the beach. Though the purpose of the beach (natural or nourished) is not explained therein, a well maintained all season beach is a positive measure in the light of climate change as explained in the Appendix 7.

Effectiveness and Impacts of Seawalls in India

Globally, seawalls have been successful for protecting the land, but the beach is often lost. There are several reasons for the loss of the beach:

1. The natural shape of the beach with a sandy beach face, berm and dune is completely destroyed by the wall. This puts the entire beach system out of equilibrium.

2. Intense wave breaking on the seawall creates strong, localized turbulence at the base of the wall. Sand is lifted and carried away by currents. The beach at the toe erodes and sometimes the wall collapses.

3. Deeper water due to erosion in front of the wall allows larger waves to reach the structure, leading to more intense wave breaking, more turbulence and more erosion.

4. Waves are reflected from the wall which is steeper than a natural beach. These big reflected waves travelling offshore disrupt the natural processes that bring sand from the offshore sand bar to the beach (especially during conditions of swell). Asymmetry of the wave orbital motion under swell brings sand shoreward at these times, but the reflected waves cancel out some / all of the onshore net movement.

5. The walls produce "end effects" whereby scour occurs not only on the front of the wall but also at the ends of the wall. This scour is often repaired by lengthening the wall and new end effects develop at the new end of the wall etc.

Overall, the walls have been proven throughout India and internationally to cause the beach to be lost (see examples from Puducherry, Karnataka, Kerala and New Zealand in Figure 6).

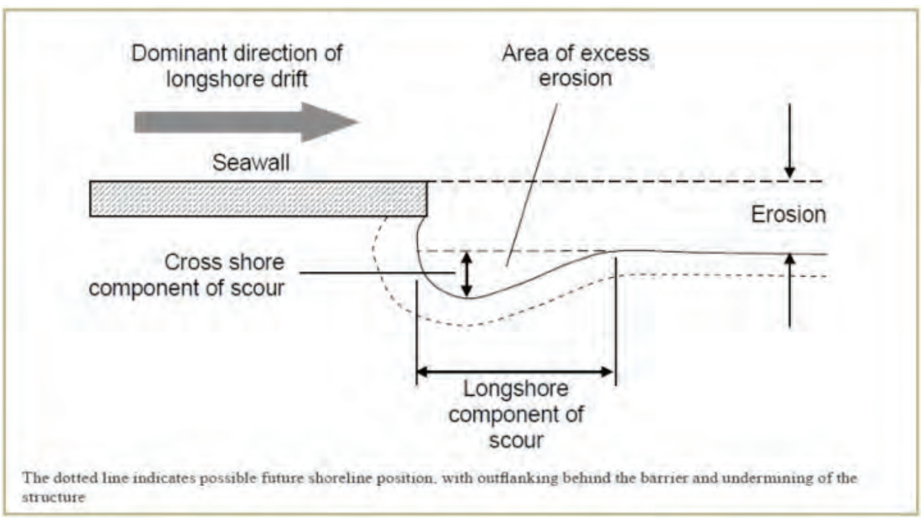
Conclusion: Seawalls protect the land, and harm the beach. Walls and beaches are not compatible.

However, seawalls in India remain the most commonly adopted coastal protection structure. For example, in Kerala there is already about 400 km of seawalls, and they have been built in most coastal states in India. The seawall is relatively inexpensive and easy to construct and they protect land-based infrastructure.

Seawalls are commonly called 'coastal protection' structures. More correctly, they are 'land protection' structures (United States Army, 1984; CWC, 2003).

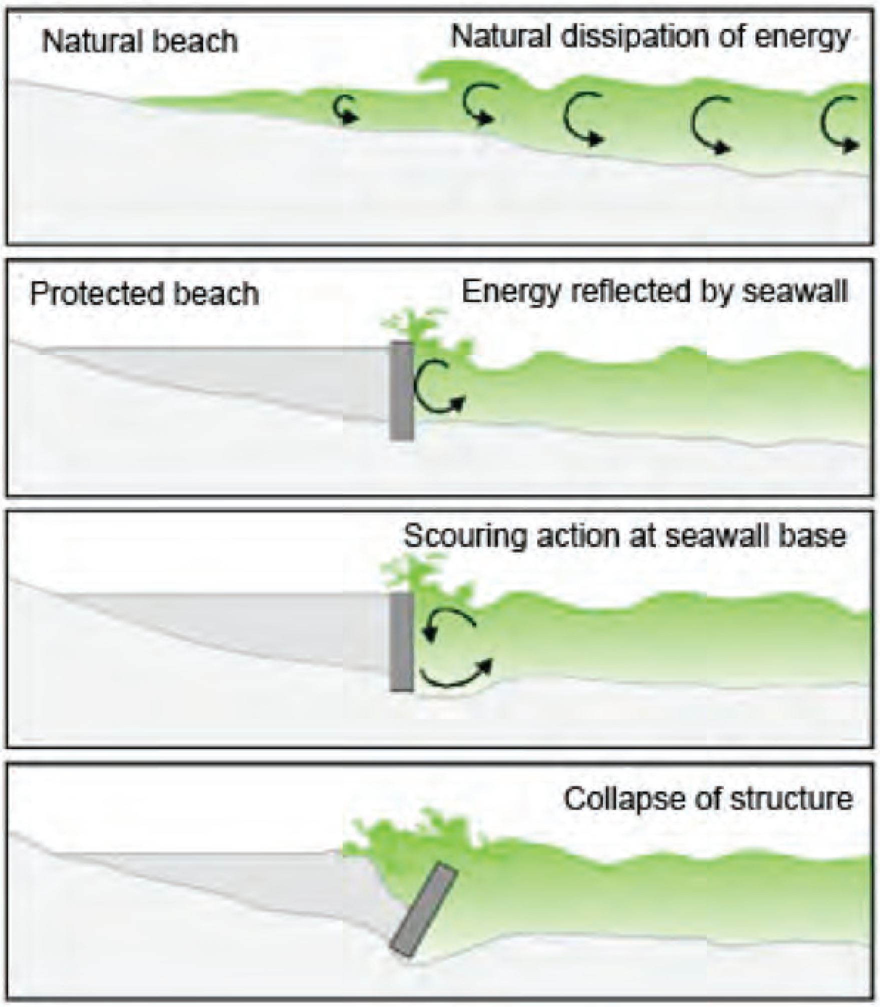
CWPRS considered the practical difficulties / deviations encountered during the design and construction of seawalls. Often the seawall is built once houses and infrastructure are threatened by erosion. By this time, the infrastructure is well forward on the beach and so there is usually very little space for the proper location of the seawall as instructed by CWC (2003) or CWPRS (2010). Thus, the seawall is normally built on the eroding beach itself. When the seawall is too far seaward, all case studies in India have shown that the beach is lost in front and the seawall does not stop the erosion; instead it continues underwater (see case studies below). Many scientific and practical engineering publications have shown this to occur. Seawalls are heavily restricted in many parts of the world, including New South Wales, Australia.

Figure 1. End effect due to seawalls



Source: McDougal et al. (1987)

Figure 2. Scour at the base of a seawall



Source: Spiegel (2013)

Figure 3. Typical seawall showing the end effect and loss of beach in front of seawall

Source: Spiegel (2013)

Figure 4. Massive seawall providing beach protection, but the beach is lost

Source: McNeill et al. (2014)

Figure 5. The Dutton Way in Portland Victoria. The port blocked the upstream supply of sand and so the wall was built to protection properties. The beach has been lost and property values are low

Source: Spiegel (2013)

Figure 6. The beach is lost in front of the rock walls at (a) Puducherry, (b) Ullal, Karnataka, (c) Kovalam, Kerala, and (d) Dunedin, New Zealand

Source: (a-c) Photos taken by consultant J. Mathew (2017) and (d) Google Earth

Limits to Adaptation for Seawalls

Potential adaptations to climate change have physical, economic and institutional limits. For example, there are practical limits to the height of seawalls. In cyclone prone areas, the rock seawalls are already as much as 12-15 m high, and many seawalls in India are already 5-10 m above the high tide line. They require large stones to reduce the constant maintenance caused by direct wave breaking on the structure.

Hudson Formula

Hudson's formula is used by coastal engineers to calculate the minimum size of rock armor blocks required to provide stability characteristics for rubble structures such as seawalls under attack from storm waves. The equation was developed by the United States Army Corps of Engineers, Waterways Experiment Station, following extensive investigations by Hudson (1953, 1959).

The Hudson formula is given by:

$$W = \frac{\rho_r g H^3}{K_D \Delta^3 \cot \alpha}$$

Where W = weight of armor unit (in Newton)

H = Design wave height at the toe of the structure (m)

K_D = Dimensionless stability coefficient deduced from laboratory experiments for different kinds of armor blocks and for very small damage. K_D = around 3 for natural quarry rock and K_D = around 10 for artificial interlocking concrete blocks

α = Slope angle of structure

ρr = Mass density of armor (kg / m3)

g = Acceleration due to gravity (m / s2)

Δ = Dimensionless relative buoyant density of rock = (ρr / ρw) – 1 = around 1.58 for granite in sea water

ρ_w = Mass density of seawater (kg / m3)

In the Shore Protection Manual (CERC, 1984) recommended the use of $H_{1/10}$ as the design wave height in the Hudson formula. Accordingly, the original Hudson formula was rewritten as follows using $H_{1/10}$ = 1.27 Hs, in terms of the stability parameter, $N_s = H_s / (\Delta D_{n50})$:

$$\frac{H_s}{\Delta D_{n50}} = \frac{(K_D \cot \alpha)^{1/3}}{1.27}$$

Where:

H_s is the design significant wave height at the toe of the structure (m)

D_{n50} is the nominal median diameter of armor stone = $(W_{50} / \rho r)^{1/3}$ (m)

At a water depth of 2 m in front of seawalls (where the tide is 1 m and storm surge of 0.2 m) the breaker height is about 2.5m. According to the Hudson formula, the armor stone weight should be 1.75t, which is an acceptable and obtainable rock size.

However, scouring due to the presence of the seawall could increase the water depth to 4 or 5 m. In addition, if sea level rises by 0.5 m plus storm surge of 0.5 m and tide of 2 m, the total water depth can exceed 7 m on a steep seawall.

> To prepare the seawall for climate change, the armor stone requirement according to the Hudson formula would be as much as 18 t. Such rocks are unavailable, expensive of cannot be transported. This means that increasing the height of the seawall under climate change is not an ideal adaptation option).

Figure 7. Seawalls in Gujarat, (left) Dwaraka and (right) Dumas, with low gradient and long toe

Source: Photos taken by individual Kanani (2015)

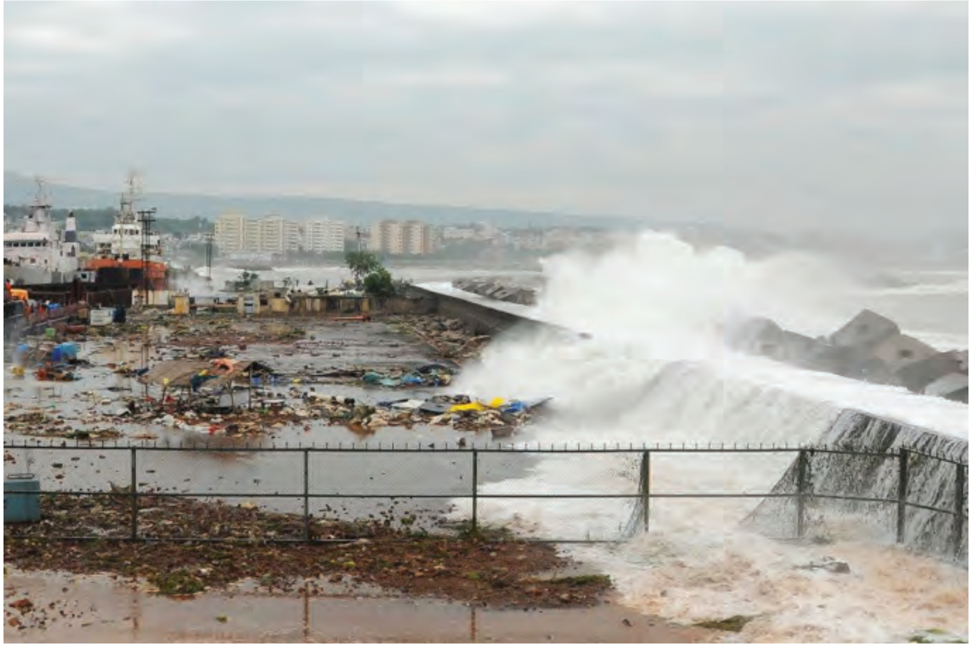
Engineers have modified the designs of seawalls to incorporate reduced frontal gradient or to build a long underwater toe (Figure 7). The toe is designed to stabilize the wall and force waves to break on stone which is underwater and therefore more stable. However, the cost of these walls and their environmental impacts are substantial. Erosion around the toe can cause the rock to sink into the sand or subside and the toe may need to be maintained or enlarged. Such a structure might have a base which is greater than 50 m wide, which spans the full beach zone (Figure 7). The natural sediment transport here is highly disrupted.

Moreover, under climate change, the maintenance of seawalls is likely to grow due to the expected increase in sea level rise, storm events and storm intensity. Increased wear and tear on coastal infrastructure will require more frequent maintenance and replacement.

Visakhapatnam District

Existing rock seawalls in the Visakhapatnam District are more than 15 m high and constructed with exceptionally large concrete blocks, as rocks of this size were not available. And yet, they are still being overtopped (Figure 8).

Figure 8. Existing rock seawalls in the Visakhapatnam district are already some 15m high, but are still overtopped during cyclones



Source: Narendra (2013)

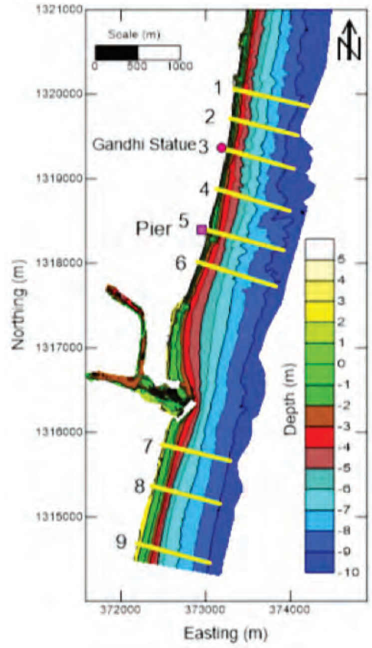
Puducherry

Significant erosion has occurred in Puducherry over the last two decades, which has resulted in substantial ad hoc protection works using groynes and rock seawalls (Figure 6a). So far, the coastal erosion has severely impacted more than 10 km of the coastline destroying houses and villages and is advancing northwards. Local opinion is that the current seawall protection has proved to be effective preventing erosion of the land but residents have lost an important beach and tourism hub for over 20 years. The old and beautiful beaches of the city are absent.

Nine cross-shore profiles north and south of the Puducherry Port were extracted from a detailed bathymetry survey conducted by the National Institute of Ocean Technology (NIOT, 2015). The profile locations are shown in Figure 9. Figure 10 shows that the zone in front of the seawall is highly eroded underwater compared to the natural beach (Figure 10). The differences show the seawall which is steeper than the natural profile near the shore, and the severely scoured profile offshore of the wall. No dry beach or berm is present in front of the seawall. Thus, erosion has continued underwater while the beach has been lost in front of the seawall. The sand quantities along the city foreshore are now so low that an attempt to protect the coast with groynes also failed to produce any positive results.

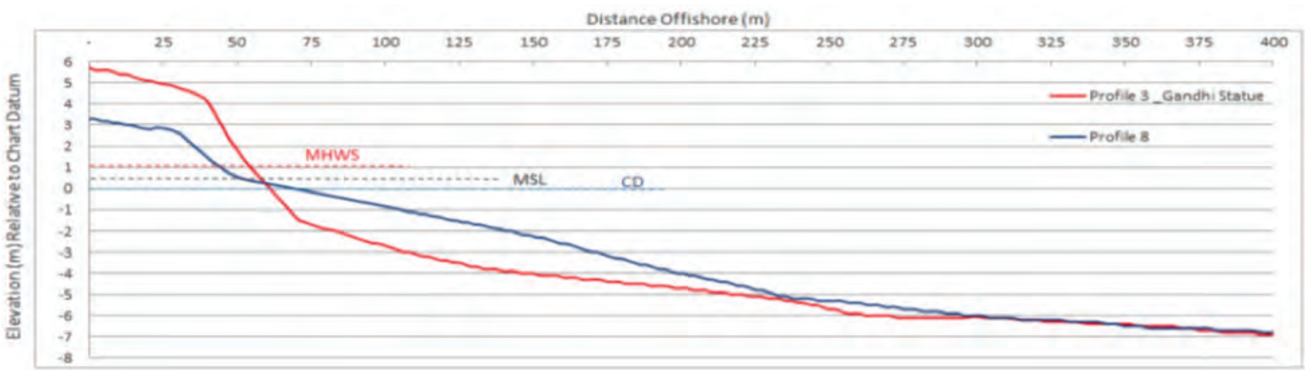
The history showed that nourishment is required to bring back the beach. A recently-approved solution for Puducherry incorporates a nearshore reef plus beach nourishment (Black and Mathew, 2016; Mathew et al., 2016).

Figure 9. Bathymetry of Puducherry and locations of cross-shore transects used for the analysis



Source: Black and Mathew (2015)

Figure 10. Measured cross-shore Profile 1 across the Gandhi statue in Puducherry and profile 8 south of Puducherry breakwater on a healthy beach



Source: Black and Mathew (2015)

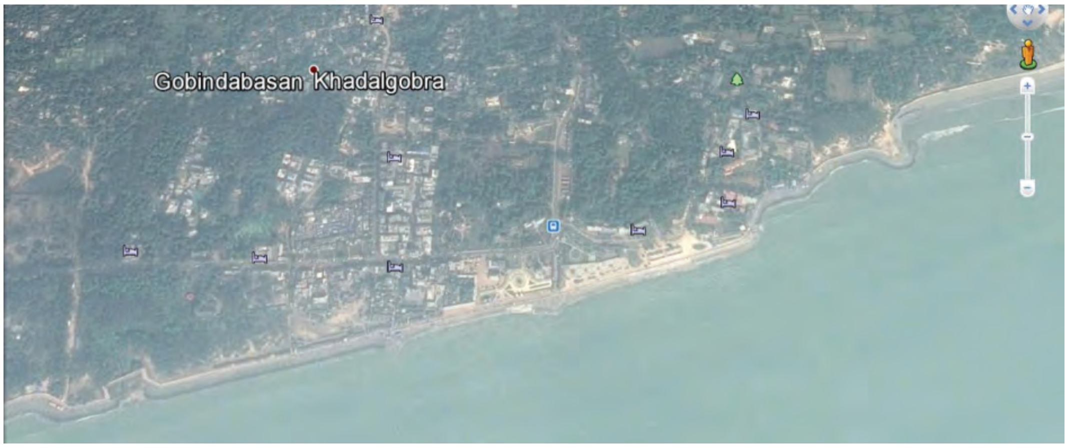
Digha, West Bengal

Digha, a tourist and fishing center in West Bengal, is another classic example of extensive seawalls and never-ending experimentation extending over several kilometers (Figure 11). The fishing harbor was constructed in the Digha River and since 1960 beach erosion was noticed at the tourist township. The resorts and hotels are almost at the shore and to protect them 3.5 km of seawall was constructed from Jatra Nalla to Sea Hawk Hotel during 1973 to 1982. The seawall replaced the encroached and eroded sand dune. The end erosion on the hotel side invited another 500 m of seawall in 2002. Bhandari (2002) reported that the lowering of the nearshore profile continued threatening the seawall with no trace of a beach during the entire monsoon season. Waves were overtopping.

A critical evaluation of the design and performance of the seawall by Bhandari (2002) concluded that the eastern side eroded further and the sand dunes on the downstream also started eroding. The erosion of the extensive dune system on the east invited several other interventions and experiments, particularly with geotubes. Bhandari (2004) recommended a groyne on the western side of the inlet. At the same time, the Digha inlet was facing siltation problems.

This case study shows that the unscientific use of a seawall in the beginning has resulted in the elimination of the attractive natural beaches and dunes, and further coastal protection experiments.

Figure 11. The Digha region of West Bengal



Source: Google Earth

Valiathura, Kerala

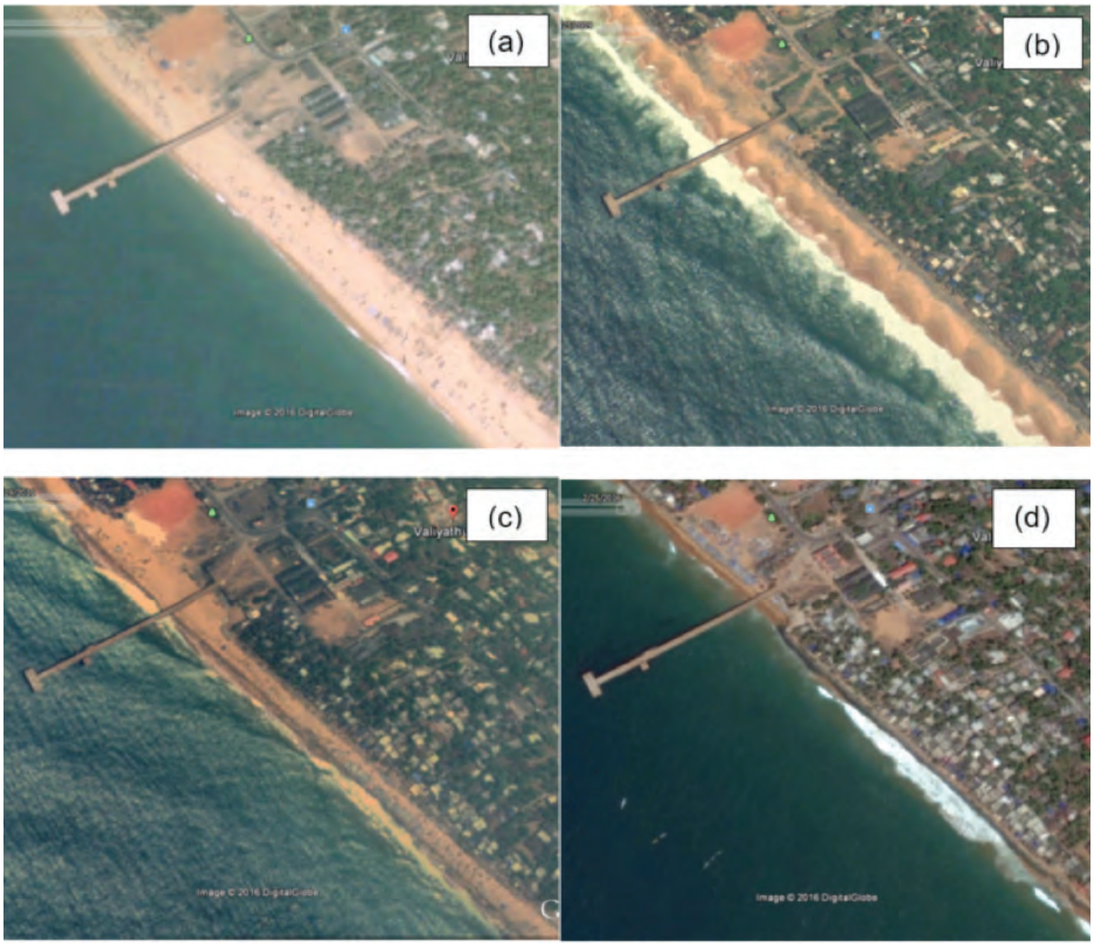
Valiathura, located along the southern Kerala coast is typical of a tropical coast which has waves as the predominant hydrodynamic force controlling the coastal processes. The wave climate dominated by the monsoonal waves has 60 to 80% above 2.5 m height during June-September (Baba and Thomas, 1987). The highest nearshore wave height recorded for this coast is 6 m. The wave periods generally vary between 5 and 18 seconds with lower periods (<10s) during June and July. The waves during the peak monsoon period are from 240 - 270° N while waves from 190 - 210° N dominate the remaining period of the year (Baba and Thomas, 1987).

The coast had a wide beach all along with a width of about 60 - 70 m on either side of the pier at Valiathura in 2003 (Figure 12a). Fishermen are settled on the hinterland areas both sides of the pier. Said to be for the protection of the fishermen settlements, a seawall was built on the southern side in 1980. This seawall was located in the backshore near the monsoon berm leaving a frontal beach of width about 50 m and was initially protecting the coast. However, end erosion occurred in the north during the monsoon (Baba and Thomas, 1987). From 1980 to 2000, the seawall was extended on the northern side. Probably due to demand from the fishermen residing on the southern side of the pier, a seawall was built again on the southern side after 2006.

Figure 12. Valiathura coast: (a) 8/1/2003 and (b) 25/2/2016. Beach on either side of the pier including the northern side of seawall had 60-70m width in 2003. The seawall on the southern side was built after 2006, and by 2016 the beach vanished from the southern side

Source: Google Earth

Figure 13. Coastal sector around and south of Valiathura pier: (a) 8/1/2003 wide beach of 60m width; (b) 25/9/2009 after construction of seawall; (c) 19/3/2011 beach build up is not up to the expected level, and; (d) 25/2/2016 beach is absent and the end effect is see

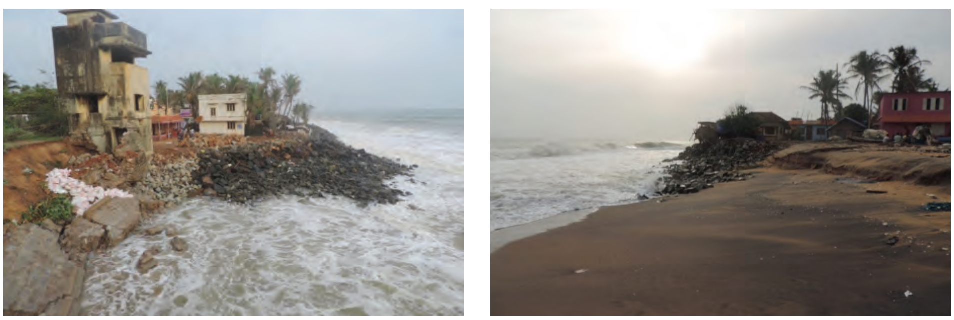


Source: Google Earth

There has been a drastic reduction in the beach width subsequently as can be seen from google images for the period 2009 to 2016 in Figure 12. In addition, the end effect of the seawall has caused severe erosion on both the sides of the pier. A flash point was reached on 20 May 2016 when the severe erosion due to the end effect took away all material between the pier and the seawall end. The wall has collapsed and the port building is partly damaged (Figure 13a). The erosion due to the end effect of the seawall on the northern side is seen in Figure 13b.

The case study shows the degeneration of a pristine beach at Valiathura. The seawall constructed in 1980 in the southern side has vanished and the seawall constructed recently is also destabilizing. The end effect of the seawall has caused loss of infrastructure in the hinterland.

Figure 14. End effect due to seawall on both sides of Valiathura pier: (a) collapse of compound wall, and (b) erosion in northern side



Source: Nair (2016)

Submerged seawall: A long and narrow wall placed parallel with the shore in the zone between the mid-tide line and breakpoint zone on a beach. These often consist of just two or three small geotubes placed along a distended length of the shoreline. They have very different dynamics to "reefs" but are more similar to seawalls.

Submerged seawalls have been constructed in India.

At North Mumbai, a continuous row of 3.0 m dia and 1.0 m dia geotubes were placed below the low tide line. The tidal range in this area is about 5.2 m and the crest of the geotubes was at mean sea level of +2.6 m. They were expected to arrest the nourished sand on the beach (well-graded coarse sand). Unfortunately, no monitoring surveys are available, however the proponents reported good results.

At Dahanu Maharashtra, geobags designed by CWPRS were placed near the low tide line, along more than 1 km of shoreline. Unfortunately, the bags were either damaged or they sank into the sand and there was no evidence of the submerged seawall about two years later.

On the east coast at Cuddallure, Tamil Nadu, another submerged seawall project using geotubes in 4 m water depth remains incomplete after the bags proved to be difficult to fill, unstable in the waves and prone to burial.

A "seawall" project made of geobags on the beach at Candolim, Goa suffered sinking, wave damage, geotextile fraying problems. The geotubes were no longer present two years after the project installation.

While there are few examples, it would appear that the geotube seawalls are subject to rapid sinking into the sands (due to their large volume to footprint (surface area) ratio) and other damage.

Discussions

Seawalls are high up on the environmental softness ladder (i.e. the hardest option) and are unlikely to be suitable in the future for several reasons. In relation to design wave heights, the seawalls block land erosion, but erosion continues underwater in front of the walls. With a deeper profile offshore, the walls are attacked by larger waves. The problem is projected to be more severe under climate change with larger waves, sea level rise and surge levels (Appendix 13). It is demonstrated that the rock sizes required for stability of the seawall will become untenable or extremely costly in the future.

In addition, seawalls prohibit access to the sea, the rocks are dangerous and slippery, fishermen using boats or nets are mostly unable to work effectively without great risk, the walls are known to subside due to toe scour or collapse due to wave impacts. They create erosion offshore underwater. The seawalls need regular replacement or topping up (Baba and Thomas, 1987). The end effect (or beach scour where the wall terminates) makes it necessary to continue lengthening the wall each season. The seawalls also bury the beach causing major environmental impact. They prevent the natural adjustments in beach orientation needed for a stable beach.

Conclusion: The seawall ranks worst of all coastal protection methods when preparing for climate change.

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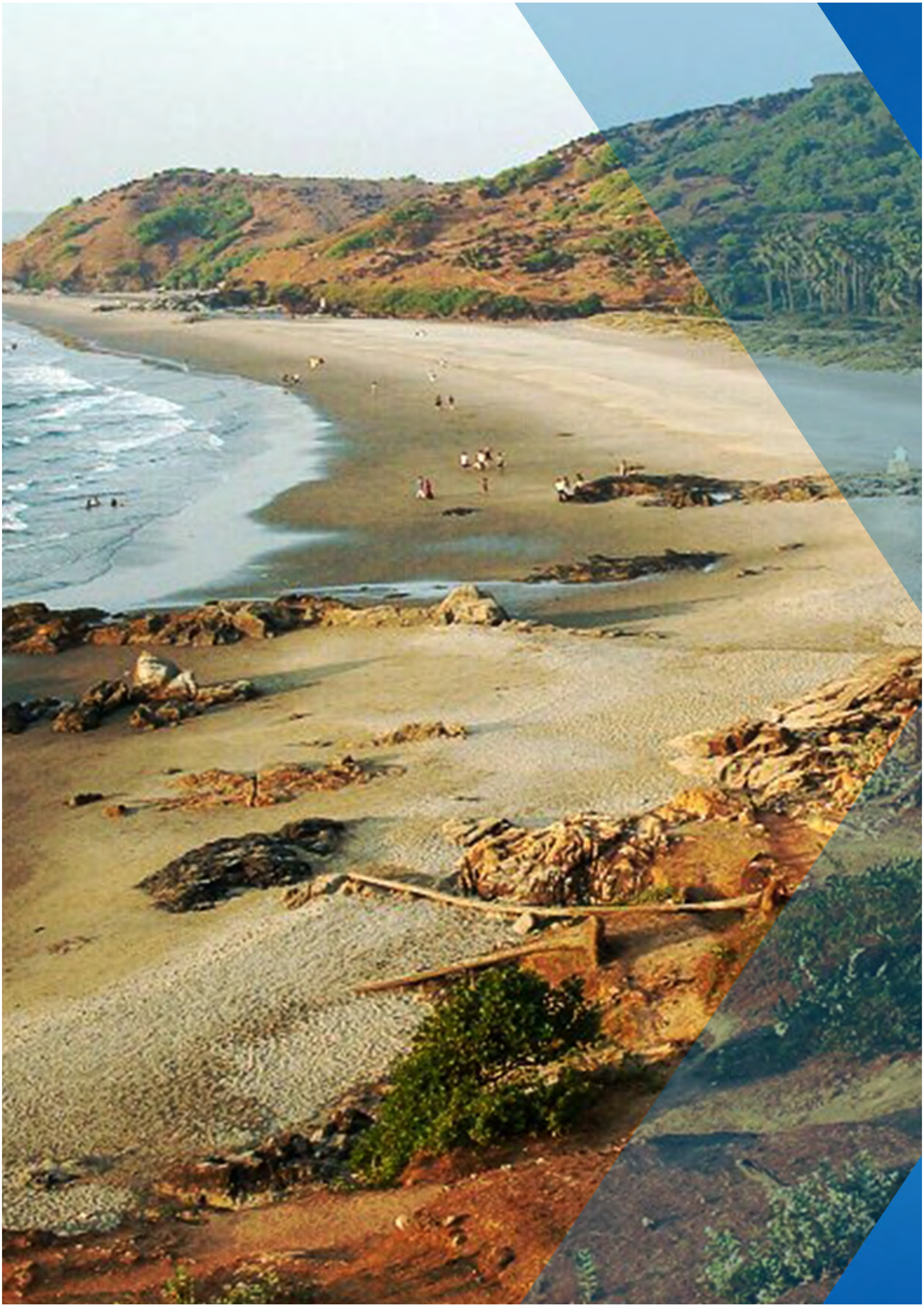

CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 2

APPENDIX 9

GROYNE DESIGN UNDER CLIMATE CHANGE

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APPENDIX 9
Groyne Design Under Climate Change

Introduction

Groynes are walls running cross-shore, sometimes at an angle to the coast but normally perpendicular. A typical groyne is built from above the high tide level to around 3 to 5 m depth offshore. They are distinguished by a crest that is above the water level, although some may taper down offshore. Groynes are typically constructed using heavy rocks or wave-dissipating elements made of concrete. The groyne width is as narrow as possible to reduce the volume and cost, while remaining stable under wave attack. Normally, they are wide enough for a truck to drive along the top and drop rocks at the tip during construction, with sloping sides for stability.

> The generic category of "groyne" may have many shapes including T-groynes, Y-groynes, or fish tailed groynes. "Groyne fields" have more than one groyne along the shore.

General theory

Groynes have been tested over much of the world but most scientific investigations are from temperate regions (USACE, 2006; Bull et al., 1998; Griggs and Tait, 1988) where the wave climate is more variable. In India, the beaches are subjected to two distinct and long seasons, the monsoon (wet) and non-monsoon (dry).

Theoretically, the groyne acts like a natural headland. The purpose is to interrupt longshore sediment transport. Very long groynes can fully partition the beach into smaller sediment cells. Shorter groynes allow sediment bypassing and are usually built to slow (rather than block) the longshore drift of sediment.

The first stage of a successful design is the analysis of local wave and sediment transport conditions at the site. This should include longshore and cross-shore transport, seasonal variations, beach morphology and a range of controlling factors like waves, currents, winds etc. and their projections under climate change (Appendices 11 and 13). A designer must choose four key variables: groyne elevation, length, spacing and number.

Elevation: The groyne elevation in India has been normally 3 to 5 m above high tide water level so that the groyne blocks all longshore drift at the beach. Considering optimum sand volumes on the beach and minimal impacts on the down-drift beaches, the crest elevation is one variable which determines the ratio of sediment bypassing to the volumes trapped in the groyne compartment. The sea level rise and other impacts on the coast as explained in Appendices 13 and 17 also need to be considered.

Length: Normally selection of groyne length is based on the percentage of longshore sediment transport to be captured. Sand will pass around the tip of very short groynes (e.g. 30 m). Long groynes (e.g. 500 m) may cause a total blockage, like a large port breakwater. Downstream impacts get larger as the trapped volume increases.

Spacing: The spacing between groynes is a more complex function which depends mostly on groyne length and seasonal beach rotation. In the seasonal wave climate of India, the waves come from different directions in the wet and dry seasons and beaches within the groyne compartments rotate so that their shore-normal is closer to the neutral wave power direction every season (Figure 1). That is, the beach tries to align into the waves within the groyne compartments. The rotation occurs because sand is pushed to one end of the groyne compartment by longshore currents in one season and then pushed to the other end when the seasonal wave directions change. The amount of sand moved will depend on the strength of the longshore currents which, in turn, depend on the intensity, orientation and height of waves. Thus, each site will display different rotations.

The seasonal beach rotations need to be understood and allowed for in the design of the groynes so that infrastructure within the groyne compartment is not attacked by waves each season. Black and Mathew (2016) found that the beach rotation on the east coast of India near Pondicherry was proportional to the length of the groyne compartment (Figure 2). They presented the following equation to predict rotation:

$$\theta = -9.832\ln(L) + 73.51$$

where L is the groyne spacing (beach length) (m). The formula above shows that short compartments will experience larger rotations and so wider spacing is beneficial.

A groyne field is often defined by the ratio of groyne length divided by groyne spacing (L / W) (Figure 3). Most fields adopt values of less than 0.5, i.e. the spacing is at least twice the length of the groyne. However, the rotation formula above shows that wider spacings lead to smaller rotations in India and so values of L / W of around 0.1-0.2 will be more appropriate in many locations, although a groyne field with short lengths and wide spacing may show limited benefits at the shoreline. Thus, the designer must find the best compromise for groyne spacing, normally within the range L / W= 0.1 to 0.5.

Number: The final decision is the number of groynes. The beach is expected to erode beyond the groyne field due to the interruption to longshore sediment transport. Thus, the Guidelines note that groynes within a section of a sediment cell will cause problems for downstream beaches (see case studies below). If groynes are selected as the preferred method of coastal protection, the designer must plan to place groynes along the entire sediment cell (unless very short groynes or low-crested groynes are being adopted). The number can be calculated by dividing the sediment cell length by the chosen groyne spacing.

Numerical modelling will be used to test design over a range of environmental conditions.

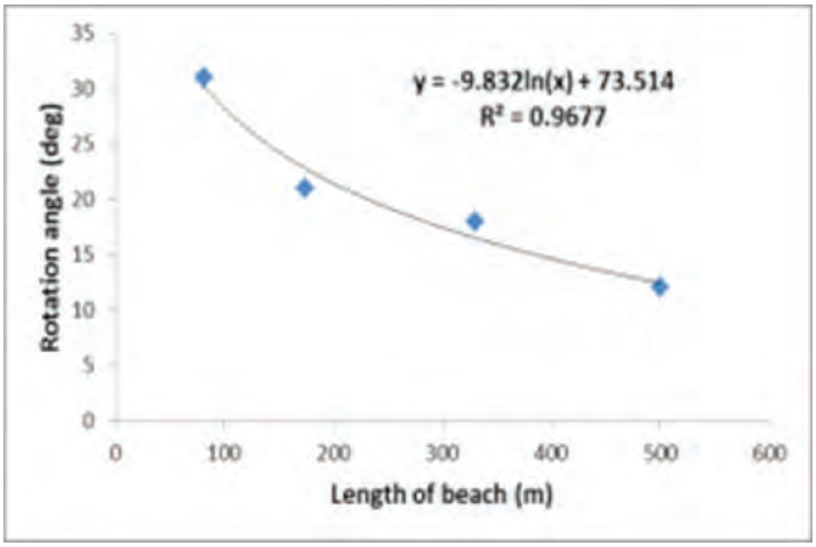
Figure 1. The beach in groyne compartments rotates seasonally in synchrony with the wave direction. The two yellow lines show the beach orientation after the NE monsoon and after the SW monsoon.

Source: Google Earth

A well-designed groyne field with correct spacing and length can substantially slow sediment erosion within the groyne compartment, particularly if the compartments are initially filled with nourishment. However, groynes have some well-known negative effects:

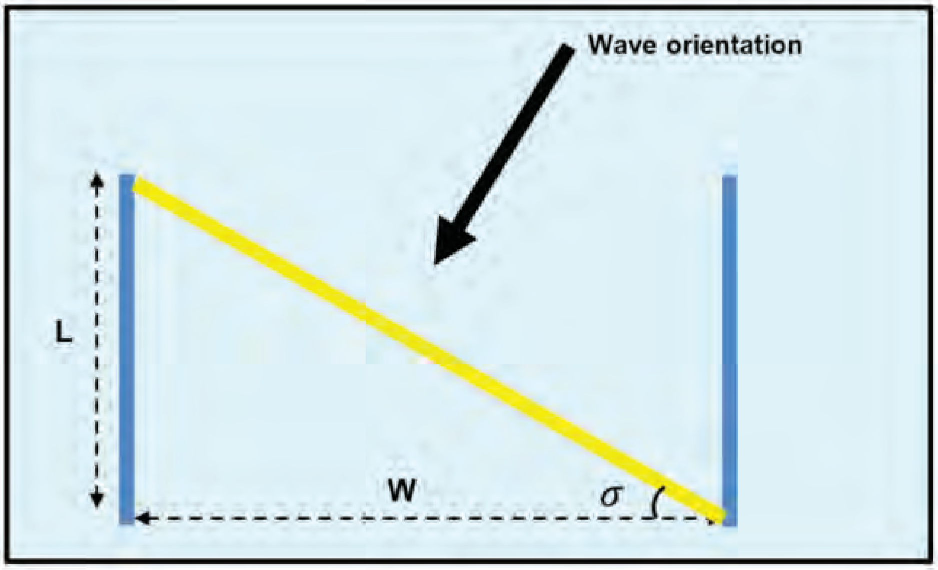
- Groynes induce downstream erosion. Figure 4 shows examples from the Shore Protection Manual (1984).
- Most published literature on groynes has come from temperate regions and so the theory of groynes in the tropics is not as well understood, which means that more computer modelling is needed to find the best dimensions for the groynes.
- Groynes deflect currents offshore, sometimes in the form of a rip current. This current carries sand from the beach to deeper water offshore.
- f the first groyne is too long, sand is unable to enter the compartments leaving the beach in the compartments unprotected and downstream erosion can be severe.
- Normally the entire sediment cell will need groynes and so the costs for a groyne field are very large on long beaches.

Figure 2. Rotation of beaches in groyne compartments versus beach length



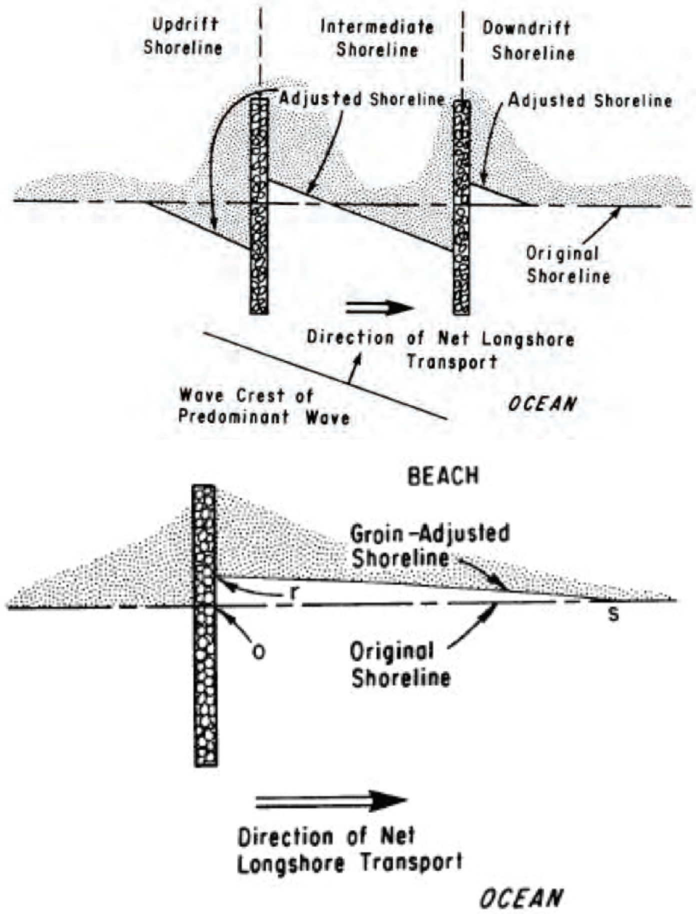
Source: Black and Mathew (2016)

Figure 3. A groyne compartment with the internal beach rotated into the wave direction. The beach orientation in the groyne compartment is σ. The spacing of the groynes is W while L is the length of the groynes.



Source: Black and Mathew (2016)

Figure 4. Downstream erosion at a groyne as shown in the Shore Protection Manual of 1984



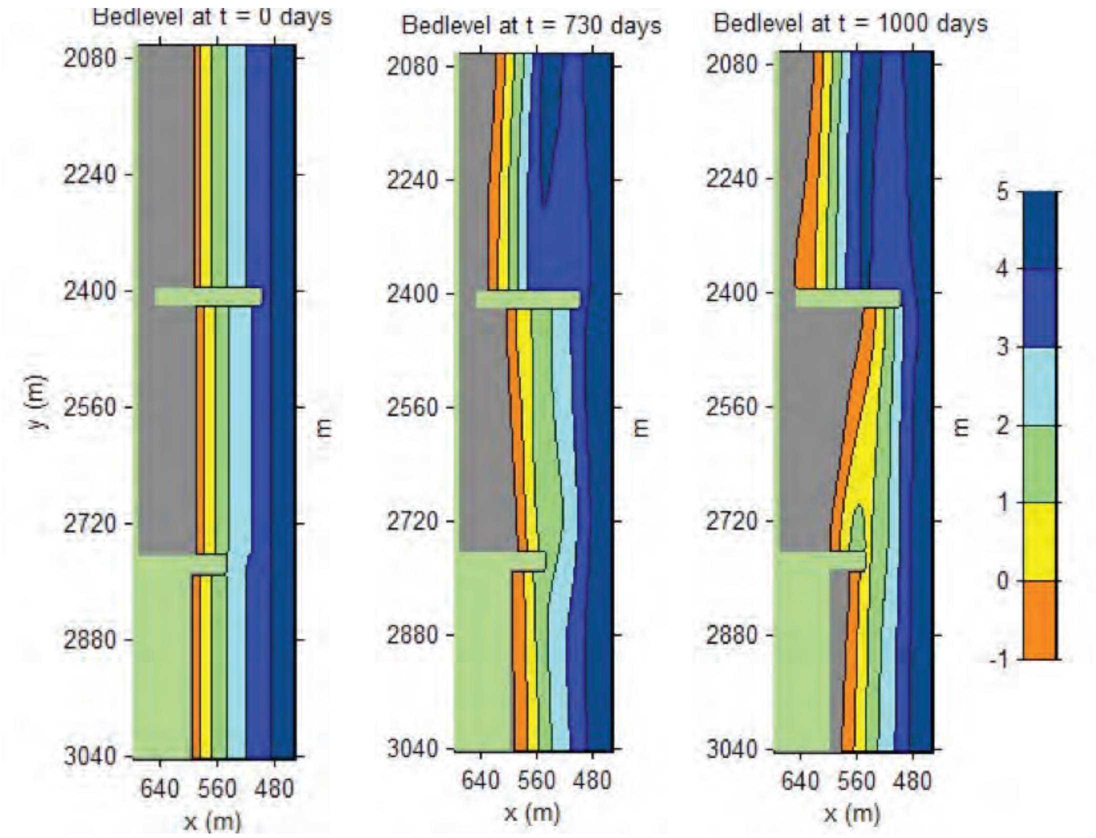
Source: USACE Shore Protection Manual (1984)

Computer Modelling of Groynes

Computer models are ideal for determining the benefits and impacts of a groyne field. The model should use local bathymetry in the local wave climate and predicted values under climate change. The model should first be calibrated to ensure that its reproducing observed behavior. In Figure 5, an example calibration is shown (Black and Mathew, 2016). Model 2dBeach from the 3DD Suite of Physical Process Models was adopted (Black and Rosenberg, 1992).

The model is simulating an actual groyne pair with natural beach to the north. Starting with an initial linear beach, the model uses three years of local wave data and shows the rotations of the beach within the groyne compartment and the erosion downstream of the northern groyne. When compared to beach adjustments seen in Google Earth images, the model was found to provide an accurate simulation of reality (Figure 6). Such calibrations are essential, particularly using the actual wave climate for at least one year to ensure that seasonal changes are considered.

Figure 5. Model predictions of bed levels at 0, 730 and 1000 days into the simulation. The grey zone is sand above 1 m elevation and the green indicates groynes and rock walls. The contours show bed levels out to 5 m depth. The beach is rotating within the groyne compartment and the beach downstream of the northern groyne erodes



Source: Black and Mathew (2016)

Figure 6. The Google Earth image overlaid with the shoreline position predicted by the computer model for July 3, 2014

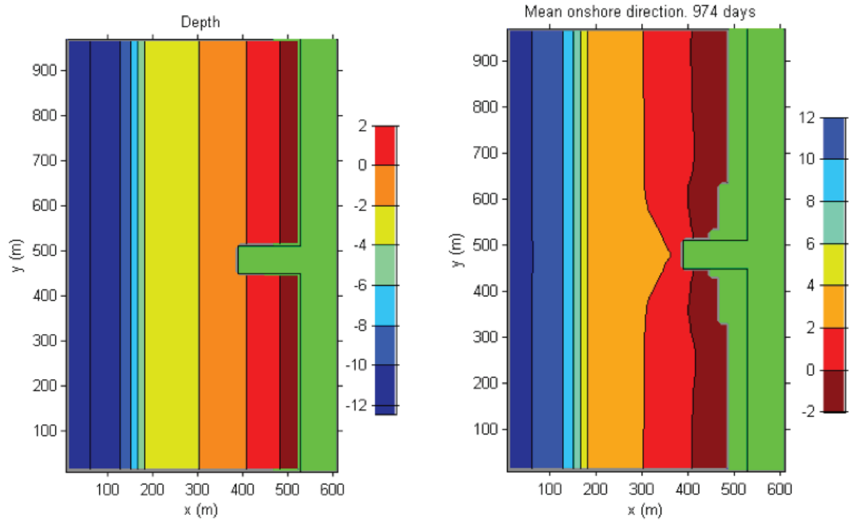
Source: Google Earth

Modelling of idealized cases also provides insight into groyne design. Here, three cases are modelled with 2dBeach (from the 3DD Suite of Physical Process Models) which are:

- Single groyne with neutral net sediment transport. The mean wave direction was 0° (directly onshore) with a + / -30° oscillation.
- Single groyne with a net transport to the north. The mean wave direction was set to 15° with an oscillation of + / -15°, which drives net transport to the north.
- Pair of fish-tail groynes with neutral net transport. The mean wave direction was 0° (directly onshore) with a + / -30° oscillation.

With neutral longshore transport, a small sand build-up occurs on both sides of the groyne (Figure 7). Some scour occurs offshore at the tip of the groyne. Notably, the beach to the north and south is unchanged. This means that groynes have no beneficial effect on beaches which have neutral sediment transport. The scour in deeper water around the tip shown by the model can lead to under-mining or collapse of the groyne.

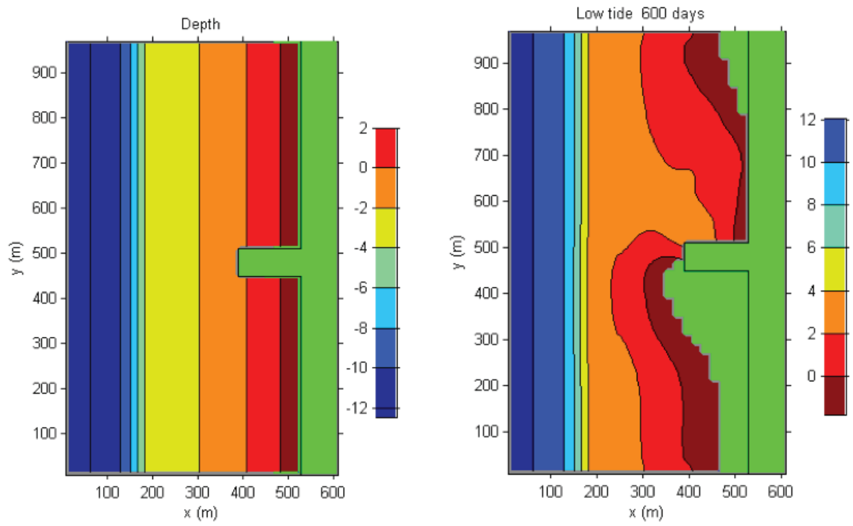
Figure 7. Beach changes around a groyne with neutral longshore transport. Initial condition (left) versus after 974 days (right)



Source: Black and Mathew (2015)

In the second case with net northerly transport, the model predicts sediment accumulation on the upstream side of the groyne and erosion on the downstream side (Figure 8). The groyne fills to its seaward limit and sand then spills around the tip of the groyne. The results agree with many field observations and the case studies below.

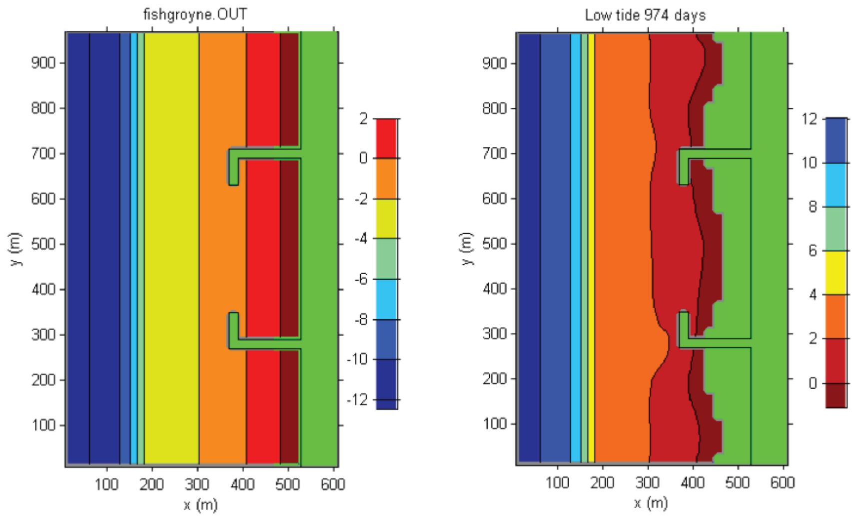
Figure 8. Qualitative comparison for the case of a single groyne subject to dominant net transport from the south. Initial condition (left) versus after 600 days (right)



Source: Black and Mathew (2015)

In the third case with L-shaped (fish-tail) groynes sediment is pushed into the two ends of the compartment in the lee of the L-arms (Figure 9). The sediment comes from the central beach, creating the scalloped shape. Many natural beaches exhibit the scallop shape between groynes and / or headlands (Figure 10). The deep scalloping relates to wave action in the compartment moving sand from the center of the beach into the lee of the structures. The breakwater causes beach widening in its lee.

Figure 9. L-groynes (fish-tail) groynes show sediment pushed into the two ends of the compartment in the lee of the L-arms. Initial condition (left) versus after 974 days (right)



Source: Black and Mathew (2015)

Figure 10.Combination of L-groynes and a central offshore breakwater at Sentosa Beach, Singapore

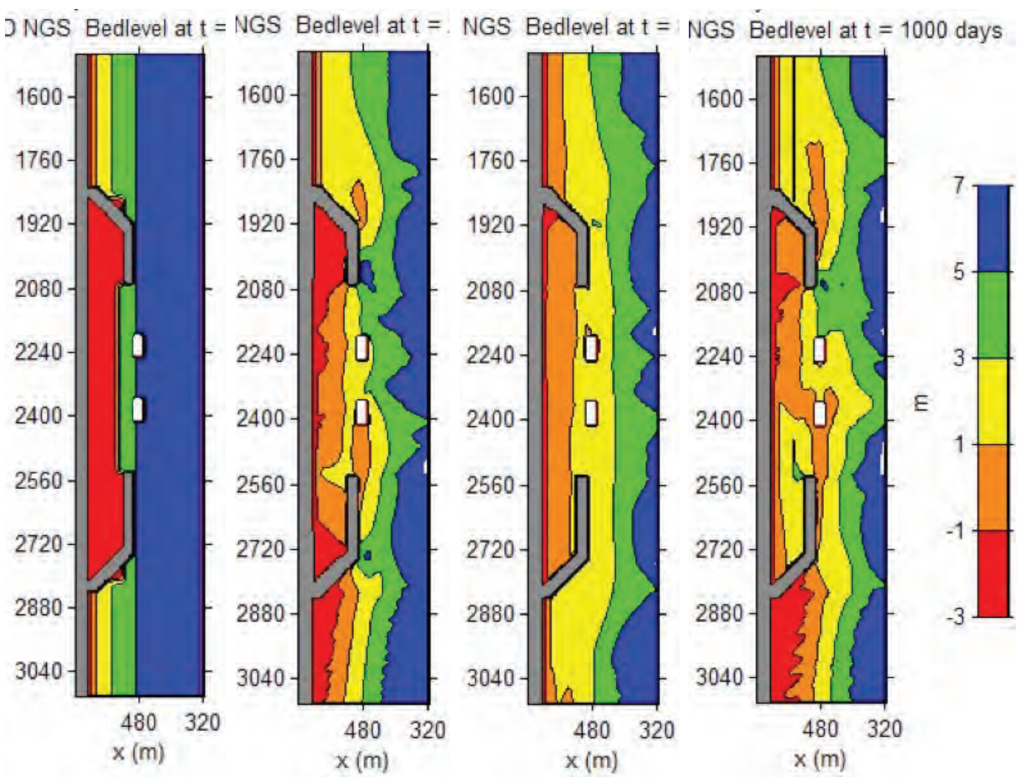
Source: Google Earth

In Figure 11, a much more complex example is shown. Two groynes each 160 m long which extend offshore at 45° to link with longshore breakwaters are considered. The base of the groynes at the shore is 1 km apart. To reduce the wave energy in the compartment, two reefs have been placed in the entrance. The total wall length is 760 m. Waves from the Pondicherry region are being simulated over three years.

The model demonstrates that the sand leaks out of the groyne compartment, particularly during the periods of high wave angle to the beach (Figure 11). Essentially, the compartment is not wide enough cross-shore to stop the sediment being washed out by waves. The structure is similar to the case shown in Figure 11 from Singapore. However, the ratio of entrance width to compartment width (from shore to the entrance) at Singapore is 1:1.5. In the case simulated the structure would have to be very large to accommodate these length scales and, given the greater offshore depth and long wall lengths, the structure is unsuitable and expensive. By carefully modelling this case, it could be rejected before construction, as so the cost savings were immense (Black and Mathew, 2015).

A tapered groyne field (Figure 12) is often adopted to allow sand to enter the compartments more easily on the upstream side while attempting to subdue the groyne effects downstream. In Figure 13, a tapered field of groynes which is similar to that recommended in the Shore Protection Manual (1984) is considered. The layout has seven groynes (Figure 13). The central one was 200 long and three groynes either side were successively 50 m shorter, i.e. 200, 150, 100 and 50 m long groynes. The spacing was 200 m and so L / W=1, 0.75, 0.5, 0.25 respectively. An initial nourishment of 500,000 m³ was placed along the beach within the groyne compartments. Net transport is to the north under the wave conditions simulated.

Figure 11. Twin groynes with shore-parallel breakwater at 0, 280, 800 and 1000 days. The sand has been lost from the groyne compartment

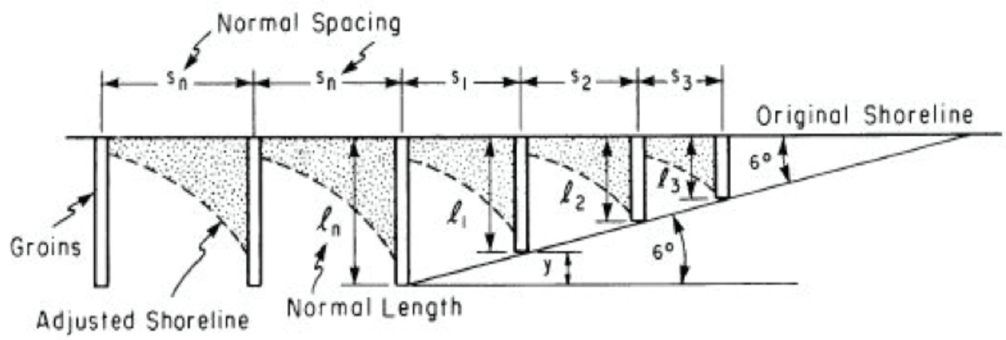


Source: Black and Mathew (2015)

The model predicts that the beaches rotate substantially each season in the compartments (Figure 13). The red and orange colors show the beach which is slowly being lost over the period of the simulation. Sediment is lost from the last two northern compartments with (L / W<0.5) and sand carried from the south by natural longshore currents keeps the southern compartments filled. Sand is deflected offshore at each groyne. Eventually the nourishment sand leaks to the north, although the rate of loss is much slower than without the groynes.

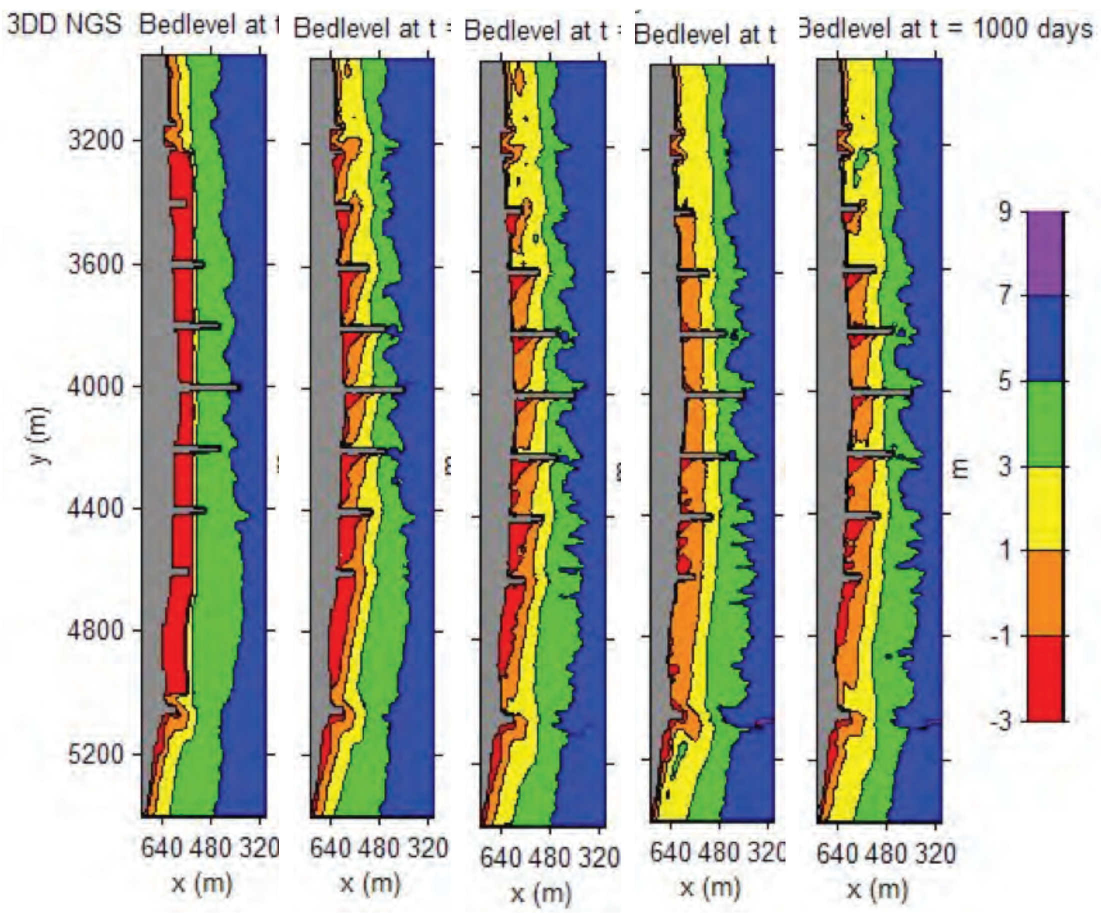
This modelling example indicates that groynes can slow the natural losses of sand from a beach, but in the case considered the losses were faster than the inputs from natural longshore drift and so the sand was eventually lost. While the groynes block sand losses at the shore, sand can still bypass offshore in deeper water. This means that the selection of the groyne length is a critical design factor. The examples show how computer modelling is needed to assess any groyne field within the local wave environment before construction.

Figure 12. A tapered groyne field



Source: USACE Shore Protection Manual (1984)

Figure 13. Sediment patterns at 0, 280, 430, 630, 800 and 1,000 days for a tapered groyne field (L=50,100, 150 and 200 m and W=200 m) using Indian east coast wave conditions.



Source: Black and Mathew (2015)3

Case Studies

Groyne Pairs at Puducherry

Two groyne pairs were constructed around Sodhanaikuppom, in north Puducherry using short groynes to protect a gap in the seawall (Figure 15). The gap was created to stabilize a short beach which would give fishermen space for their boats and access to the sea. Rock seawalls are common on this coast, but no seawall was built within the gaps.

The beach in the gaps has been stable (Figure 14). Thus, these groyne pairs have produced a better result than the adjacent seawalls by allowing a beach to form where fishermen have access to the sea. There's no beach in front of the seawalls. There's substantial erosion downstream of the last groyne (Figure 14). In the left image, the groynes protect a gap in the seawall and the internal beach has been stable. In the right image, the beach within the groyne pair has been stable, but the beach to the north of the groyne pair has eroded.

Figure 14. Groyne pairs at Puducherry

Source: Google Earth

Groynes North of Chennai Port, Tamil Nadu

Groynes north of Chennai port were built to stop erosion associated with the sand blockage caused by the port. After a decade, the groyne compartment remain devoid of sand, and the water is still reaching the backup rock seawall (Figure 15).

Groynes are not always successful. Quite clearly at this site, there is not enough sediment arriving to fill the groyne compartments because the port has blocked the net transport from the south and the first groyne is too long, which prevents sand from entering the groyne compartment.

The example shows that cross-shore transport cannot be relied on to fill a groyne compartment. The rock wall in the compartment also disrupts the formation of a natural beach (Appendix 8).

When the littoral drift is small, groynes won't solve the erosion problem. Natural capture of sand is not viable.

A hybrid solution may be needed i.e. using structures with nourishment. The long groynes at Chennai create small sediment cells which are likely to be relatively independent of each other and nourishment would be beneficial. Further studies with computer modelling would be needed to meet the requirements of the Guidelines before nourishment was added.

Figure 15. Groyne compartment to the north of Chennai Port in February 2015

Source: Google Earth

Groyne Pair at Panathura coast, Thiruvananthapuram

The Panathura coast forms part of a straight sandy coast between the rocky headland at Kovalam in the south and the lateritic cliffs at Varkala in the north (Figure 16). The inner shelf is relatively steep with a slope of about 0.01. The coast is micro-tidal with a tidal range of about 0.8 m, but has relatively higher wave energy, with a maximum recorded wave height of 6.5 m at Vizhinjam south of this coast. Longshore currents are southerly during the monsoon months and northerly the rest of the year. Sheela (2014) has estimated a net northerly longshore sediment transport of 99,000 m³ per year for this coast. The site has a tidal inlet at Panathura through which the Karamana river flows into the sea.

A transitional groyne system consisting of ten groynes of varying lengths for the protection of 3 km stretch of Panathura coast was proposed (Figure 17) (Thomas et al., 2007). Note that the assumption of net transport from the north was subsequently proved incorrect in both direction and magnitude. After revisions which led to fewer and shorter groynes (without scientific studies as a basis), a very short northern groyne was built with a length of 25 m and a southern one of 33 m. The spacing between the groynes was 150 m. Thus, the length to spacing ratio was small at 0.2 (Figure 18). In Figure 19, the top left image shows the coast in 2006 before construction and others show the period 2008 to 2016.

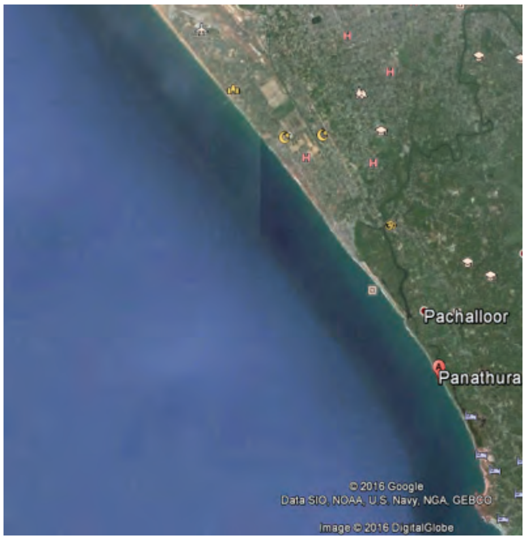
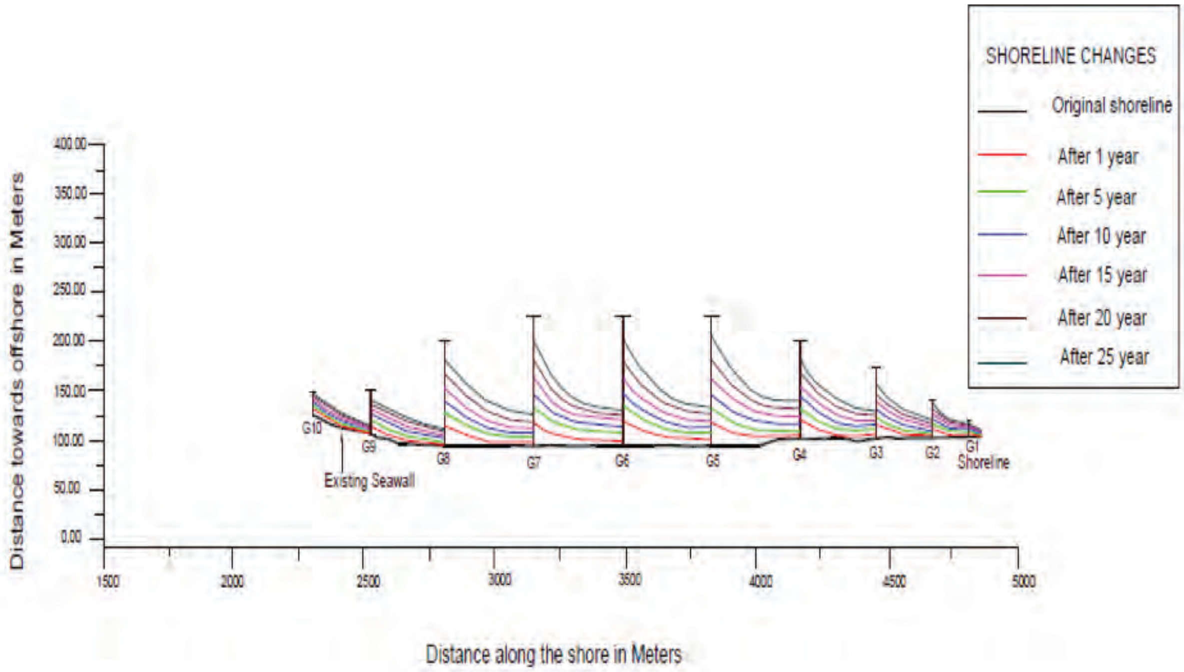


Figure 16. Valiyahura, Thiruvananthapuram, southwest coast of India

Source: Google Earth

Figure 17. The original design of tapered field with ten groynes for the Panathura coast



Source: Thomas et al. (2007)

The analysis revealed that the coast, though protected by seawall, had a frontal beach during non-monsoon in 2003. However, sand deficiency became acute with further time. In June 2006, the beach is completely eroded.

By September 2009 monsoon, no frontal beach is seen north of the northern groyne. Some deposition is seen in the compartment between the two groynes and south of the southern groyne. The pattern is indicative of southerly longshore transport. Even in the month of after the monsoon, the beach did not return. The pattern resembles that of the monsoon.

By January (as seen from the image for January 2015) further consolidation of the build-up of beach around the groynes is seen with the prevalence of northerly longshore transport. The compartment between the groynes is nearly filled up and there is even bypassing of sand to the inlet region. However, erosion predominates through March and April and by the start of the monsoon in August only traces of sand are seen in the compartments.

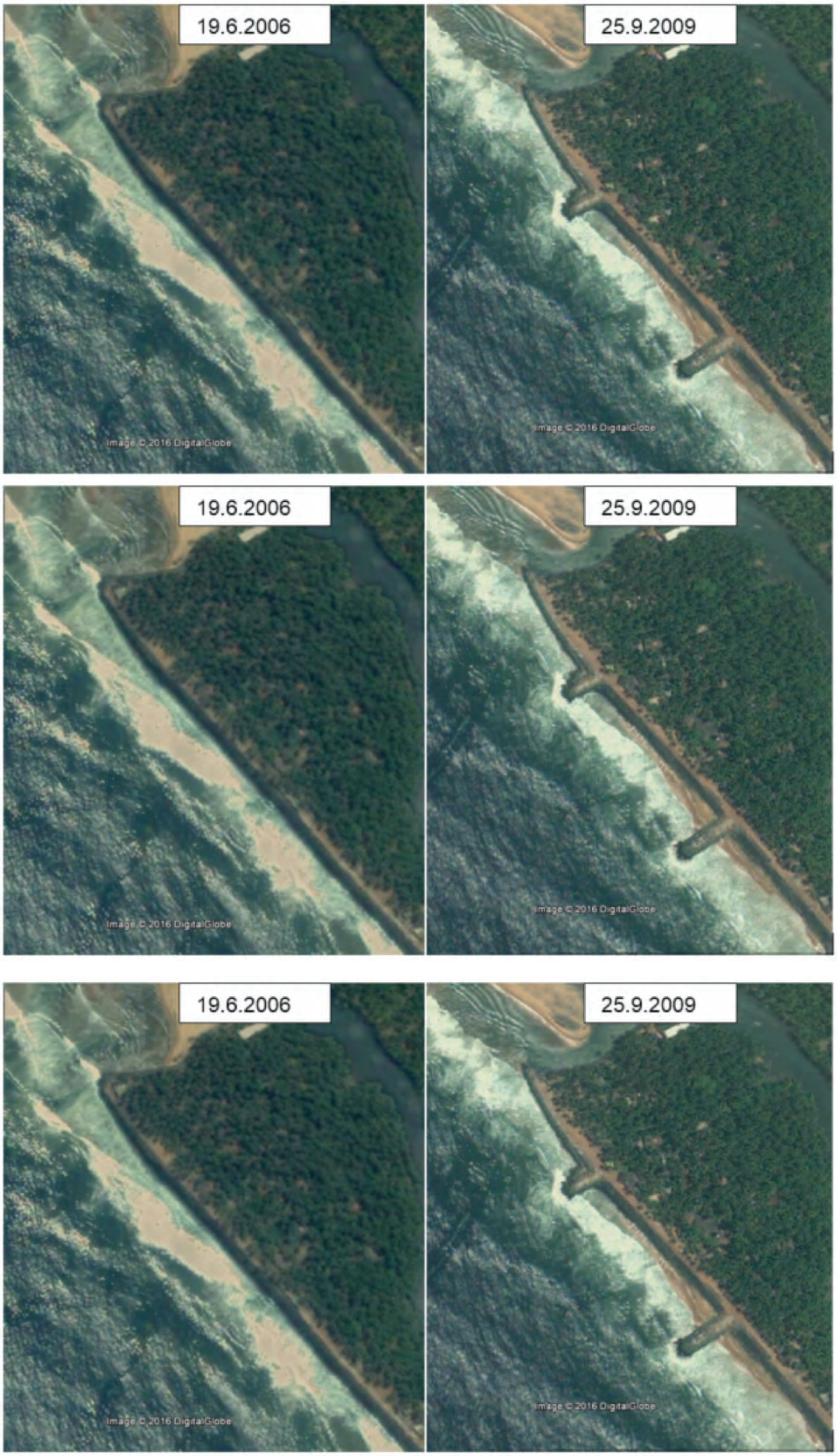
The groynes have not provided any protection for the coast during the rough monsoon months. There appears to be a deficiency in onshore transport of sediments on to the beach, partly due to the presence of the sea wall which does not present the ideal slope and conditions favorable for settlement of sand.

This case study denies several of the guidelines:

- Insufficient studies and field measurements;
- Inadequate understanding of the longshore transport regime;
- Inadequate interaction between the various stakeholders, designers, scientists and engineers;
- Lack of comprehensive computer modelling to determine the likely success of the structure before construction, and;
- Major changes to the original design during the project.

Figure 18. Panathura coast towards south showing the groyne in October 2010
Source: Thomas et al. (2007)

Figure 19. Panathura coast before construction of the pair of groynes in 2008, and after construction in 2009



Source: Google Earth

Groyne, Gold Coast, Australia

The Gold Coast in Australia is heavily dependent on its beaches for income through surfing and tourism. High and low rise construction also needs to be protected. The groyne in was found to cause severe erosion on its downstream side at times. A rock wall was constructed to protect the shoreline and infrastructure downstream. This groyne has been the subject of public debate and was eventually shortened to allow more bypassing. Then, in more recent years, the Gold Coast has been undertaking large-scale sand nourishment.

Groyne Field, Bournemouth, England

Some groyne fields are designed to enable sand migration from one compartment to the next. In Bournemouth (England), a field of some 200 groynes was constructed at 185 m spacing with length of 75 m (Figure 20). They nourish all compartments about once per decade. Thus, the groyne field was designed to slow the beach sediment losses, rather than prevent them. Although viable and meeting the design requirements, the high nourishment volumes and groyne maintenance costs for a "leaky" system like Bournemouth may prove unsustainable in India.

Figure 20. Groyne pairs at Boscombe (Bournemouth), England / *Source: Google Earth*

Low-Crested Groynes, Point Lonsdale, Victoria, Australia

The groynes at Point Lonsdale (Victoria, Australia) superseded an unsuccessful seawall. Erosion in front of the seawall and wave splash over the wall drove the decision to trial low-crested groynes (Figure 21). The groyne, with crest just above high tide, is a simple narrow-base rock structure with timber interior to prevent the rocks from being washed away.

The sand has built up in fillets or wedges against the groynes, which also acts to rotate the beach and slow sediment transport. The net longshore transport is strongly uni-directional from south to north. Once the fillet is full, the bulk of the sand can bypass to downstream beaches. However, an end effect occurs and a rock seawall is still present after the last groyne. This case demonstrates that low-crested groynes can widen beaches when net longshore transport is large and natural sediment supply is adequate.

Figure 21. Low-crested groynes at point Lonsdale, Australia

Source: Google Earth

When and Where Should Groynes be Used

The case studies have shown a mixture of successes and failures with groynes. However, in assessing each groyne project, difficulties arise for several reasons.

First, every groyne field appears to be different, with different lengths and different spacings. For example, at Panathura, a much longer groyne with nourishment of the beaches to the south may have been more successful. For many reasons that were not totally scientific, only a 33 m long groyne was built. This is relatively small for a coast which stretches 3 km to the south.

Second, pressures that come to bear during a project in India, can lead to design changes between design and construction. For example, the original design at Panathura recommended groynes that were 125 m long, but a 33 m groyne was built instead as a trial.

Third, each segment of coast along the Indian coast is fundamentally different. Some coasts like Kerala or Pondicherry have net transport which is dominantly in one direction. Others like Goa and Maharashtra or within small embayments have net transport which is close to zero (just alternating each season).

Fourthly, groynes have been placed in locations with very small sediment inputs. The concept of capturing natural sand will fail in these cases.

Fifth, groyne fields may be designed to deliberately leak sand. Usually there will be pressure to ensure that downstream beaches receive inputs and so a “half-way” design is put in place and the groyne is then seen by some as being unsuccessful. The groynes at Bournemouth were designed to leak because the downstream residents wanted sand on their beaches, but the cost of groyne maintenance and sand replenishment is very large. This may be unsustainable in India. The politics of beaches and the delivery of sand downstream will often lead to decisions like the construction of groynes which are shorter than the designer wants.

Sixth, while a method of coastal protection may be considered a failure in some locations, the failure may be due to the design engineer rather than a failure of the whole coastal protection method. The engineer may not have considered the environmental conditions (especially net longshore transport) and factors beyond their control may have influenced the final decision. Insufficient data collection, proper analysis or inadequate computer modelling may be also at fault. Thus, while one groyne field may be successful in a location, the same design may not be suitable elsewhere.

Seventh, there are three key variables to consider, i.e. number of groynes, spacing and length. In India, these factors vary sufficiently and appear “random”, with different lengths and spacings being noted, even within a single groyne field. There are numerous forms of groyne like T-groyne, fish-tail groyne, curved groyne etc.

Overall, the question of what should be built, which takes account of the existing environment and under climate change, needs to be answered.

Designing a Groyne Field

Groynes can be designed to block a percentage, or most of the longshore transport of sand. They act like a headland and create a new sediment cell which is completely or partially self-contained. Short groynes act to slow losses while very long groynes can create a fully isolated and independent sediment cell. Because they block the beach transport, they interfere with the natural flow of sand and erosion downstream is common.

To address the question of where groynes might be suitable, it is first necessary to look at beach dynamics in more detail. In Appendix 6, it was shown that beaches can be grossly divided into two types. The first is the stable or “happy” beach where net sediment transport is very small. Of course, sand oscillates up and down the beach between the seasons, but the net transport when averaged over decades is close to zero.

Such beaches are common between two headlands or in locations where the beach is essentially normal to the net wave power. The second type is the "hungry" beach with a strong net transport in one direction when averaged over decades. Typically, these beaches developed over thousands of years in locations where there was a good sediment supply upstream such as a river. In recent times, many of the rivers have dams or mining of sand and so this supply has greatly reduced. Without the supply, the hungry beach will simply erode because its angle is not perpendicular to the average wave power. Sand moves in one direction and there is little replenishment at the upstream end and so the erosion migrates alongshore over decades. Examples of hungry beaches occur in Kerala and on the east coast around Pondicherry and Tamil Nadu. Of course, there are shades between the two extremes, but for now we will consider these only.

This division is fundamentally important when making decisions about coastal structures. Case studies of major blockages due to ports etc. have shown dire consequences for downstream beaches in zones of strong net transport. However, one port in north Kerala at Koilandy was found to have little effect on downstream beaches because the net transport at the site was small (Volume I). Thus, neutral beaches are fundamentally more stable than hungry beaches as they do not need a large and continuous sediment supply.

In the absence of structures or any interventions, what happens to a beach when sediment supply stops or the coast is badly oriented with the waves? Two case studies are considered, in Port Phillip Bay, Victoria Australia (Figure 22) and at Arugam Bay in Sri Lanka (Figure 23). The premise to be discussed is that beaches like to be neutral. That is, in the absence of supply, they prefer to rotate onto the angle which puts the beach perpendicular to the wave power averaged over decades. Port Phillip Bay is semi-enclosed so that all waves in the bay are locally generated within the bay itself. In a peer-reviewed science publication, Black and Rosenberg (1992) used long-term wind records to produce a wave climate for each beach. They were able to show that every beach in the bay was actually perpendicular to the average wave power. While waves come from many directions, the perpendicular orientation made the net sediment transport neutral along each beach. Thus, while the bay is essentially circular, each beach has attained an orientation which is neutral. Even the curvature in the beaches near headlands could be explained by the partial wave sheltering caused by the headland. Figure 22 (right panel) shows a series of "indented" beaches on the north-east coast of Port Phillip Bay. To achieve the required orientation, the beaches have eroded at one end in the form of an indentation, which allows the beach to be neutrally aligned. The yellow lines show the succession of indented beaches where the beach has eroded on one end to create the neutral alignment.

A second classic case is Arugam Bay in Sri Lanka which receives a similar wave climate to India (Figure 23). A long series of indented beaches occur, each with similar orientations. The beaches have eroded at one end to form a succession of headlands and indented beaches. The stable orientation arises when the beaches attempt to neutralize the net sediment transport. Thus, beaches can be much more stable when they convert from hungry to neutral. In India, with changed sediment supplies from rivers, it may be assumed that many beaches are currently attempting to rotate, but this is being stopped by human intervention.

The Sri Lanka case has a series of headlands with indented beaches. If these headlands were actually man-made groynes, then it would be possible to stabilize many of the beaches currently suffering erosion by artificially creating the headland and then allowing the beach to rotate. However, human habitation next to the coast may prevent such rotation from being allowed. Thus, the combination of a series of very long groynes accompanied by substantial beach nourishment would be a suitable use of groynes on hungry beaches with reduced sediment supply. This may be achieved at lower cost if the groyne spacing was of order 5 km. The amount of rotation required to stabilize the beach can be calculated from the long-term wave climate and this would determine the length of the groynes. It is anticipated that groyne length may be as much as 500 m or more on some coasts with strong net transport, but it could be less on milder coasts. Of course, this method would have to be adopted throughout the full sediment cell, otherwise severe downstream erosion would occur at the last groyne.

Once the beach has neutral longshore transport, it will be far easier to sustain under climate change. The engineer would need to determine if the wave climate and mean direction of the waves is predicted to vary under climate change, as the beach will try to follow that adjustment by rotating.

Such a grand scheme with large groynes would require considerable investigation by Indian research institutes and their international colleagues and would require a major financial commitment from central government. The main consideration is to identify the neutral alignments and design accordingly.

The key message in this description is that all beach works should have a primary goal of putting the beach onto an alignment that leads to neutral net longshore sediment transport today and in a climate change scenario. This can lead to downstream impacts because deliveries to neighboring zones will reduce. Thus, the full sediment cell must be considered. However, once a beach is neutral, it is much easier to sustain and beach nourishment within the cell has extremely positive benefits, lasts for a long time and allows the beaches to be prepared for climate change.

At smaller scales, groynes can be used to rotate beaches within smaller compartments. However, because they cut off the longshore drift, the full cell needs to be treated. The groynes are then placed only to reduce longshore transport like Bournemouth, rather than act to find a new beach alignment. In these cases, the use of an offshore reef would be preferred because reefs allow bypassing of sand at the shoreline.

In general, groynes have no positive benefit on neutral beaches. If neutral beaches are eroding, the cause will be sand lost due to reclamation, mining or human interference at the shoreline disrupting the berm and beach. Sometimes neutral beaches can be temporarily out of alignment due to annual or decadal oscillations in the wave climate and disruption of the cross-shore transport during periods with more storms. However, the sediment will still be within the sediment cell.

Low-crested groynes were shown to cause localized rotations of the beach in the form of a fillet adjacent to the groyne. These can be adopted on hungry beaches to solve localized problems. They have the benefit of not disrupting total sediment transport and usually have the crest around 1 m above the high tide level, depending on the net transport intensity. For cases with larger longshore drift, the crest could be raised to 2 m above high tide.

Figure 22. Beach orientation in Port Phillip Bay, Australia

Source: Google Earth

Figure 22. Beach orientation in Port Phillip Bay, Australia

Source: Google Earth

The need for beaches to rotate is one reason why rock seawalls are unsuitable. They simply block all natural movement of the beach leaving no chance for the beach to come closer to equilibrium.

Conclusion

A dominant goal when designing coast protection is to bring the beach onto a neutral alignment. This can be achieved with long groynes which create new sediment cells within a longer domain. But the whole sediment cell needs to be treated. Smaller groynes induce local rotations within the compartments, and they can be used to reduce longshore transport. But once again, the full sediment cell needs to be treated.

Groyne design is complex and one design cannot be transferred to another site with confidence. Groynes will fail in zones with small sand inputs or if the groynes are too long to allow sand to enter the compartments. In these cases, nourishment will be needed within the compartments. They can also fail if the groyne is too short, relative to the size of the domain and the wave climate.

Groynes provide no real benefit on beaches with neutral sediment transport. The designer must determine the longshore transport rates before undertaking groyne field design. Computer models are an essential aid, noting the complexities of local sediment supplies, wave climate, storm frequency and downstream effects.

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CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 2

APPENDIX 10

DESIGNING OFFSHORE REEFS, BREAKWATERS AND ISLANDS FOR CLIMATE RESILIENT COASTAL PROTECTION

ADB TA-8652 IND:
CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

APPENDIX 10
Designing Offshore Reefs, Breakwaters and Islands for Climate Resilient Coastal Protection

Introduction

Although natural reefs and islands have been protecting many parts of the Indian coast, artificial reefs are a relatively new means of coastal protection in India but they are now more common and accepted by many maritime states.

The first multi-purpose artificial reef for coastal protection and public amenity to be built in India was at Kovalam beach in Kerala in 2010. Another coastal protection reef using geocontainers was completed at Mirya Bay, Ratnagiri, Maharashtra in 2016. Two large rock reefs are being constructed at Ullal in Karnataka at 700 m offshore, and in early 2017 one was 70% completed and the other was beginning construction. In central Karnataka at Murudeshwara, a reef has been accepted for construction and project implementation is anticipated in 2017. On the east coast at Puducherry, a reef has been designed and construction has commenced. Offshore reefs have been designed for Visakapatanam but are yet to be finalized. Reefs are being considered by the Maharashtra Maritime Board for Marine Drive Mumbai to assist the stability of nourishment and protect a pier, Ganapatipule (Ratnagiri) to protect the Temple and Tarkarli / Devbag to prevent coastal erosion. Another "reef" was accidentally created by a ship-wreck to the south of New Mangalore Port.

Though reefs are construction-based, they fit into the "soft" solution category because they do not damage or grossly interfere with the beach and allow natural flow of sand along the beaches:

- Reefs provide a strong coastal protection benefit;
- They widen the beach;
- Equations are available to forecast the growth of the beach in the lee of a reef prior to construction;
- On the wider beach, they overcome social problems associated with structures built too close to the beach within the coastal regulation zone;
- They allow natural bypassing of sediment, unlike a groyne;
- Environmental effects are positive. For example, they do not bury the beach and foreshore, like a seawall;
- Offshore reefs are a suitable method of coastal protection for climate change adaptation and resilience;
- If an island is adopted, then the land on the island may be used for public benefit, and;
- If a reef is adopted, they have minor visual impacts, require no construction on the beach, can be modified as a water sport enhancement (e.g. surfing) and the habitat they provide can greatly benefit marine species and fishers.

Offshore reefs and breakwaters have been constructed for coastal protection and amenity in several countries internationally.

Definitions

Reefs are offshore and underwater (crest at high tide or lower). Breakwaters and islands create a stronger wave sheltering effect than a reef because their crest is above the high tide line. An offshore breakwater has no connection to the beach, unlike a groyne or port wall.

Breakwaters are common in Indian ports, but they are used only for protection of boats, not beaches.

Theory of Offshore Reefs

An offshore reef acts on the waves, which are the most common cause of erosion. Other land-based structures like groynes and seawalls act on the effects at the beach. Philosophically, it is preferable to fix the cause rather than putting a "bandage" on the effects. Any structure offshore will help to protect a coastline, but the degree of protection depends on the design. Parameters such as crest height, longshore length, and distance offshore all need to be appropriately set. Optimum parameters will give the appropriate beach protection, while still allowing sediment to pass naturally along the shore, thereby eliminating downstream impacts.

The theory behind the shoreline response in the lee of offshore structures was studied by Prof. Black and his team at the University of Waikato, New Zealand (Black and Andrews, 2001a). Prior research around breakwaters had assumed that the primary physical process responsible for the accumulation of sediment in the lee was diffraction. Prof. Black showed that the actual mechanism on open beaches was the reduction in wave height in the structure's lee. This caused the littoral drift to be less behind the structure, which allowed sediment to accumulate (Black and Andrews, 2001b).

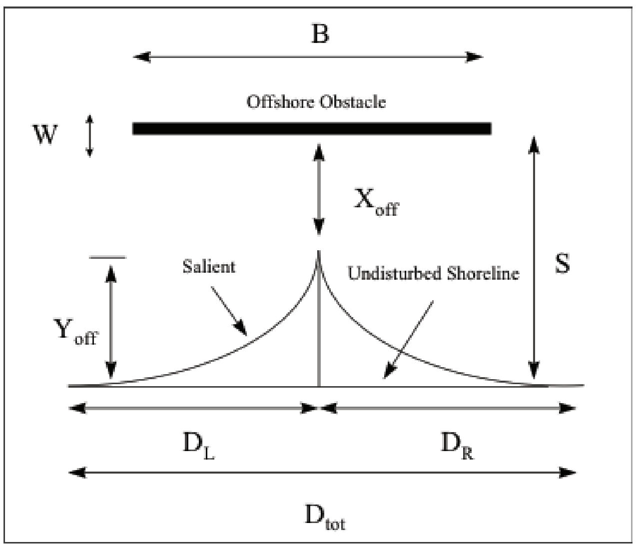
Black and Andrews (2001a) digitized the shapes of numerous salients in the lee of natural submerged and emerged reefs. They defined the variables in Figure 1. Their analysis showed that the size of the salient was primarily dependent on two variables: the alongshore length of the structure and the distance offshore (Figure 2). They obtained the following relationship to pre-determine the size Yoff of the salient at its widest mid-point:

$$X_{off} / B = 0.5\ (B / S)^{-1.27} \qquad (1)$$

Further research (Black and Andrews, 2001b) indicated that the shape of the salient was described by an asymmetric sigmoid (Figure 3).

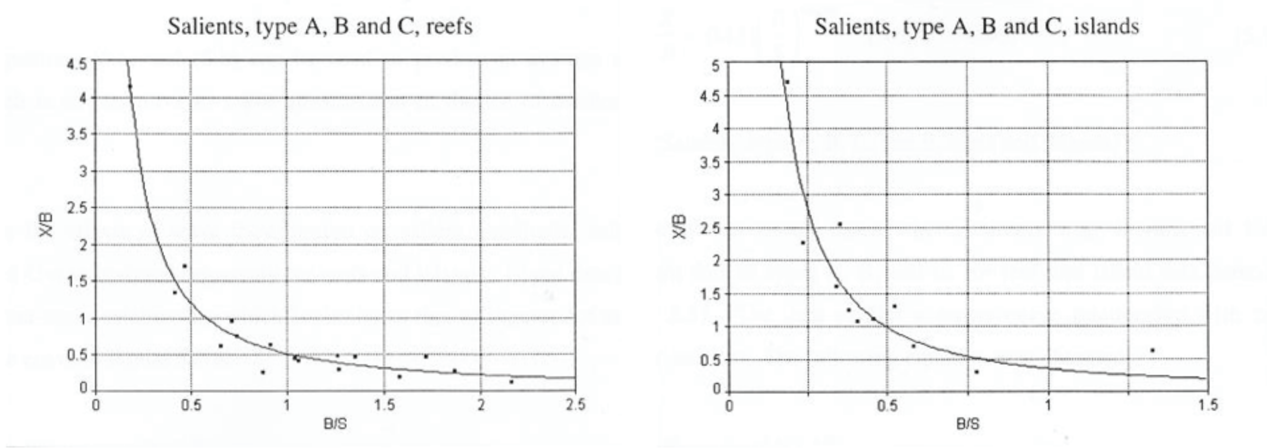
Knowing the geometry and shape allows the salient to be forecast prior to construction of an offshore structure and without computer modeling. However, numerous calibrated simulations with computer models later showed that the theory could be reproduced by the models.

Figure 1. Definition of variables defining a structure and salient



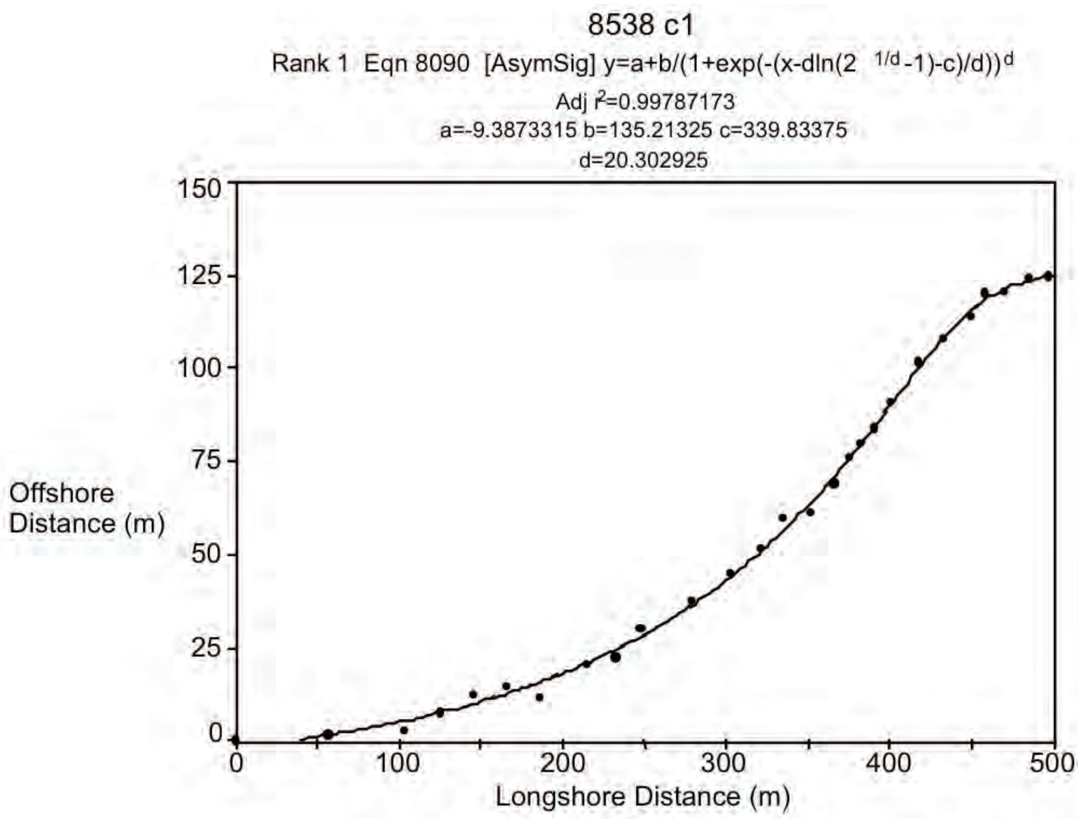
Source: Pilarczyk (2003)

Figure 2. Salient Xoff / B versus B / S for reefs and islands



Source: Black and Andrews (2001b)

Figure 3. The asymmetric, sigmoid shape of salients



Source: Black and Andrews (2001b)

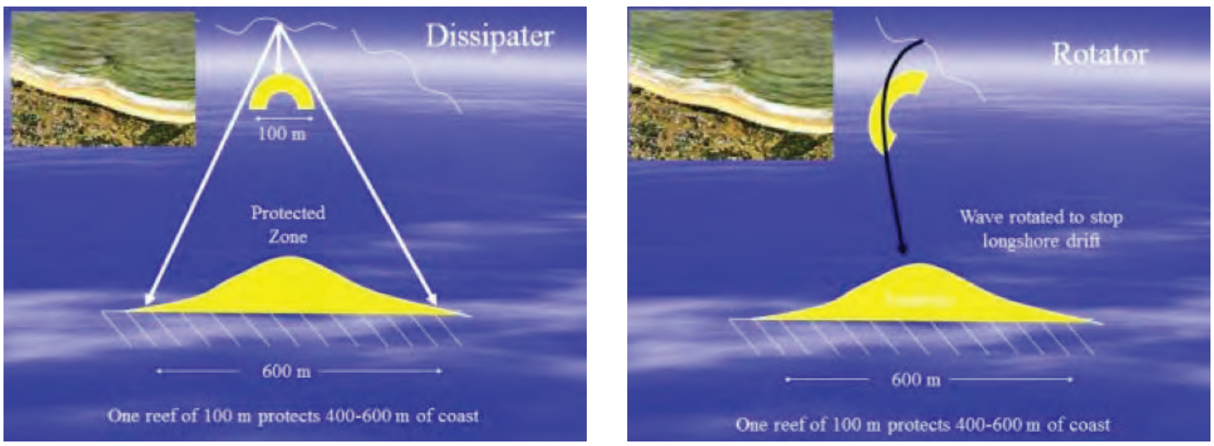
The physics is explained simply in Figure 4. Reefs, which block waves, are called dissipaters. The reef produces a wave shadow zone at the shore. When waves arrive from different directions the shadow zone moves as the wave angle changes (Figure 4). This produces a shoreline wave shadow much broader than the reef, and leads to protection along a longer section of coast than the longshore reef length. The maximum protection occurs in the line of the dominant wave direction and grows less to either side, which forms the common salient shape sketched in Figure 4. The length of shoreline protected can be up to eight times the longshore length of the reef (Black and Andrews, 2001a), which substantially reduces the cost per meter of coastal protection.

Alternatively, submerged reefs can also help protect a coast by rotating the waves. Waves arriving at an angle to the coast drive littoral sediment transport in the direction of the waves (Figure 4). Thus, if the wave is rotated (e.g. onto a more shore-parallel angle), the littoral drift can be changed to the benefit of the beach. Prof Black patented this powerful concept of wave rotation on reefs for coastal protection and has since granted full public access to his patent. The third option is a wave reflector. In this case, the offshore structure is constructed to reflect the incoming energy, rather than induce wave breaking. Once again, this reduces the wave height at the shore and leads to accumulation of sediment in the form of a salient.

A classic example of a massive salient is Kapiti Island in New Zealand. The large island stretches longshore over 9 km and lies a similar distance offshore (Figure 5). The shape of the salient in its lee fits the theory. Black and Andrews (2001b) demonstrated that the formulae were valid across the range of offshore construction lengths from 30 m to more than 10 km. Budgewoi in New South Wales (Australia) shows the same response, but to a submerged reef rather than an island (Figure 6). The reef is 500 m long and the distance offshore of the reef is 450 m. The large salient has grown out to nearly touch the reef.

The artificial reefs are primarily built to protect the coast, but they also have several public amenity benefits: improved fishing; snorkeling for visitors; and improved safer beaches.

Figure 4. Dissipating reef and rotating reef

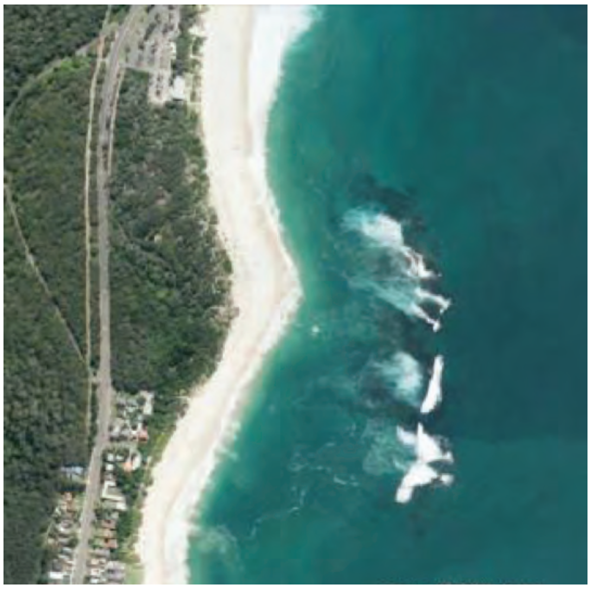


Source: Pilarczyk (2003)

Figure 5. Kapiti Island, New Zealand. The island is 9 km long and the coast has responded with a salient due to save sheltering

Source: Pilarczyk (2003)

Figure 6. Response of the coast to a submerged reef at Budgewoi, Australia. The reef is 500m long and 450m offshore.



Source: Google Earth

Salients in the Tropics

Black and Andrews (2001b) examined salients in the temperate waters of Australia and New Zealand. No reefs or islands in the tropics were considered. To test if the theory was applicable to the tropics, two further investigations have been undertaken:

- Salients formed inside the lagoons of tropical reefs at Mauritius in the southern Indian Ocean, and;
- Salients formed in the lee of reefs and islands on the coast of India.

For each salient case, the following key measurements were made using Google earth images:

- Reef length (B) in the longshore direction (m)
- Baseline location where the salient projects beyond the natural beach (length=Dtot)
- Cross-shore distance (S) from the baseline to the reef
- Apex cross-shore width of the salient (Yoff)

Using the two parameters B and S, the theoretical salient width was calculated using Equation 1 and compared to the actual measured size.

Mauritius Salients

There are several well-formed salients along the shoreline in eastern Mauritius in the southern Indian Ocean (e.g. Figure 7). The length scales for five cases (Table 1) are extracted from Black (2015). Figure 8 compares the measured salient width with the theoretical width. The figure shows that the Black and Andrew's formula derived for cases in other countries is also applicable within the tropical lagoons of Mauritius. The best-fit curve is linear with a gradient of 1.04. The R2 of 0.92 means that 92% of the variance is accounted for by the linear curve and this value is highly significant for five data points. The gradient indicates that actual salient widths are 4% smaller than predicted by the formula, and so a small correction can be applied.

Notably, the reef is protecting a length of coast which is 3.7-5.3 times longer than the longshore length of the reef (Table 1).

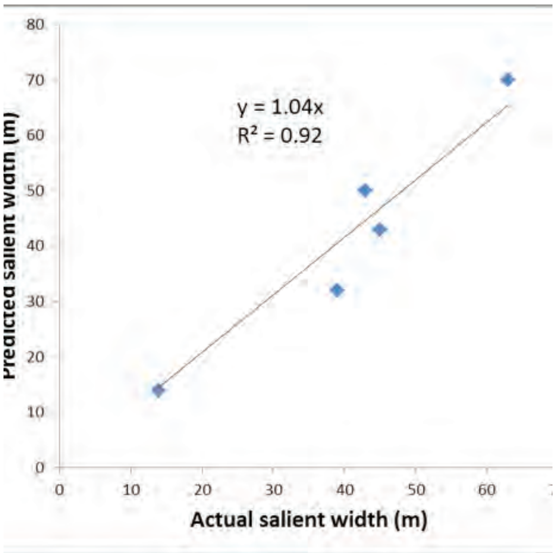
Figure 7. Salient 3 in St Geran, Mauritius

Source: Google Earth

Table 1. Dimensions of the five salients at St Geran, Mauritius

	REEF WIDTH	DISTANCE OFFSHORE	SALIENT SIZE	BASE LENGTH	BASE / REEF WIDTH	THEORETICAL SALIENT SIZE
Salient	**B (m)**	**S (m)**	**Y_{off} (m)**	**D_{tot} (m)**	**D_{tot}/B**	**$Yoff_m$ (m)**
1	34	90	39	125	3.7	32
2	18	36	14	85	4.7	14
3	42	146	45	211	5.0	43
4	46	187	43	244	5.3	50
5	72	220	63	321	4.5	71

Figure 8. Cross-shore salient apex width predicted by the Black and Andrews (2001a) formula versus the actual cross-shore salient width for five salients at St Geran, Mauritius



Source: Google Earth

There are several well-formed salients along the shoreline around the Indian coast (Figure 9). The measured length scales for seven cases are presented in Table 2. Figure 10 compares the measured salient cross-shore length with the theoretical cross-shore length for the first six cases. Sri Lanka is not included.

The best-fit curve is linear with a gradient of 0.99 (R^2=1.00). The gradient indicates that actual salient widths are 1% larger than predicted by the formula, which is small and within the data scatter. Thus, Black and Andrew's formula derived in temperate regions is valid for Indian conditions.

The delta at Cauvery in the lee of Sri Lanka has resulted from centuries of deposition from the river (Figure 9g). It has the shape of a salient and so we tested the theory to examine the extreme limits of the formula. While the geometry is not symmetrical, the lengths measured are shown on Figure 9g. For example, Figure 9b is taken as the width of Sri Lanka.

We found that the formula of Black and Andrews predicts the salient size, i.e. measured and theoretical widths were 62,882 m and 61,447 m (Table 2). Sri Lanka shelters the Cauvery from the dominant southerly waves and so the delta appears to have formed into a salient shape with predictable dimensions.

Figure 9. Salient at (a) Enayam, (b) Hadin, (c) Majali, (d) Palissery, (e) Panavilai, (f) Periakulam and (g) Cauvery in the lee of Sri Lanka

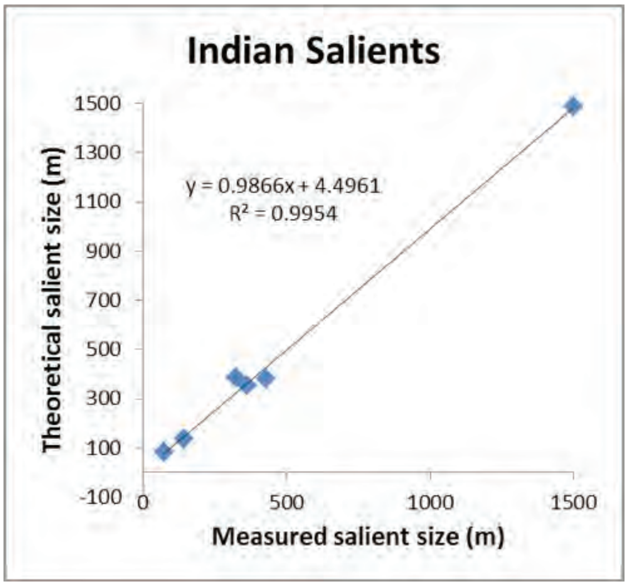
Source: Google Earth

Source: Google Earth

Table 2. Dimensions of the seven salients on the coast of India

	REEF / ISLAND WIDTH	DISTANCE OFFSHORE	MEASURED SALIENT SIZE	THEORETICAL SALIENT SIZE
Salient	**B (m)**	**S (m)**	**Y_{off} (m)**	**$Yoff_m$ (m)**
Enayum	355	1079	363	351
Panavilai	239	288	145	137
Periakulam	1948	3638	1497	1485
Hadin	93	817	75	82
Majali	736	776	429	382
Palissery	552	900	325	386
Sri Lanka	231 130	102 695	62 882	61 447

Figure 10. Theoretical salient size versus measured size for Indian cases



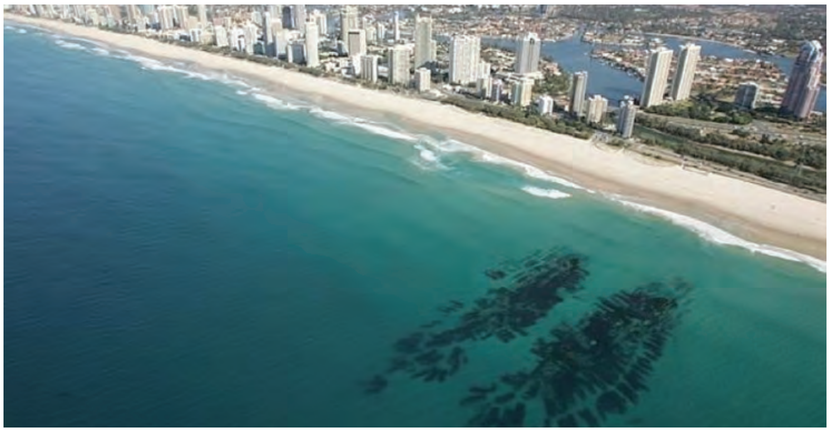
Case Study: Gold Coast, Australia

The Gold Coast reef is a cross-shore design with two arms (Figure 11) (Black, 1999). The Gold Coast City asked the designers to allow 60-70% of the longshore drift to by-pass the reef so that downstream beaches would be secure, while retaining protection upstream (Black, 1999). The design proved to be highly successful. Figure 12 shows the beaches after a major storm in 2013 and then again in 2015 after recovery. It shows that the beach has recovered in 2015 and the beach is wider to the south, while the northern beach is still in good condition. The salient formation is as predicted by both physical and mathematical models prior to construction.

The reef was constructed from 20 m long geotubes which were filled with sand in a split-hopper barge and dropped to the seabed (Figure 13). This method is suitable when the reef has a low crest or the tidal range is large, as the boat needs draught to navigate off the reef, after dropping the bag.

The reef was built on soft sand bars which are mobile. The sinkage has been relatively minor, i.e. less than 1.5 m. However, geobags with their narrow cross-section are prone to sinkage on active beaches.

Figure 11. The Gold Coast Reef (Australia) constructed from 400 geotubes each 20m long



Source: Ecocoast (2017)

Figure 11. The Gold Coast Reef (Australia) constructed from 400 geotubes each 20m long

Source: Ecocoast (2017)

Figure 13. The Gold Coast reef was constructed from over 400 large geotubes filled with sand. They were pumped up on a split hull barge which then drove over the site and the bags were dropped.

Source: Black (2000)

Case Study: Borth, Wales, United Kingdom

The Borth Reef was designed to protect the town beaches from very large storms. The goals were to provide offshore protection from waves, while also creating a structure which may be suitable for surfing (Black et al., 2003).

The reef was constructed from rocks, after geotubes were rejected (Figure 14). A temporary road was built from the shore to the reef to bring the materials. Excavators then worked the rocks into the required shape. For better stability, the surface rocks were larger and packed into a tight tessellated pavement. In the lower picture (Figure 14), the large salient which the reef has produced is evident. The reef has successfully protected the Borth coast which receives very large storms.

Figure 14. Construction of the reef at Borth

Source: Borth Community (2011)

Kovalam Reef, Kerala

Kovalam Reef was designed to be multi-purpose to protect the shore and provide quality surfing for visitors and locals. The reef was designed after the most intensive studies undertaken in India for a beach protection solution (Mathew et al., 2008). Substantial field data under-pinned computer modeling which had three goals: (1) to determine the cause of the beach erosion; (2) to find the best solution which would overcome the cause, and; (3) to model the various options and optimize the solution. The studies revealed that sand was leaking from the bay during the monsoon from the southern end around a headland. The losses were associated with a strong rip current against the headland.

The solution to the erosion was the elimination of the rip current and was achieved by building a reef at the southern end. The waves breaking on the reef generated shoreward currents which opposed and cancelled out the rip current.

The reef was made using 28 geotubes of 1.5 to 3 m high and 3 to 4 m across. The tubes were 38 m long. The reef was a single layer of geobags to make a total length of 110 m. The modeling revealed that the bags should be staggered to put the reef at an oblique angle to the shoreline.

Observations and surveys of the beach following construction showed that the computer predictions were correct. The beach was much wider. In addition, surfing wave quality was very good and news went global. Many international visitors came to Kovalam for the surfing. Many of the locals have learned the skill which has allowed them to set up small businesses based around surfing.

Unfortunately, because the project was independent of the Irrigation Department which is responsible for shore protection, there was no budget for maintenance. The geotubes have a high ratio of volume (weight) to surface area (base) which means that they are prone to sinking. Many of the geobags can still be seen at the site, but maintenance is required to put a second layer on the reef.

Figure 15. Before and after photos of the Kovalam reef

Source: Photo taken by consultant J. Mathew (2017)

India's first multi-purpose reef at Kovalam was constructed from sand filled geocontainers. Upper pictures (Figure 15) show the beach immediately after the reef construction in February 2010 and one year later February 2011. In the lower pictures, show the beach width before and after the reef construction. The reef has successfully protected the Kovalam beach particularly during monsoon storms.

In a more recent project at Puducherry, a new system was designed to overcome the sinking and durability problems with geotubes (Black and Mathew, 2016). The reef is being made using steel plate on a frame. The full reef (which is triangular with 60 m sides) is being constructed on land, towed to the site, and water is allowed into the structure to sink it into position.

Discussion

Reefs / islands are a very natural solution for coastal erosion. They simply copy the example set by nature. Most importantly, once the beach salient is formed, they allow natural bypassing of sand. Many stakeholders prefer this solution because it meets most of their aspirations. The reef has minor visual impacts, requires no construction on the beach, can be modified as a water sport enhancement (e.g. surfing). The habitat they provide can also greatly benefit marine life and fishers.

The benefit / cost ratios for well-designed reefs can be very large, particularly in tourism areas. In addition, reefs deal with the waves, which are the cause of the erosion, rather than trying to deal with the effects at the shore. This makes it ideal for climate change adaptation. The crest can be raised, if required.

Further examples of hybrid projects using offshore breakwaters and beach nourishment are shown in Figure 16 and Figure 17.

Figure 16. Maumee Bay State Park (United States) showing a nourishment program combined with offshore breakwaters

Source: USACE (1992)

Figure 17. A series of offshore breakwaters with nourishment. The beach has formed into a patter of salient and tombolos

Source: USACE (1992)

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CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 2

APPENDIX 11

DATA COLLECTION AND MODELING

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APPENDIX 11
Data Collection and Modeling

Introduction

This Appendix discusses the requirements for data collection and numerical modeling to understand a site when planning and implementing coastal protection measures. Modeling provides a vehicle by which coastal engineers can illustrate complex interactions, test theories and project future situations and outcomes. The data is needed in its own right and to supplement the modeling with information for calibration.

Planning and designing for adaptation in the coastal zone must be based on sound coastal knowledge and understanding. The starting point is an understanding of the coastal processes. To quantify those processes data and modeling are needed. Data are required to quantify the present situation along the coast, the assets and uses affected and to enable models to be set up, validated and run. Baseline data for monitoring the outcomes of coastal management and planning actions is also needed.

Typically, in India many studies have been undertaken to measure waves and currents. However, very little has been done at the beaches and virtually no data has been collected, before embarking on a protection scheme, to measure longshore currents, longshore sediment transport and beach dynamics covering the surf zone.

There is a need in India to provide the research institutes and professional consultants with the urgency and means to undertake a broader range of measurements and to study the beaches to prepare for climate change. Several organizations have the capacity to make wave and current measurements but none have the sophisticated equipment or expertise to work within the surf zone.

In addition, more intensive analysis of data is needed with a focus on understanding the dynamics. Many consulting projects in the past have simply recorded and presented data, without delving into what the data reveals. With models, they have been used at times to simply prove that modeling has been undertaken, rather than using the models to fully test options, scenarios, storm conditions and a careful consideration of the physical system. The model is a powerful tool, but it must be used to really understand the existing system first and then used to examine potential benefits or impacts of proposed methods to solve an erosion problem. As far as we know, there have never been any measurements in India of the dynamics around seawalls and associated sediment transport, turbulence or wave dynamics. And yet, seawalls are the most common form of coastal protection in India.

International coastal scientists have adopted many modern advances in instrumentation and models and so the focus here is to show the level of study which is undertaken internationally with data collection and modeling. Many of the examples are drawn from studies by the National Institute of Water and Atmosphere, New Zealand, (NIWA) and the University of Waikato, New Zealand. The model studies have been undertaken using the 3DD Suite of Physical Process Models (Black, 2000).

Data Collection

In most studies, the data collection forms the basis for understanding the system within the sediment cell so that solutions can be designed which are compatible with the environment and any impacts can be forecast for a decision to be taken with full knowledge of project costs and future reparation that might be required.

For beach studies, data is normally needed across a range of categories:

- **Bathymetry -** finding the depths around the region of interest, including offshore not only beach profiles. Bathymetry will often need to be recorded at least twice; at the end of the wet and dry seasons.

- **Wind -** many of the processes are responsive to winds, including currents along the coast. Wind measured inland is usually not suitable.

- **Sea level -** sea levels vary with tides and a range of other factors like storm surge, coastal-trapped waves and direct wind forcing. Sea level is one of the primary factors determining the design of structures.

- **Currents -** recording the currents both offshore and within the surf zone under a variety of weather and wave conditions.

- **Waves -** measurements of waves are essential to predict longshore currents, longshore sediment transport, design material sizes and to know the size and stability of a solution needs to be put in place.

- **Sediment dynamics -** direct measurements of sediment fluxes on beaches are rare in India but they need to be made to confirm empirical equations and models.

- **Beach morphology -** beach-dune-sand bar transitions provide an important understanding of the cross-shore and longshore sediment dynamics. At inlets, the interactions that occur between waves and river / tidal flows are reflected on the beach morphology.

- **Grain sizes -** the sand size plays a critical role in predictions of sediment dynamics and needs to be measured along cross-shore profiles from the top of the beach to at least 10 m depth.

- **River flow -** river flows determine the delivery of sand to the coast and have a strong influence on the formation of spits, sand bars and deltas at the entrance.

- **Water parameters -** temperature, salinity, density and chemical contents are often needed to determine the state of the water quality.

- **Primary production -** while many coastal projects have no impact on primary production, some projects like power stations, hot water discharges and sewage discharges require good knowledge of the impact on phytoplankton and zooplankton, which underpin the marine food chain.

- **Beach and dune vegetation -** for beach-dune care or nourishment projects the information on native vegetation becomes very important.

Bathymetry

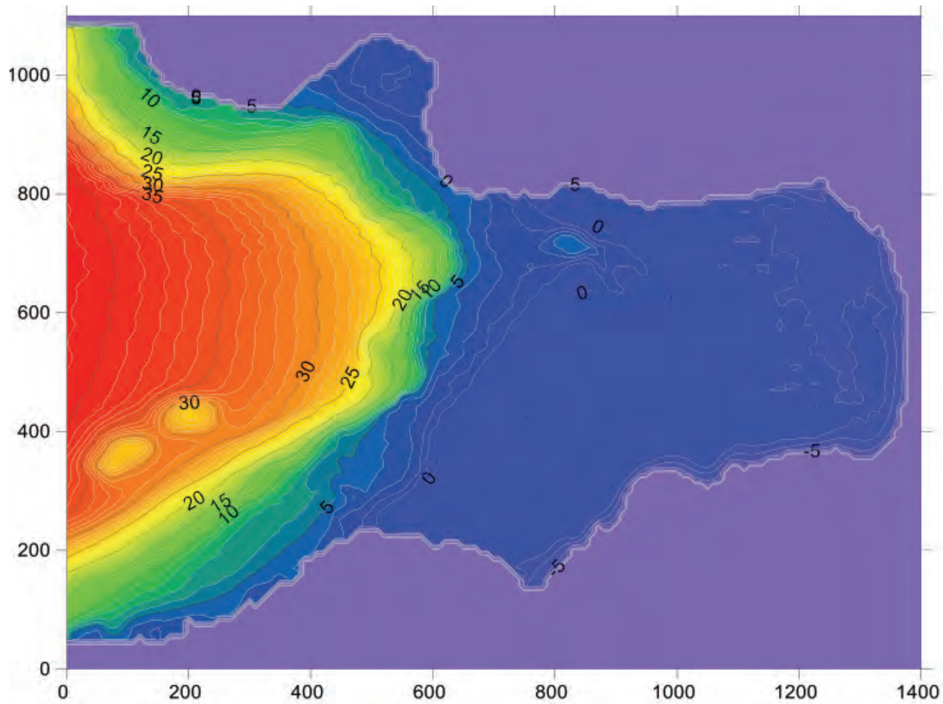
Coastal bathymetry is an essential prerequisite for any study (Figure 1). Normally surveys are undertaken offshore from a vessel while a land-based total station system is used for the nearshore zone. Jet skis are now commonly rigged with high quality bathymetry instruments in water proof boxes to enable measurements in the surf zone (Figure 2). Alternatively, sleds with a global positioning system (GPS) and reflector can be towed through the surf zone to obtain profiles (Figure 3).

Issues to be confronted relate to the use of high quality equipment that corrects for wave action through differential GPS, careful measurement of the datum and knowledge of the relationship to chart datum. The surveyor must ensure that the "run–line" spacing is small enough to resolve important bathymetric features. When determining the spatial scale, it is important to consider the sediment cell size, likely wave orientations and model grid size. Many studies will require 2 to 10 m horizontal resolution cross-shore and 40 to 100 m resolution longshore.

Data for the seas and coast around India is available from the National Hydrographic Office, Dehradun *(http://www.hydrobharat.nic.in/)* in contour form. These data provide a high quality baseline, but most studies require more detailed measurements around the region of interest and close to the coast. An example of large-scale bathymetry is shown in Figure 4.

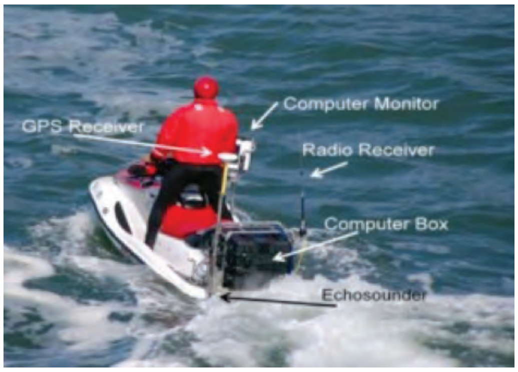
On most Indian coasts, the nearshore bathymetry will change between the seasons and so surveys at the end of both the wet and dry seasons are normally needed.

Figure 1. High resolution bathymetric surveys show the seabed depths underwater and the beach in Seychelles



Source: Black (2014)

Figure 2. Jet ski nearshore hydrographic survey system

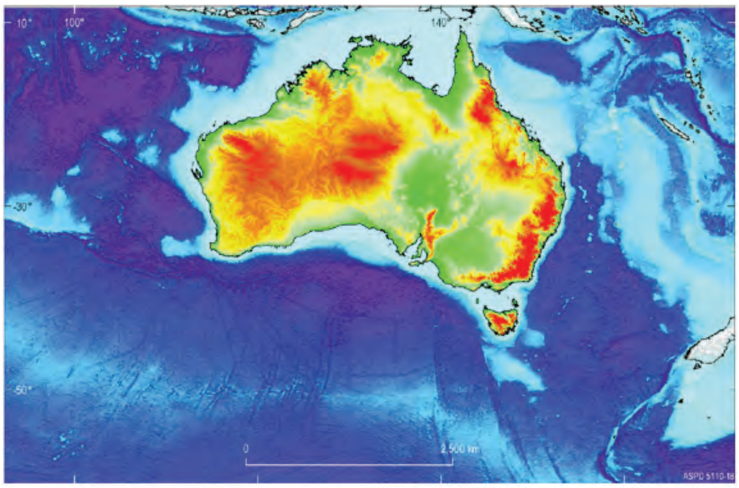


Source: Wood and Ruggiero (2014)

Figure 3. Sled that is towed through the surf zone

Source: Hutt et al. (1999)

Figure 1. High resolution bathymetric surveys show the seabed depths underwater and the beach in Seychelles



Source: Geosciences Australia dataset

Wind

Currents along the coast, sea level and wave conditions are all responsive to winds. The number of quality wind stations along the coast in India is usually inadequate. For each field deployment, a wind station needs to be established at least 5 m above ground level, without obstructions. Figure 5 shows a typical wind measurement tower that has two sensors so that the boundary layer effects can be distinguished. Normally one set of sensors at 5 to 10 m above open ground level is sufficient. The instruments should measure barometric pressure and air temperature. The former is used to eliminate barometric pressure effects from the pressure-based sea level measurements.

Figure 5. Typical wind measurement tower

Source: Calvin College (2010)

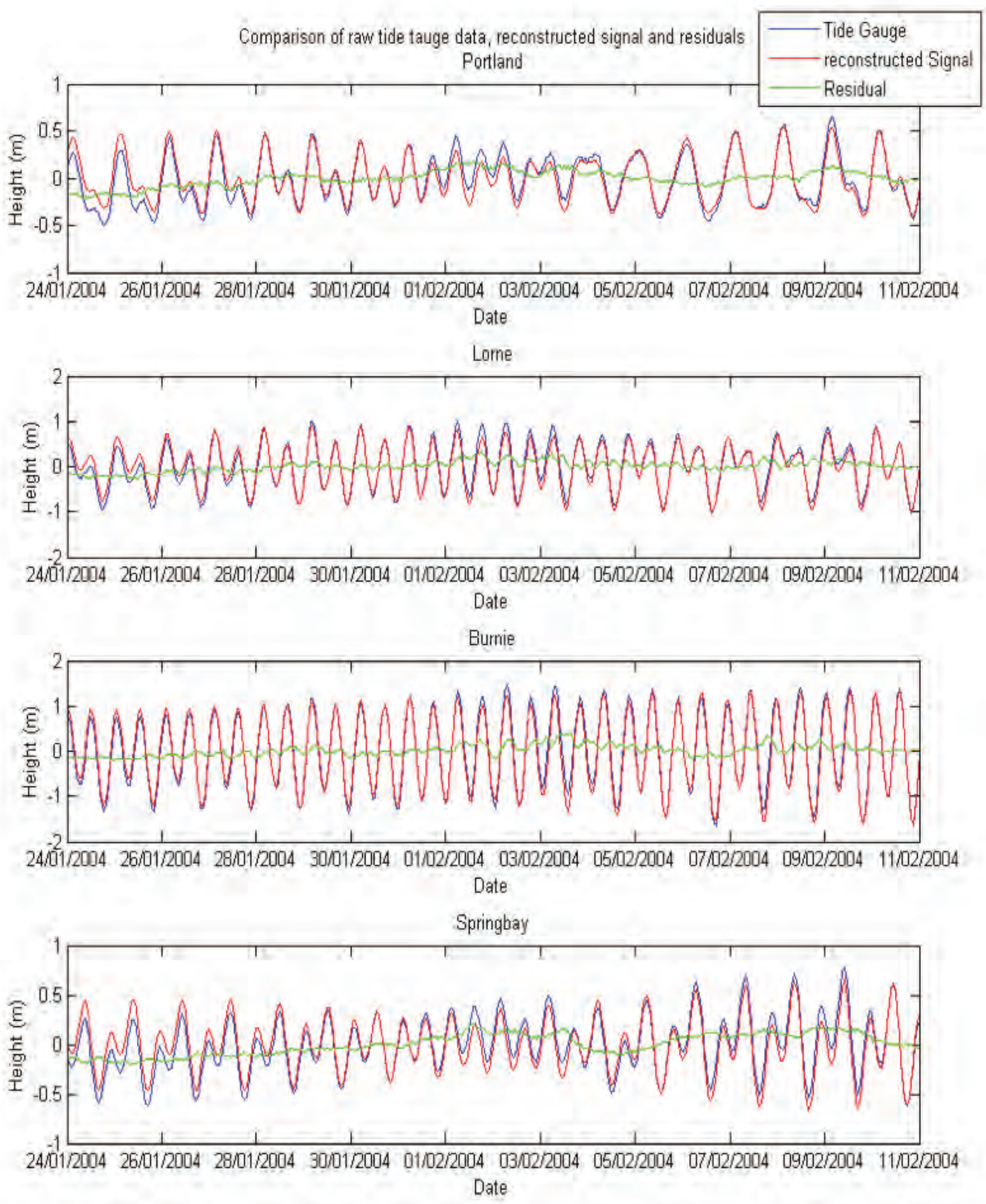
Sea Level

Raw sea levels are normally measured at the site by a pressure sensor with in-built digital memory. To discriminate the spring / neap tidal cycle at least 30 days of measurements are needed. In some cases, a convenient sensor may be already located in a nearby port.

The raw records are subjected to a tidal analysis, whereby: (1) barometric pressure is removed; (2) the tidal constituents are found; (3) the residual levels after removing the tides are calculated, and; (4) the residual is correlated to local winds (Figure 6). Many sea level records will contain variations due to coastal-trapped waves which have not been studied in detail in India.

For modeling the open coast, it is often necessary to have two sensors, one at each end of the model domain so that boundary conditions can be established. If an estuary or river is being modeled then levels need to be recorded outside the entrance and deep into the estuary. If a river is involved, then records need to be taken during high and low river flows and the effect of the river on levels needs to be determined.

Figure 6. Analyzed sea level records showing raw data, tidal signal and residual



Source: Geosciences Australia dataset

Current

Currents can be recorded in conjunction with waves using a modern wave / current meter (Figure 7). These record flows at a particular depth while also recording the sea level variations at high frequency to obtain wave information. The currents are normally taken as the average over 10 to 15 minutes, while the wave record is often at 2 Hz. Many instruments use burst mode where a burst of data is collected every 30 to 60 minutes, which enable longer time periods to be stored in memory.

More sophisticated acoustic doppler current profilers (ADCP) will measure simultaneously in layers through the water column. These are especially useful in stratified flows or to record up / downwelling on a coast.

Deployments preferentially have duration of at least 30 days to record the spring / neap cycle and obtain currents under a variety of wave and wind conditions. Measurements will be needed during both the wet and dry seasons.

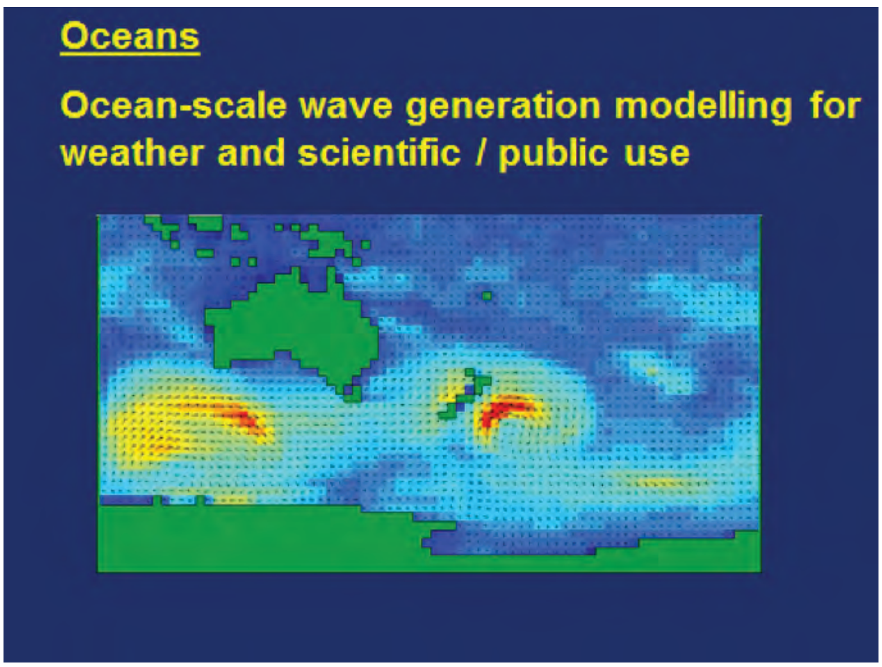
Figure 7. Diver retrieving an InterOcean S4, wave and current meter after long deployment

Source: McComb et al. (2001)

Waves

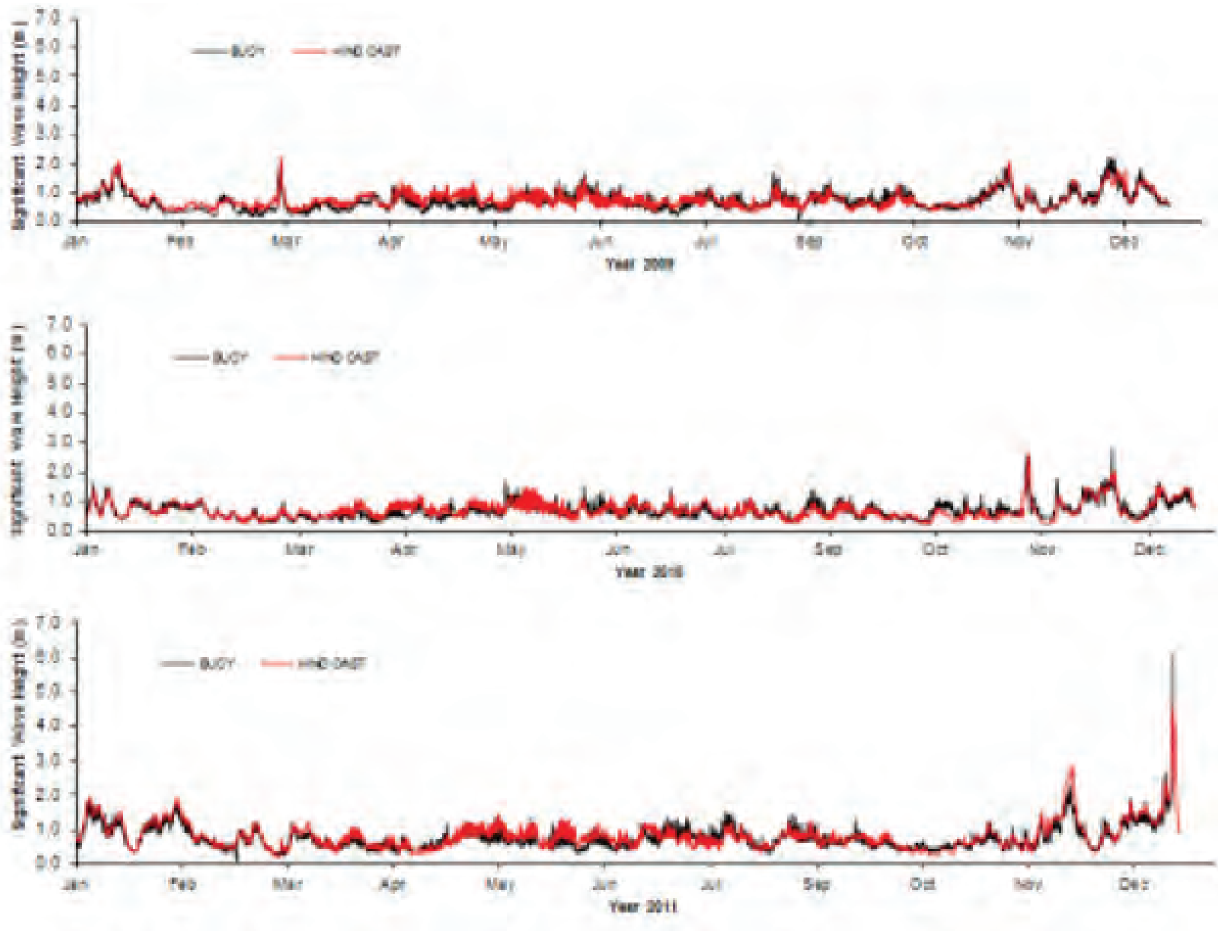
Waves can now be very closely predicted by global or regional wave models (Figure 8). Time series of wave heights, periods and angles are also readily available for the Indian coast for purchase from professional suppliers via the internet. Wave hindcasts of more than 30 years provide a high quality time series for calculating long-term sediment transport fluxes on beaches and for assessing storm intensity and extreme events. Comparisons with local measurements show that the global wave models can accurately reproduce the wave conditions at sites around the Indian coast (Figure 9).

Figure 8. Wave models can now accurately predict wave height, period and orientation globally



Source: Gorman, NIWA (2017, pers. comm.)

Figure 9. Wave height recorded locally (wave-rider buoy) versus computer hindcast over 3-year period (Pondicherry, India)



Source: Black and Mathews (2015)

Sediment Dynamics

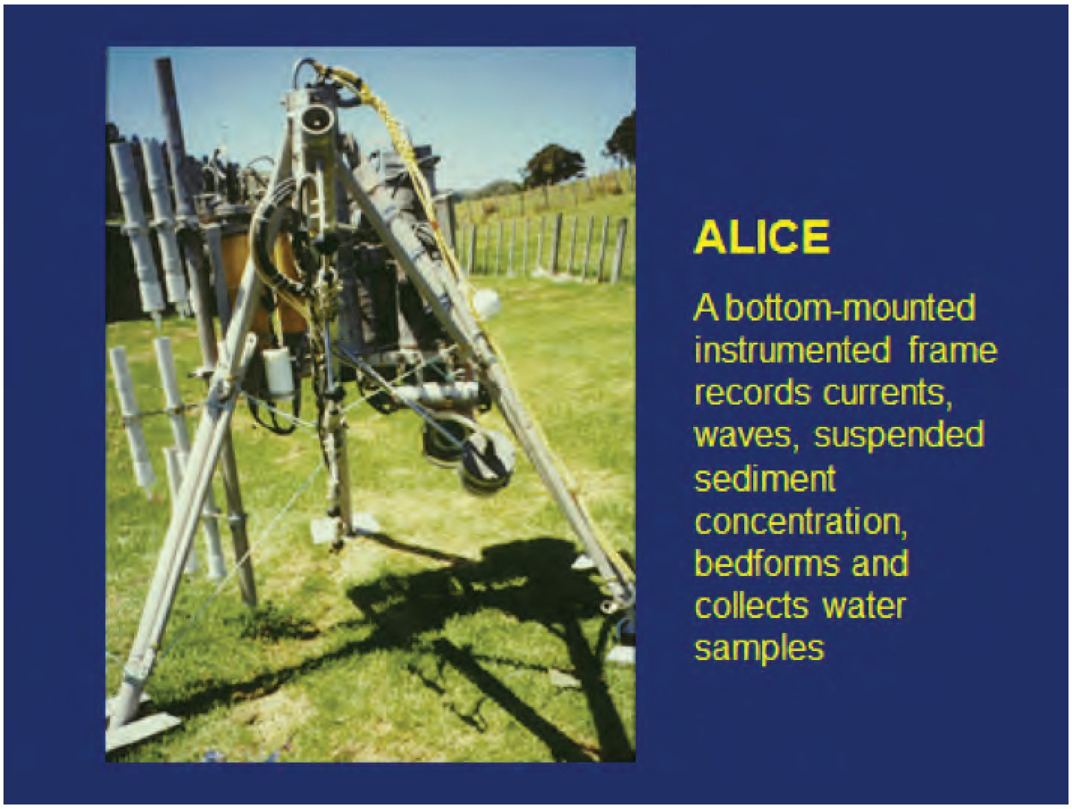
Measurement of sand concentrations in the water column and under waves has become technically feasible, although sophisticated equipment is needed which has not been used in India yet. The cost of the equipment is high but at least one research center in India needs to be given access to this type of equipment, noting the importance of beaches.

Typical sensors are infra-red to record sediment concentrations or acoustic to measure bedforms on the seabed. Others act by trapping a water sample, analyzing the sediment for concentration and grain size and then releasing the sample. This may be repeated every 30 minutes. Complex arrays of equipment may be placed on a seabed tripod (Green et al., 1997; Green and Black, 1999) (Figure 10 to Figure 15).

A less expensive and useful technique is the sediment trap. This is made simply from household polyvinyl chloride (PVC) pipe with a hole in the top. Sediment falls into the trap over time and the volumes can be converted to water column concentrations, knowing the grain fall velocity. These traps were used to assess the impacts of sand mining at Chavara in Kerala (Black et al., 2002). Vijayakumar et al. (2013) used traps to record longshore transport at Pondicherry.

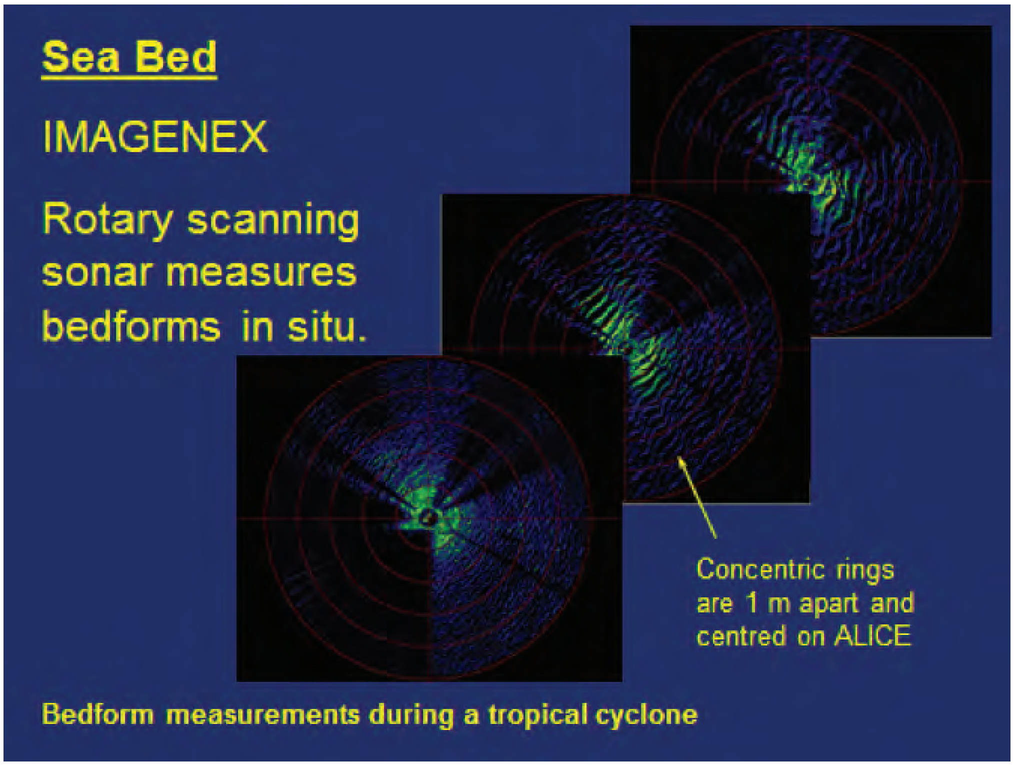
In some studies, marked tracers can be adopted. These may be actual sand grains marked with radiation, sand painted fluorescent or purpose made sediment beads from fluorescent plastic (Burgess et al., 2007). This technique is particularly useful for directly measuring longshore sediment transport and has been used to track dredge spoil or sand movement around headlands (McComb et al., 2004).

Figure 10. ALICE tripod containing an array of instruments to measure sediment transport, waves, bedforms and water samples



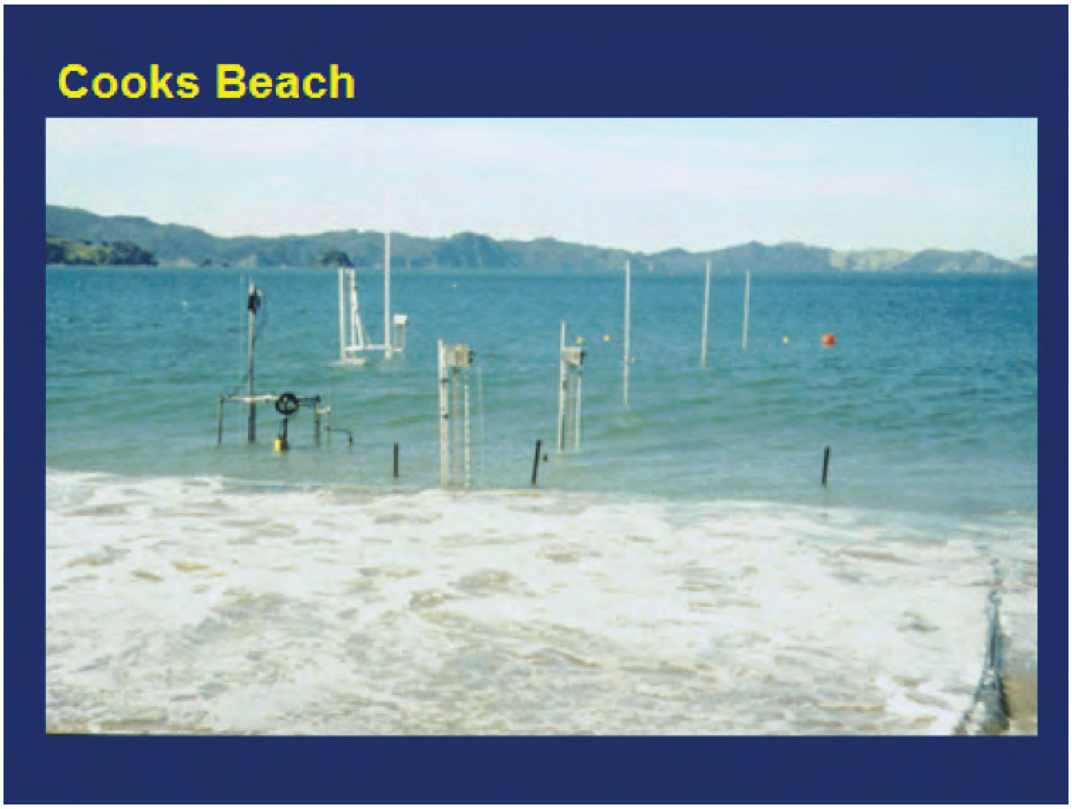
Source: Green and Black (1999)

Figure 11. Variations in bedforms over a storm, as measured with an Imagenex acoustic sensor on the ALICE tripod



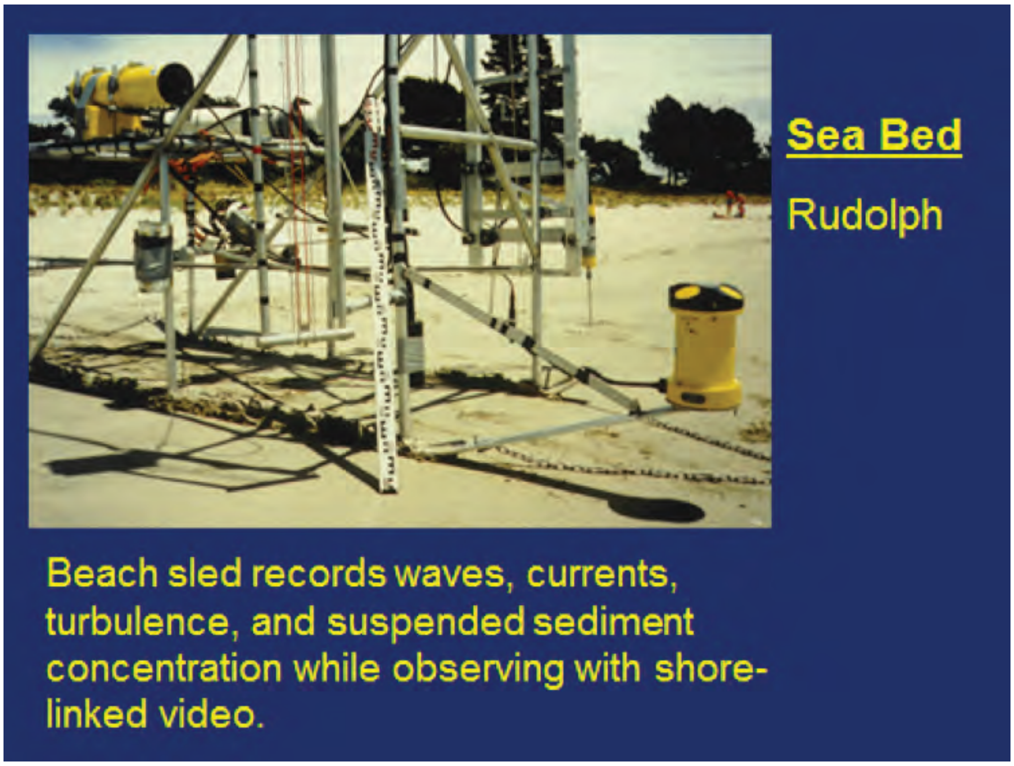
Source: Hume, NIWA (2017, pers. comm.)

Figure 12. Complex array of sensors in Cooks Beach, New Zealand, to record wave transitions and sediment dynamics. No similar experiments have been done in India



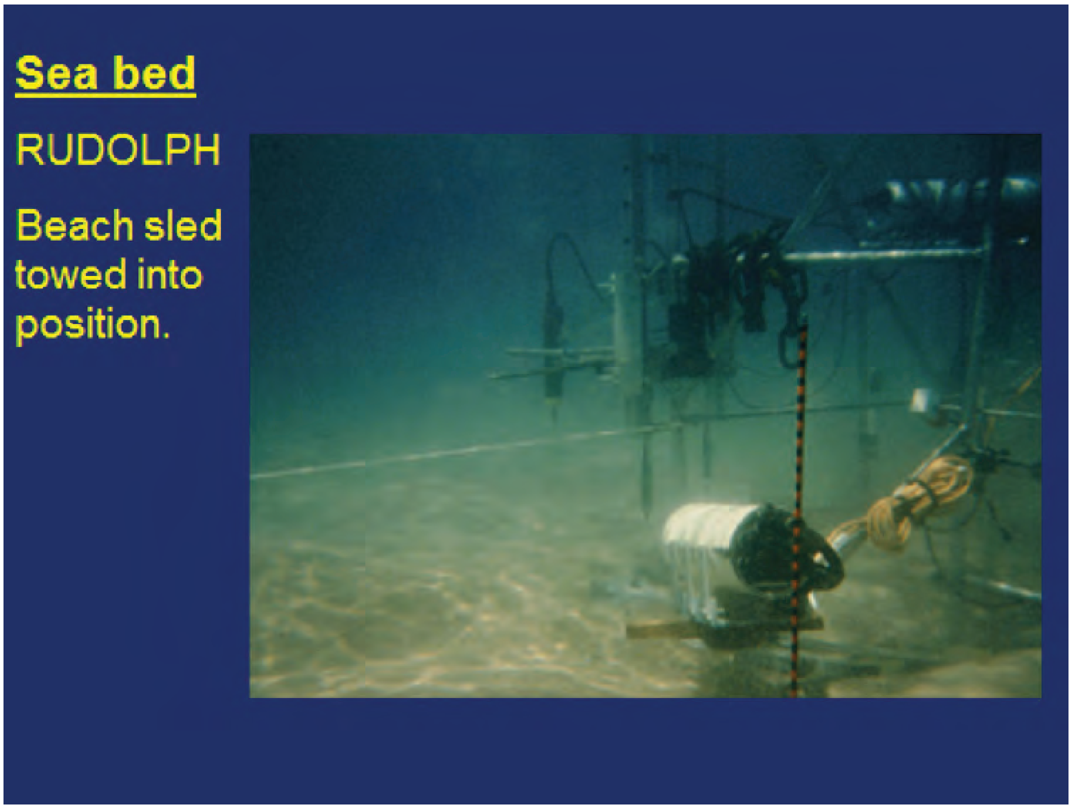
Source: Grant et al. (1998)

Figure 13. Rudolph sled that was developed to be towed through the surf zone measuring the seabed profile, suspended sediment load, 3D currents and micro-scale turbulence



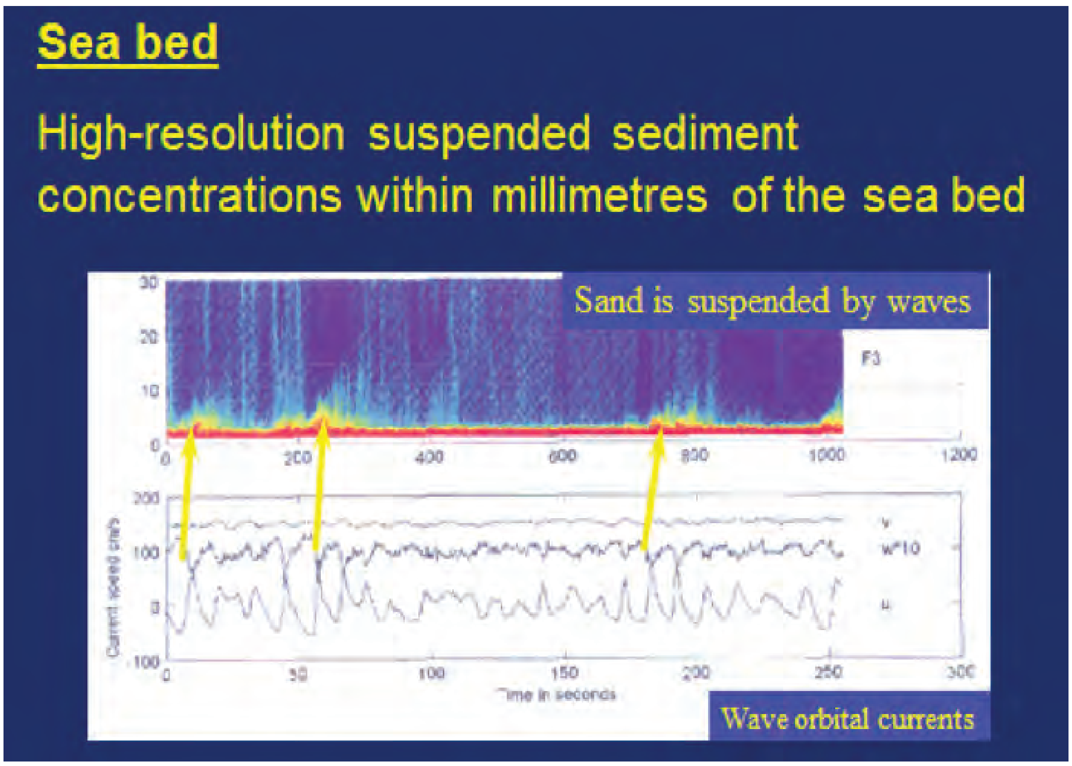
Source: Grant et al. (1998)

Figure 14. Rudolph sled in action. A video camera records the dynamics around the sensors recording micro-turbulence, suspended sediment, waves and currents



Source: *Grant et al. (1998)*

Figure 15. Sensors are now able to record sediment suspension within millimeters of the sea bed. this record shows puffs of sand rising from the sea bed as waves pass overhead



Source: *Black and Vincent (2001)*

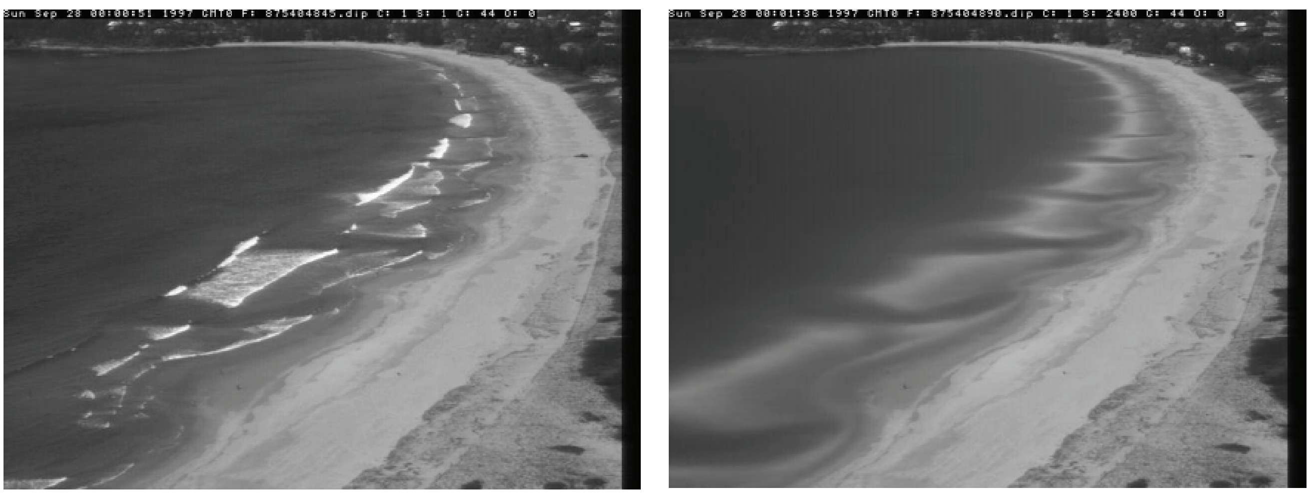
A common method to record the changes that occur on beaches is time lapse photography or video (Figure 16 to Figure 18). This allows the beach to be watched for periods when events sculpt the beach topography and sand bars.

With careful surveying and software, the images can be "rectified" to provide vertical images that allow the changes to be mapped and digitized in known coordinates.

Figure 16. CAM-ERA time lapse video image at Tairua, New Zealand

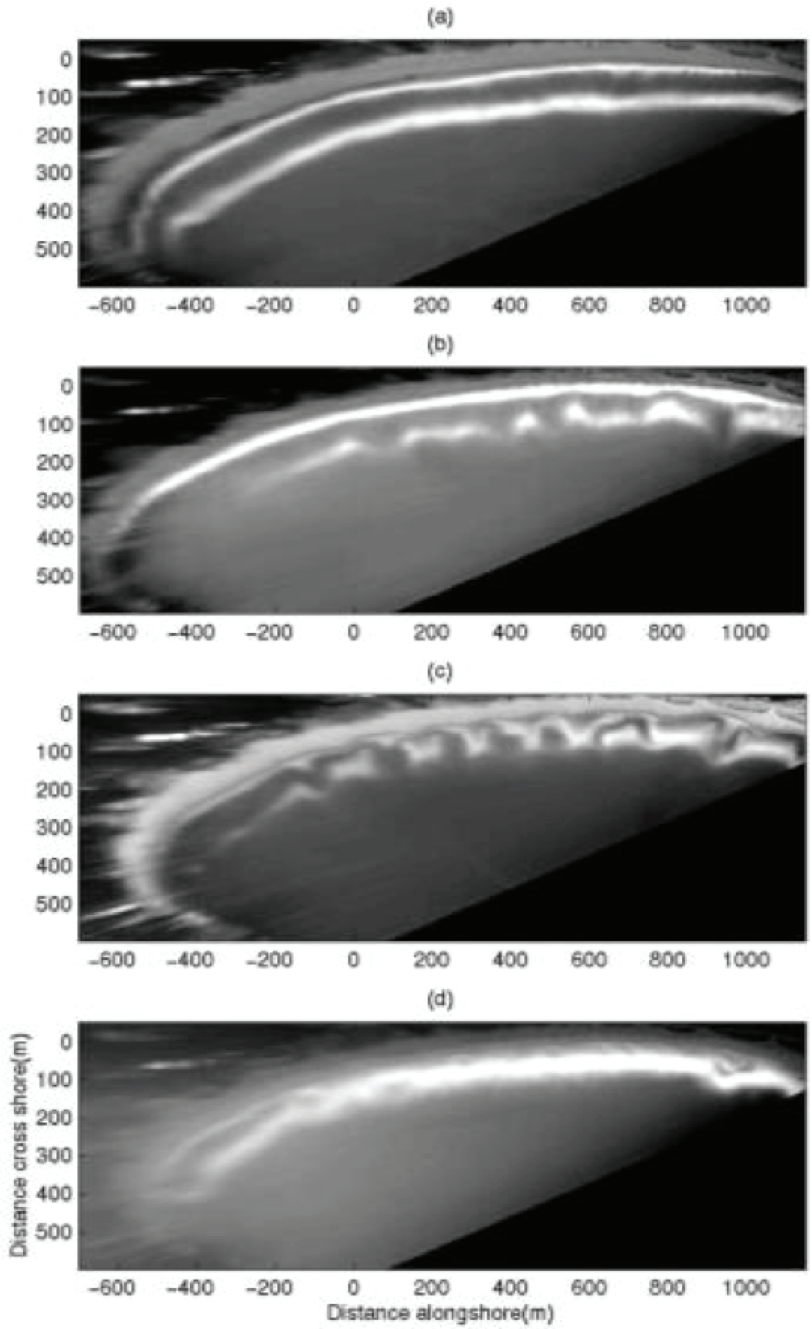
Source: Hume et al. (1999)

Figure 16. CAM-ERA time lapse video image at Tairua, New Zealand



Source: Ranasinghe et al. (2004)

Figure 18. Transitions in beach bars can be observed over long time periods with time lapse video systems



Source: Ranasinghe et al. (2004)

Grain Size

The sediment grain sizes on a beach are a key input parameter to models. In India, a sample is normally analyzed using sieves of different sizes to find the fraction of each size. For modeling, the fall velocity is needed and so “fall tubes” which measure the time for sand to fall through water are more useful.

Normally samples will be taken from the low tide, beach face, high tide and upper beach. Further samples need to be taken underwater in mid-surf zone, at the breakpoint bar and at two to three locations offshore.

In many parts of India, the quartz sands are mixed with iron rich black sands (Black et al., 2002). These have different densities and so both components need to be analyzed separately. They behave differently under waves and have been observed to be in different ratios on beaches in different seasons (Prakash et al., 2005).

River Flow

River flows are very difficult to obtain in India. Far more attention needs to be put to this deficiency because the rivers have a very strong influence on the coast and are responsible for much of the sand delivery to the beaches. The most common way to measure flows is by using the river levels which are converted to flows using a calibrated period when the currents are measured simultaneously.

River volume inputs are often an essential dataset for modeling of an estuary or estuary entrance. The river levels also determine flooding, mud inundation, collapse or growth of mud / sand banks and currents around many ports.

Water Parameters

The most common water parameters to record are salinity, temperature, turbidity and conductivity (Figure 19). These measurements will be needed in all estuarine studies to define the intrusion of salt water and mixing processes. They act as a surrogate for current metering, by showing the estuarine dynamics and mixing. Models are often calibrated against salinity as it indicates the advection and mixing of the river inputs with the salt waters from the entrance of the estuary. Turbidity is an important indicator of the concentration of muds being carried to the sea from the river.

Figure 19. Citadel conductivity, temperature and depth meter for profiling real-time data collection

Source: Ocean Innovations (2017)

Primary Production

Knowledge of larval dispersal and primary production is needed to sustain species for future fishers. Primary production measurements have played an important role in fisheries regulations, marine parks and most ecosystem projects. Excessive nutrients can lead to harmful algal blooms (Figure 20).

Primary production involves the measurement of phytoplankton and zooplankton. The simplest measurement for phytoplankton is fluorescence as a surrogate for Chl-a concentrations. Some researchers will take water samples to be later analyzed in the laboratory. Zooplankton is normally measured by towing nets through the water and then analyzing the captured species under a microscope.

Primary production is a measure of the health of the ecosystem. As climate changes, species move with water currents and follow temperature isotherms, the measurements give early warning against potential failures of the fishery.

Figure 20. Blue green algal bloom in Lake Erie

Source: Essex Region Conservation Authority (2011)

Beach and Dune Vegetation

The term "vegetation", as used here, encompasses all the different plant species that grow from the high waterline to the back of the beach through the dunes. The different climatic and environmental conditions influence the species growing in different regions of the beach-dune ecosystem through the process of vegetation succession. For beach and dune management base line information should be gathered so that changes in vegetation cover and species composition can be monitored over time. The vegetation on the restored beach-dune system need to be sustainably managed by regular monitoring procedures decided specific to the site.

Establishing a Field Program and Modeling

When planning a field program, the modeling requirements must be kept in mind. It is normally essential to make measurements simultaneously during an intense measurement period. For example, if currents are measured after sea levels, then it is difficult to link these to each other and formulate model boundary conditions or undertake calibration.

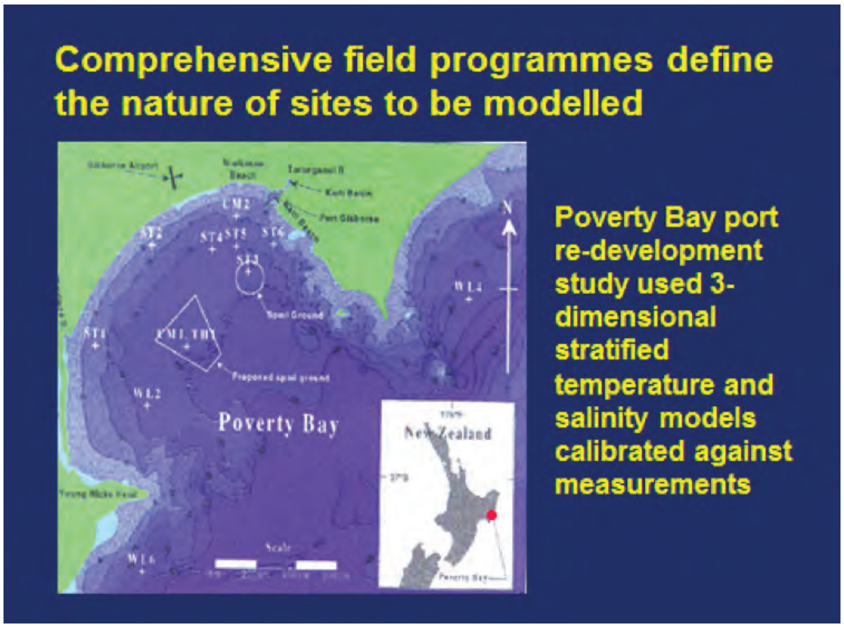
The factors to accommodate are the need to record bathymetry in the surf zone, the difficulty of working in a surf zone and the need to make a broad study, rather than just offshore currents and sea levels. Specialized equipment will be needed. On an open coast, the boundary conditions are more complex than in an estuary as the model zone is subjected to water level gradients due to tides and factors such as coastal-trapped waves (Middleton and Black, 1994).

As an example, a case study at Gisborne, New Zealand, is shown in Figure 21. The goal was to predict infilling rates in port channels and design a new port. This bay receives large quantities of fresh water from the river, making it stratified. This meant that surface and bottom currents were different and so ADCP current meters were used to record throughout the water column, in synchrony with water level and other measurements. A 3D stratified hydrodynamic and wave model was established with detailed bathymetry. Sediment transport predictions were needed to assess infilling rates of port channels for maintenance dredging and a new port was being designed (Healy et al., 2002).

A second example is shown from the Hauraki Gulf, New Zealand. Here, currents were measured in 3D to show the complex circulation in a large eddy on the headland which determined the distribution and patterns of drifting larvae and from a marine park and sediment dynamics around the headland (Figure 22).

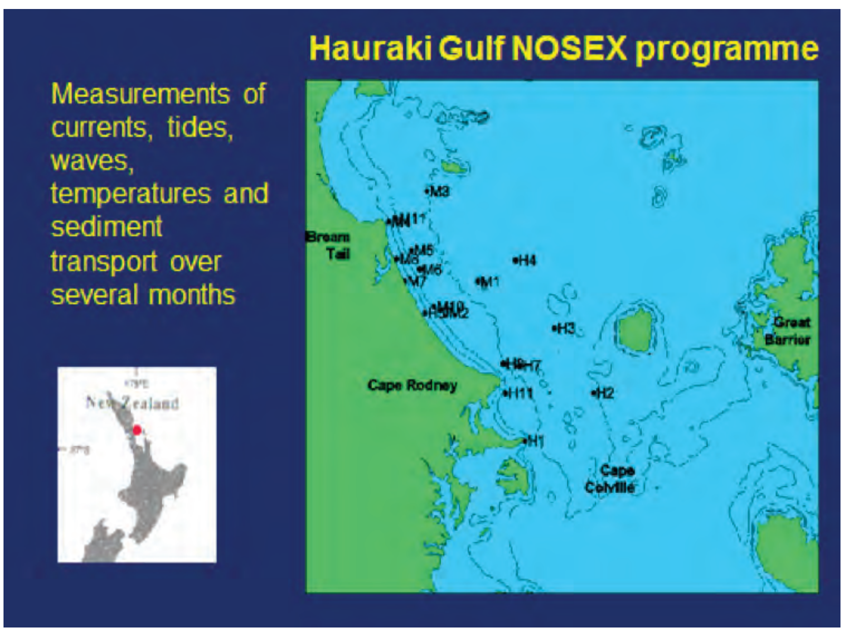
The third example shows measurements made to determine the impacts of dredge sand disposal from a port on New Zealand's west coast (Figure 23). The marine colonies on the nearby reefs were to be protected from sediment inundation. This project adopted numerous sediment traps and tracers which showed the direction and volume of sediment transport over a period of months. Sand samples were collected regularly and the number of tracer beads in each sample was counted under a fluorescent microscope. At the same time, sea levels and currents were measured at multiple sites. Figure 23 shows the very large experiment that was conducted to determine the movement of dredge sands after disposal. The goal was to gain consents for nearshore sand dumping as the beaches downstream of the port were eroding due to disposal offshore. The data proved to be useful for model calibration (McComb et al, 2001).

Figure 21. A field measurement program in a stratified bay, New Zealand, recorded currents at many positions through the full water column, with waves and sea levels



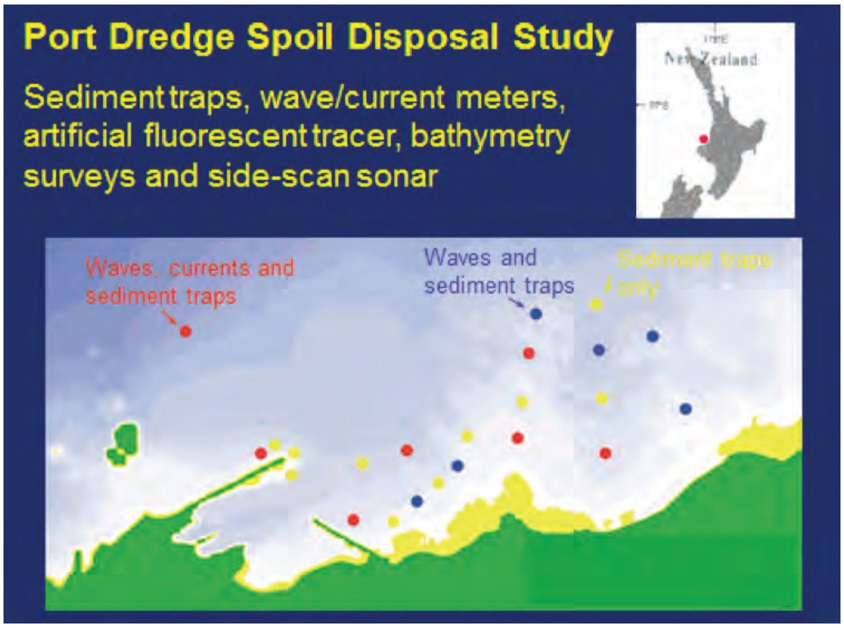
Source: Healy et al. (2002)

Figure 22. Measurements made in 3D around a marine park in Hauraki Gulf, New Zealand



Source: Black et al. (2005)

Figure 23. Large experiment conducted to determine the movement of dredge sands after disposal.



Source: McComb et al. (2001)

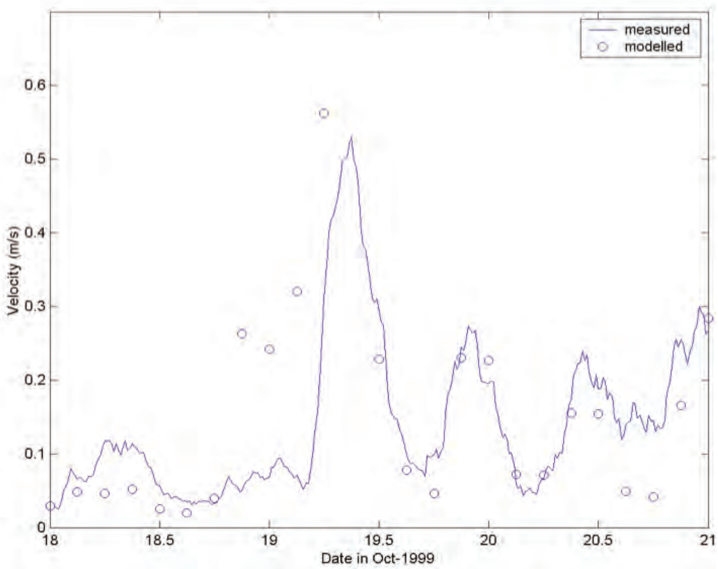
Model Calibration

Model calibration is the most difficult stage of any project. But before calibration is started, the modeler must analyze all the data to understand the system and thereby carefully choose the models to be used and the boundary conditions. All data must be prepared and presented and any insights about the site coming from the data must be fully evolved and reported before commencing the modeling.

Normally a range of models will be used to simulate waves, currents, sediment transport and beach morphology. The calibration involves comparing the model with the measurements to ensure that both the model and the modeler's assumptions and choices are correct, and matching the environment being simulated.

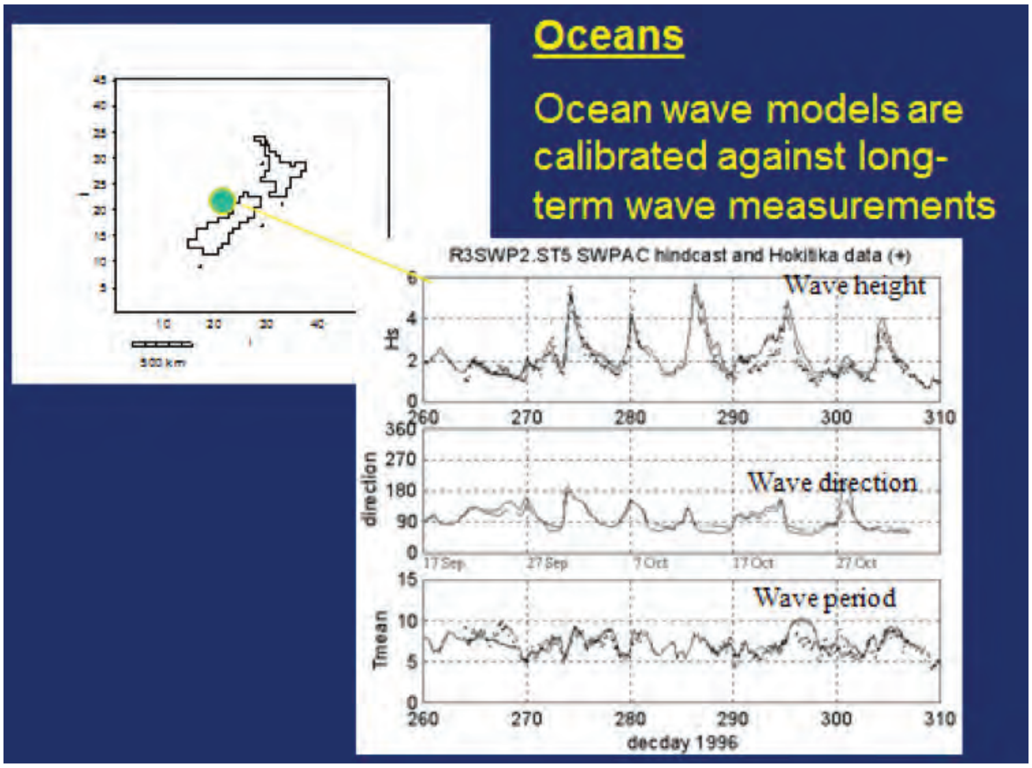
Figure 24 to Figure 35 show a breadth of examples of model calibrations. Calibration is required for every aspect of a project and can prove to be very time consuming. Models cannot be relied on without calibration, and so "off-the-shelf" models without supporting data are not adequate when important decisions need to be taken about coastal solutions.

Figure 24. Calibration of measured rip current velocities and the model predictions on a beach



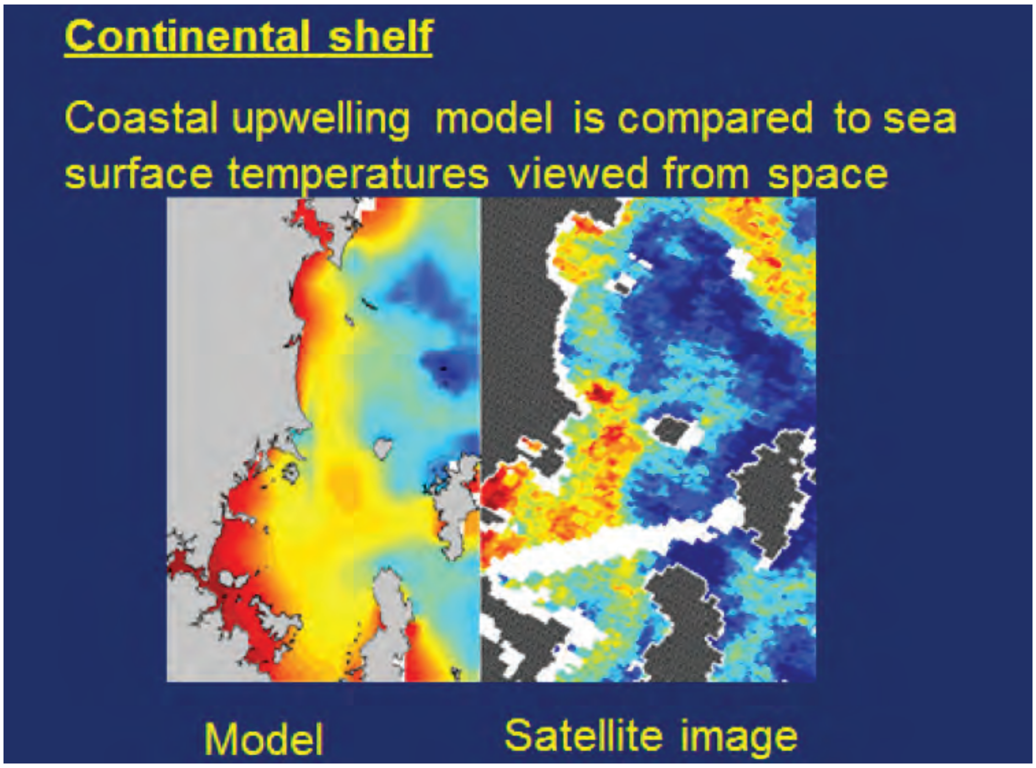
Source: McComb et al. (2001)

Figure 25. Comparison of measurements and a wave prediction model showing wave height, direction and period



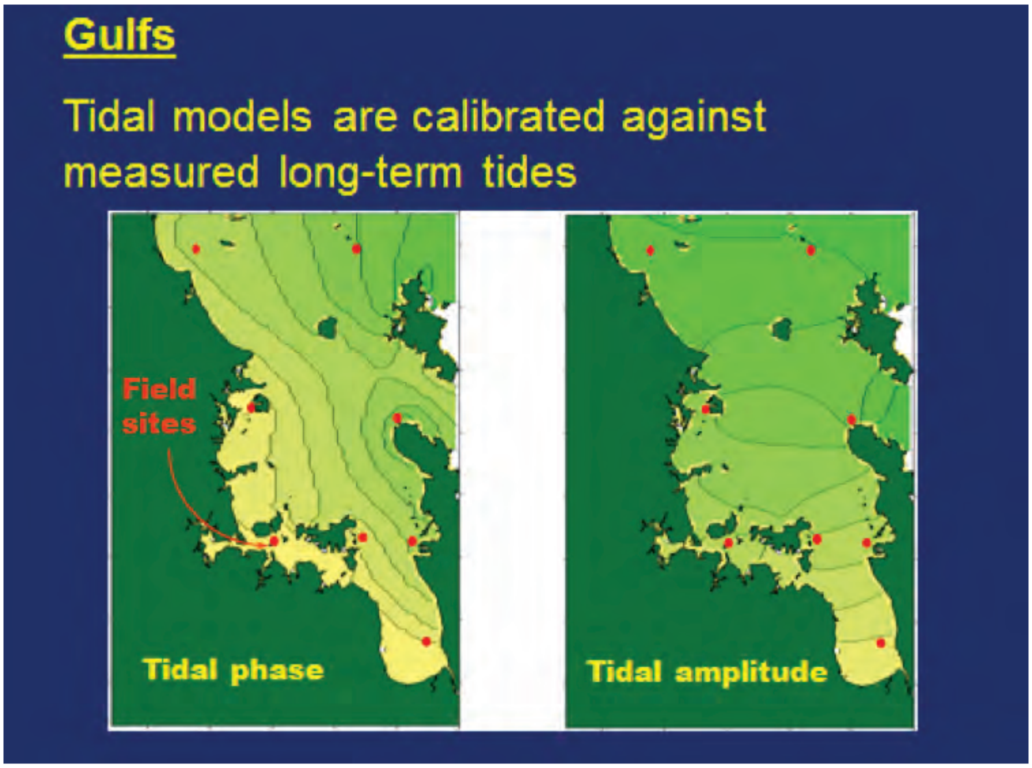
Source: Gorman, NIWA (2017, pers. comm.)

Figure 26. Calibration of a model against satellite images of hot water upwelling within a large embayment on the east coast of New Zealand



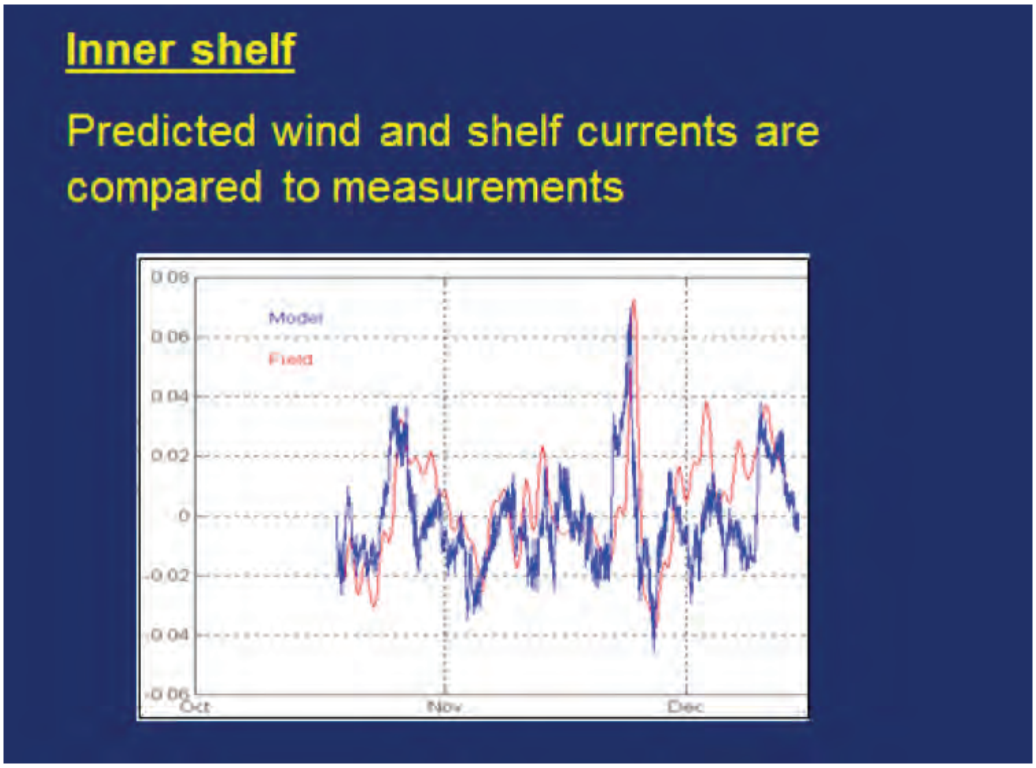
Source: Gorman, NIWA (2017, pers. comm.)

Figure 27. Calibration of a tidal model against tidal phase and tidal amplitude at numerous sites in the long Hauraki Gulf, New Zealand



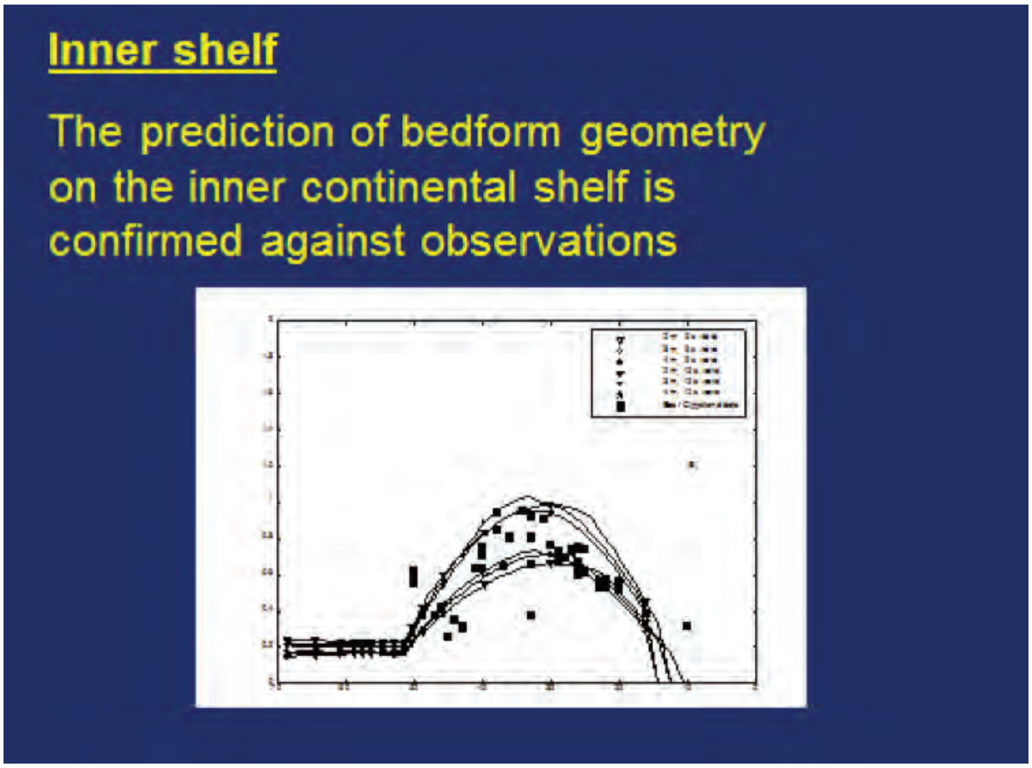
Source: Black (2017, pers. comm.)

Figure 28. Calibration of a model against measured currents on the continental shelf



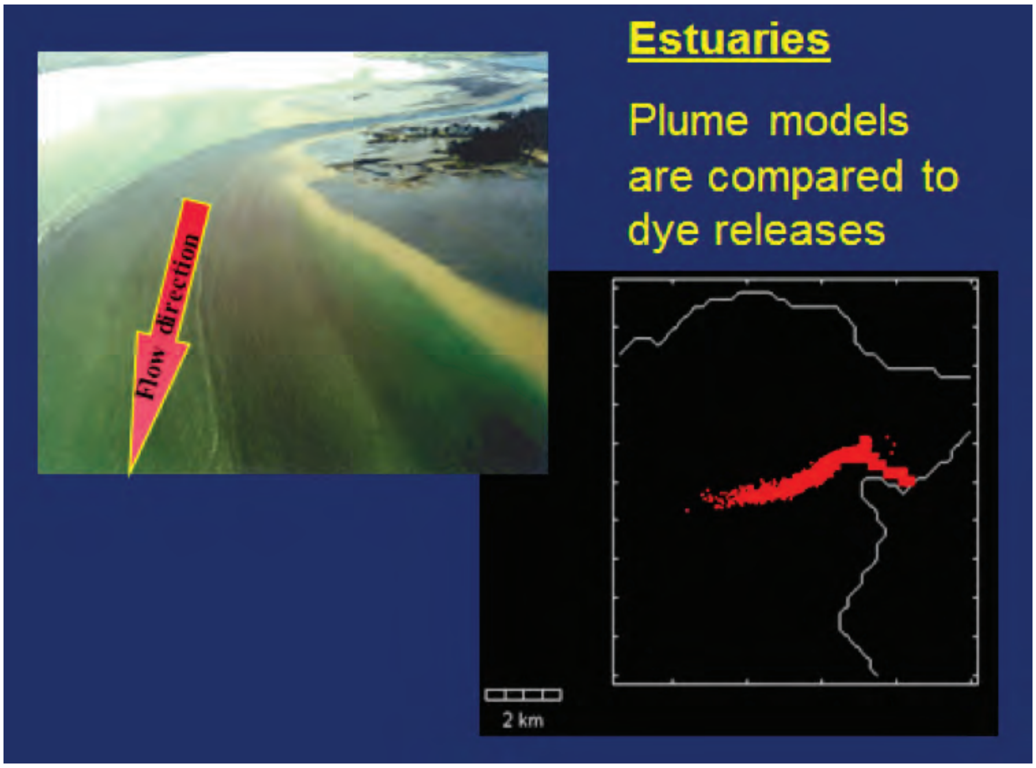
Source: Black (2017, pers. comm.)

Figure 29. Calibration of a model against measured bedform geometry on the continental shelf



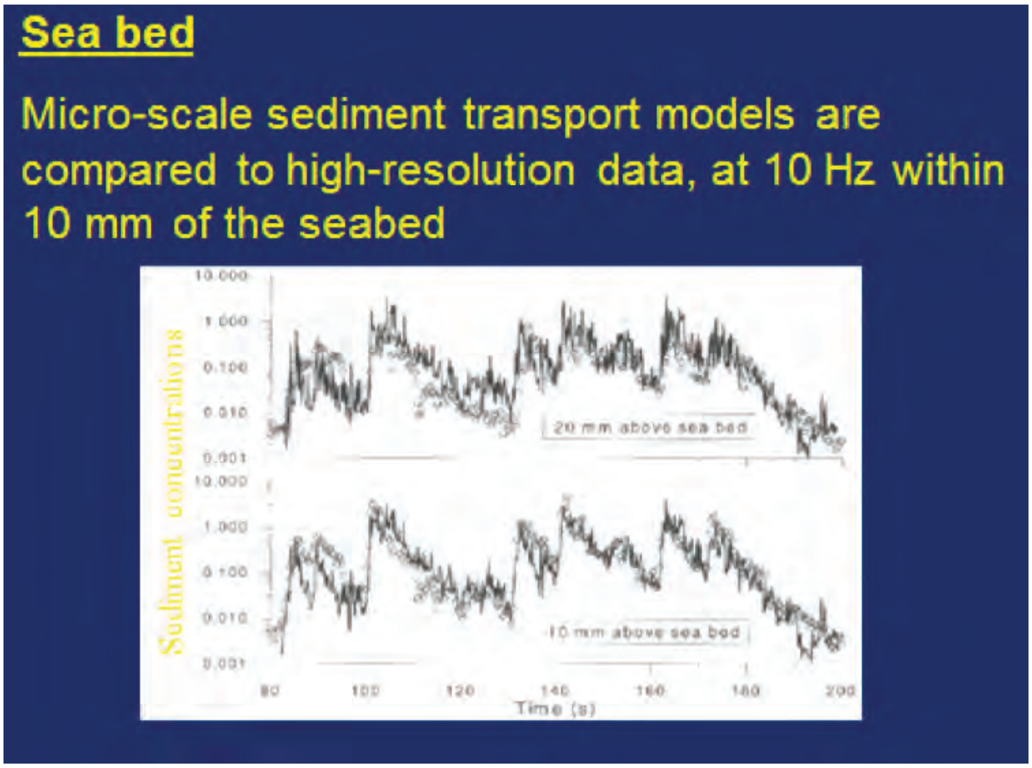
Source: Black and Oldman (1999)

Figure 30. Calibration of a 3D stratified hydrodynamic model against measured currents and temperatures



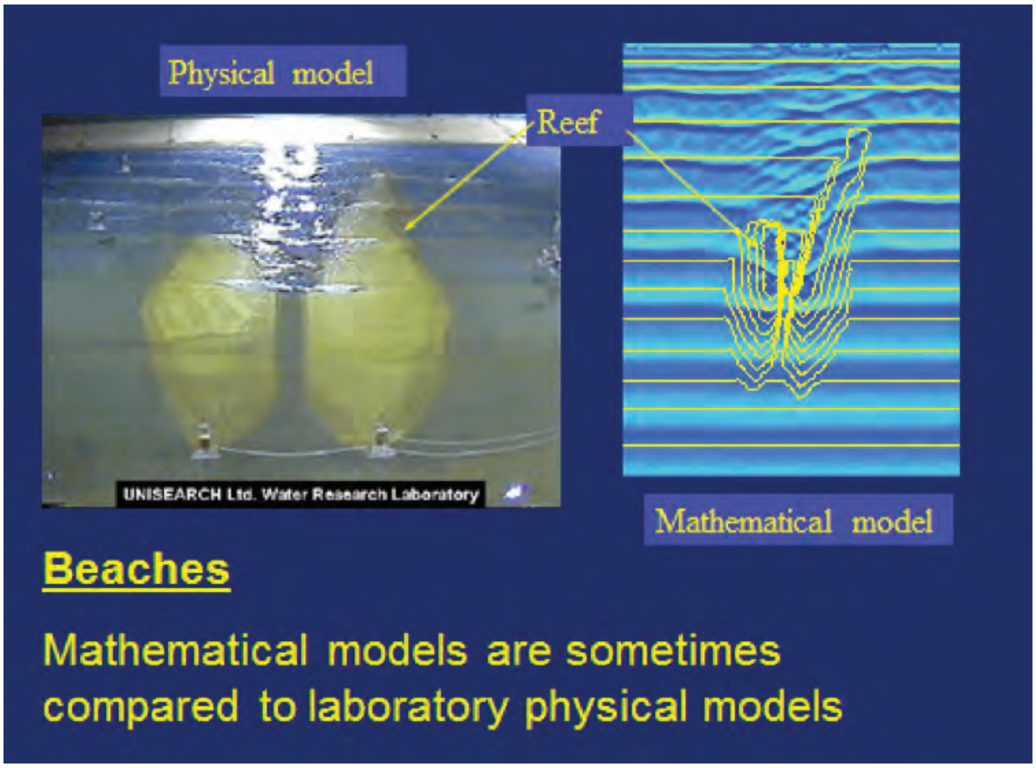
Source: Bell et al. (1996)

Figure 32. Calibration of a micro-scale model of sediment suspension under waves (within mm of the bed and within the wave cycle) against acoustic measurements



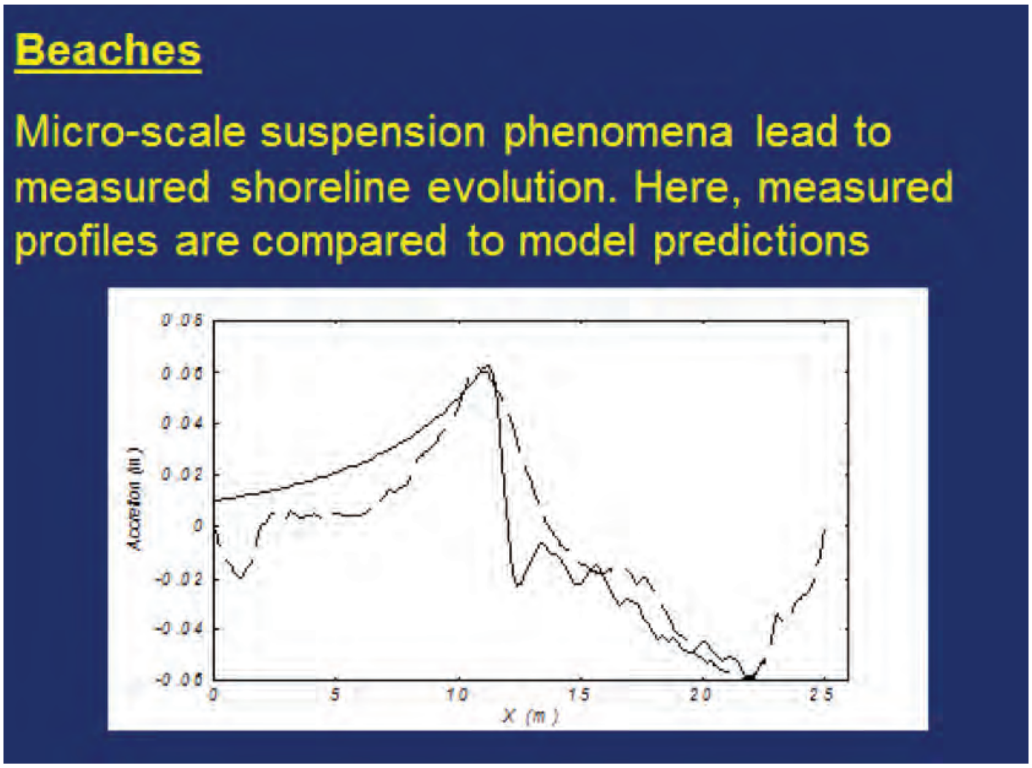
Source: Black and Vincent (2001)

Figure 33. Calibration of a mathematical model against a physical model of the Gold Coast Reef for coastal protection and surfing



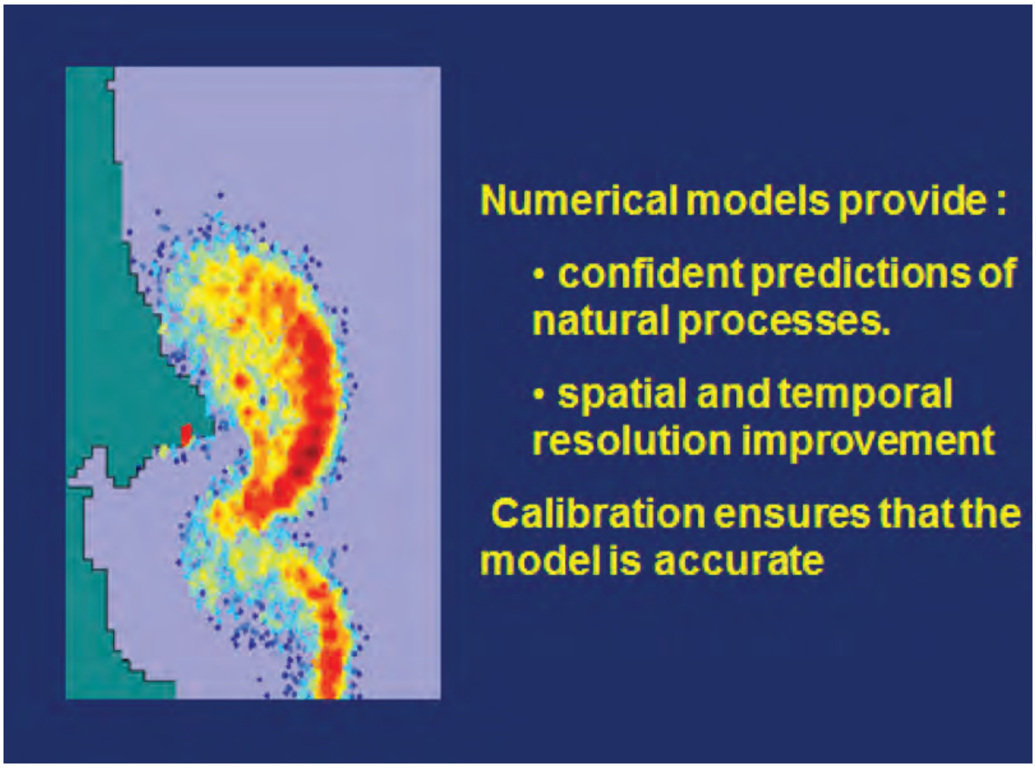
Source: Black (1999)

Figure 34. Calibration of a beach sand bar model against measurements of bar evolution



Source: Black (2017, pers. comm.)

Figure 35. The dispersal of larvae around the headland was confirmed by calibrating against measured currents in 3D



Source: Black (2017, pers. comm.)

Case Study: Sediment Budgeting for the Chavara Coast, India

In India, a sediment budgeting study was carried out by the Centre for Earth Science Studies from 1999 to 2002 and is presented here as a case study (Black et al., 2002). Comprehensive data collection and numerical modeling were used to address sustainability in beach sand mining. The coast under study was the Neendakara - Kayamkulam sector of length 22 km along the southwest Indian coast which is referred to as the Chavara coast (Figure 36) and is world famous for its rich placer (mineral rich black sand) deposits. Beach sand mining by the Indian Rare Earths Ltd. (IREL) and its predecessor companies was going on at various sites along the Chavara coast since 1930 for extraction of heavy minerals. This barrier beach has been undergoing erosion over the past few decades and the local population attributed this to mining by IREL. While studies on waves and beach processes have been going on in great detail on the Kerala coast (Baba and Kurian, 1988), large measurement programs of a range of sedimentary processes have not been previously attempted in Kerala. Consequently, this project was the most informative work about coastal sedimentary systems along the coastline ever undertaken in the country at that time.

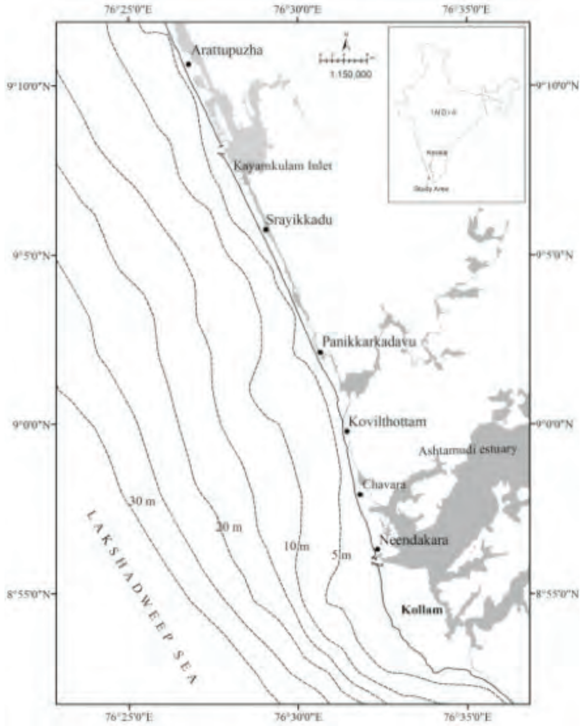
The project, initiated in 1999, included the following objectives:

- Quantification of the heavy mineral input / output from / to different sources / sinks along the Neendakara - Kayamkulam coast;
- Budgeting of the heavy mineral resources along the Neendakara - Kayamkulam coast;
- Assessment of the contribution of beach mining to the erosion along this coast, and;
- Suggestions for spatial and temporal limits for the beach mining to facilitate the sustainable development of heavy mineral resources along this coast.

Methodology for the study: A field experiment was designed and various oceanographic and sedimentological parameters were measured in the offshore and beach adjoining the Vellanathuruthu and Kovilthottam mining sites of IREL at Chavara (Figure 37) (Black et al., 2002). The major instruments deployed were:

- Directional Wave-rider Buoy;
- InterOcean S4 Current Meter;
- FSI Acoustic Current Meters;
- Sontek Acoustic Doppler Profiler;
- Dobie Wave Gauge;
- HydroCamel Automated Submersible Water Sampler;
- Sediment Traps;
- Anemograph;
- Automatic Video Camera;
- Echosounder, and;
- Shallow Seismic Profiler.

Figure 36. Chavara coast extending from Neendakara inlet to Kayamkulam inlet and adjoining coasts. The sand extraction sites of IREL are Vellanathuruthu (midway between Kovilthottam and Panikkarkadavu) and Kovilthottam



Source: Kurian et al. (2002)

Beach-based field programs were carried out along the Neendakara - Kayamkulam coast. Beach profiling at 300 m spacing was carried out along the Kovilthottam and Vellanathuruthu mining sites and coarse grid profiling at 1 km intervals along the rest of the coast. In addition, sled profiling was done to get profile of the nearshore which is not possible to be collected through echo-sounding. The sled is towed through the surf zone while a shore-based total station records elevations to show the underwater bathymetry. A video camera established at the beach provided video images of the beach and littoral processes and an anemograph installed on the same tower enabled measurement of wind.

Four computer models were adopted from the 3DD suite of numerical process models (Black, 2000). A consolidated model was developed to provide predictions of potential extraction quantities.

Figure 37. (Left) Directional wave-rider buoy deployed at the offshore site; (Right) sediment trap assembly being deployed at the site

Source: Kurian et al. (2002)

Key Results: A sediment budget was computed for the coast which revealed that sand movement to the south on the inner shelf was essentially balanced by sand movement to the north in the surf zone. Similarly, the cross-shore fluxes were close to net zero:

Longshore transport

Towards north in the surf zone	1,67,000 m^3 / year
Towards south in the inner shelf	1,72,000 m^3 / year

Cross-shore transport

Onshore flux	53 m^3 / m / year
Offshore flux	44 m^3 / m / year

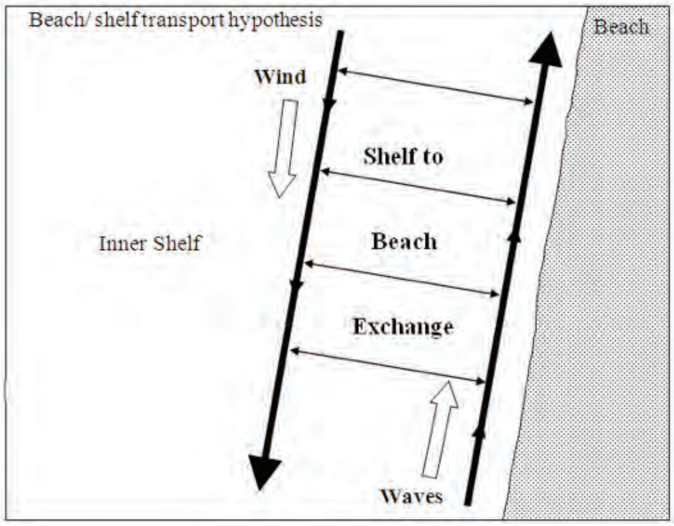
A sediment transport hypothesis likened to a "step-ladder" was proposed (Figure 38).

> On the Kerala coast at Chavara, the sedimentary equilibrium is maintained by an annual net northerly littoral drift, driven by surf zone wave-induced currents, which is balanced by the net southerly flux further offshore on the inner shelf driven by the wind-induced currents. These two counter-directional sedimentary pathways are linked by a cross-shore bridging transport.

The cross-shore fluxes occur in synchrony with wave-induced beach erosion during the stormy onshore winds and accretion during the periods of narrow-banded swell, thereby supplying or delivering the sediment to or from the beach to be further transported on/offshore by shelf currents.

This study showed for the first time that the net transport up the Kerala coast at Chavara may be balanced by return transport offshore, rather than requiring a constant source of new sand to feed the Hungry beaches. If so, the mining should lead to erosion, as has been observed.

Figure 38. Schematic showing "step-ladder" sediment transport hypothesis



Source: Black et al. (2008)

Monitoring During and Post Construction

To understand the performance of the structures / measures and their impact across and along the coast, it is essential to continue the monitoring and evaluation during the development and in the post-development phase. Ideally all the parameters measured and used in the modeling and design should be monitored. This will help in the assessment of the success of the intervention and allow mid-term corrections in the design and construction strategy to be made. Similarly, as the intervention normally takes years to prove its utility / impact the post monitoring is required to establish this. The duration and periodicity of measurements will be determined based on the size and criticality of the structure / intervention.

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CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 2

APPENDIX 12

ENVIRONMENT IMPACT ASSESSMENT OF COASTAL PROTECTION

ADB TA-8652 IND:

CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

APPENDIX 12
Environment Impact Assessment of Coastal Protection

Introduction

Environmental Impact Assessment (EIA) is a tool that seeks to ensure sustainable development through the evaluation of those impacts arising from a major activity (policy, plan, program or project) that are likely to have significant environmental effects. EIA systematically examines both beneficial and adverse consequences of the project and ensures that these effects are taken into account during project design. It helps to identify possible environmental effects of the proposed project, proposes measures to mitigate adverse effects and predicts whether there will be significant adverse environmental effects, even after the mitigation is implemented. By considering the environmental effects of the project and their mitigation early in the project planning cycle, environmental assessment has many benefits, such as protection of environment, optimum utilization of resources and saving of time and cost of the project. Properly conducted EIA also lessens conflicts by promoting community participation, informing decision makers and helping lay the base for environmentally sound projects. Benefits of integrating EIA have been observed in all stages of a project, from exploration and planning, through construction, operations, decommissioning and beyond site closure.

EIA is intended to prevent or minimize potentially adverse environmental impacts and enhance the overall quality of a project. The main benefits and advantages of EIA are:

- Lower project costs in the long-term;
- Increased project acceptance;
- Improved project design;
- Informed decision-making;
- Environmental sensitive decisions;
- Increased accountability and transparency;
- Reduced environmental damage, and;
- Improved integration of projects into their environmental and social settings.

The climate change adaptation guidelines require the coastal protection project shall prepare Comprehensive EIA including climate change impacts before any construction approvals are given. The guidelines emphasize that the design must be site-specific and based on a clear understanding of the coastal processes for the entire 'sediment cell', the long-term stability or instability of the entire cell and the ecological impacts therein. A comprehensive EIA based on long-term monitoring of the 'sediment cell' has been recommended. This appendix provides the basic requirements for the preparation of EIA and EMP for a coastal protection / management project.

For the EIA process the Ministry of Environment, Forests and Climate Change (MoEF&CC) has promulgated EIA notification in 1994 under the Environmental Protection Act (1986) making environment clearance mandatory for setting up new projects listed therein. The detailed Notification and the guidelines for EIA approval process is available in *www.moef.nic.in/environmental_clearancegeneral.*

The Environmental Impact Assessment Process of the Ministry of Environment, Forests and Climate Change

The basic objectives for EIA are to predict environmental impact of projects, find ways and means to reduce adverse impacts and shape the projects to suit local environment.
An EIA is expected to cover at least the following matters:

- Description of the proposed activities;
- Description of the base environmental and climatic conditions and potential affected environment including specific information necessary to identify and assess the environmental effect of the proposed activities;
- Analysis of the land use and land use change, waste generation, water consumption (and the existing balance), power consumption etc. along with the social and health impacts (in terms of number of people displaced, etc.);
- Description of the practical activities as appropriate;
- An assessment of the likely or potential environmental impacts of the proposed activity (like air pollution, noise generation) and the alternatives, including the direct or indirect, cumulative, short-term and long-term effects;
- A risk assessment report and disaster management plan to mitigate adverse environmental impacts of proposed activity and assessment of those measures;
- An indication of the likely area to be affected by the proposed activity or its alternatives, and;
- A detailed environmental feasibility report.

Project Proposal and Scoping

Preparation of a project proposal is the first step. The project proposal shall include all relevant information available including a land use map. Scoping is a process of detailing the terms of reference of EIA. Quantifiable impacts are to be assessed on the basis of magnitude, prevalence, frequency and duration and non-quantifiable impacts (such as aesthetic or recreational value), significance is commonly determined through the socio-economic criteria. After the areas, where the project could have significant impact, are identified, the baseline status of these should be monitored and then the likely changes in these on account of the construction and operation of the proposed project should be predicted. Base line data describes the existing environmental status of the identified study area. The site-specific primary data should be monitored for the identified parameters and supplemented by secondary data if available.

Impact Prediction and Assessment of Alternatives

Impact prediction is a way of mapping the environmental consequences of the significant aspects of the project and its alternatives. For every project, possible alternatives should be identified and environmental attributes compared. Alternatives should cover both project location and process technologies. Alternatives should then be ranked for selection of the best environmental optimum economic benefits to the community at large. Once alternatives have been reviewed, a mitigation plan should be drawn up for the selected option and is supplemented with an Environmental Management Plan (EMP) to guide the proponent towards environmental improvements. The EMP is a crucial input to monitoring the clearance conditions and therefore details of monitoring should be included in the EMP.

The Environmental Impact Assessment Report

An EIA report should provide clear information to the decision-maker on the different environmental scenarios without the project, with the project and with the project alternatives. The detailed Project report provides information in logical and transparent manner.

Monitoring has to be clearly spelt out for both construction and operation phases of a project. It is done not just to ensure that the commitments made are complied with but also to observe whether the predictions made in the EIA reports are correct or not. Where the impacts exceed the predicted levels, corrective action should be taken. Monitoring also enables the regulatory agency to review the validity of predictions and the conditions of implementation of the EMP. The generic structure of EIA report is condensed in Table 1.

Table 1. Generic structure of the EIA report

NO.	EIA STRUCTURE	CONTENTS
1	Introduction	• Purpose of the report • Identification of project and project proponent • Brief description of nature, size, location of the project and its importance to the country / region • Scope of the study – details of regulatory scoping carried out (as per terms of reference)
2	Project description	• Condensed description of those aspects of the project (based on project feasibility study), likely to cause environmental effects. Details should be provided to give a clear picture of the following: • Type of project • Need for the project • Location (maps showing general location, specific location, project boundary and project site layout) • Size or magnitude of operation (including associated activities required by or for the project) • Proposed schedule for approval and implementation • Technology and process description • Project description including drawings showing project layout, components of project etc. Schematic representations of the feasibility drawings which give information important for EIA purpose • Description of mitigation measures incorporated into the project to meet environmental standards, environmental operating conditions, or other EIA requirements (as required by the scope) • Assessment of new and untested technology for the risk of technological failure
3	Description of the environment of the entire sediment cell	• Study area, period, components and methodology • Establishment of baseline for valued environmental components, as identified in the scope • Base maps of all environmental components
4	Anticipated environmental impacts and mitigation measures	• Details of investigated environmental impacts due to project location, possible accidents, project design, project construction, regular operations, final decommissioning or rehabilitation of a completed project • Measures for minimizing and / or offsetting adverse impacts
5	Analysis of alternative coastal protection measures	• In case, the scoping exercise results in need for alternatives: • Description of each alternative including the results of the model studies • Summary of adverse impacts of each alternative • Mitigation measures proposed for each alternative • Selection of alternative
6	Environmental monitoring program also covering the entire sediment cell	• Technical aspects of monitoring the effectiveness of mitigation measures (including measurement methodologies, frequency, location, data analysis, reporting schedules, emergency procedures, detailed budget and procurement schedules)

7	Additional studies	• Public consultation • Risk assessment • Social impact assessment; resettlement and rehabilitation action plans
8	Project benefits	• Improvements in the physical infrastructure • Improvements in the social infrastructure • Employment potential-skilled; semi-skilled and unskilled • Other tangible benefits
9	Environmental cost-benefit analysis	• If recommended at the scoping stage
10	Environmental management plan	• Description of the administrative aspects of ensuring that mitigation measures are implemented as their effectiveness monitored, after approval of the EIA
11	Summary and conclusions (this will constitute the summary of the EIA report)	• Overall justification for implementation of the project • Explanation of how adverse effects have been mitigated
12	Disclosure of consultants engaged	• The names of the consultants engaged with their brief re-sume and nature of consultancy rendered

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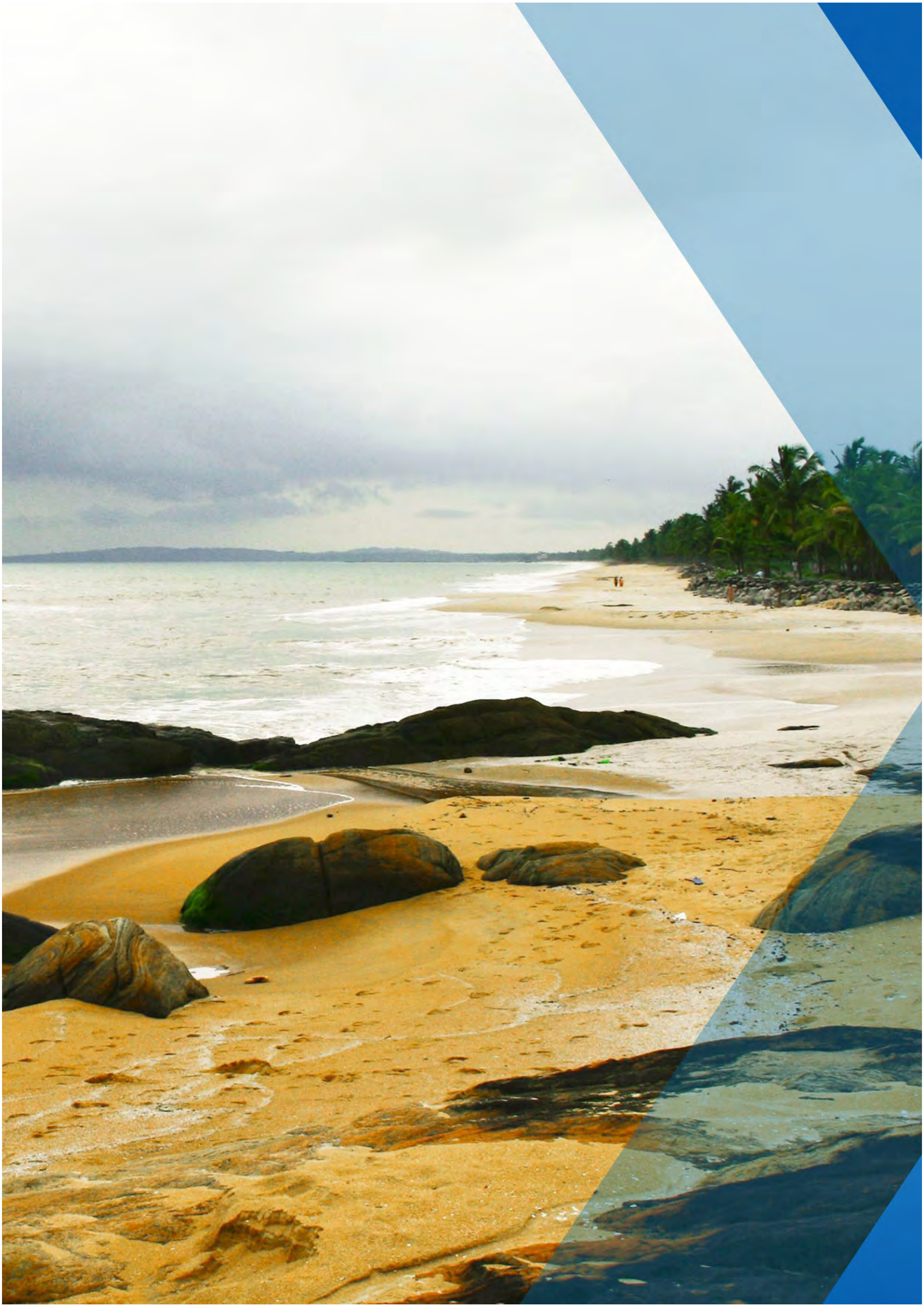


CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 2

APPENDIX 13

CLIMATE CHANGE PROJECTIONS FOR INDIAN COAST

ADB TA-8652 IND:

CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

APPENDIX 13
Climate Change Projections for Indian Coast

Climate and Climate Change

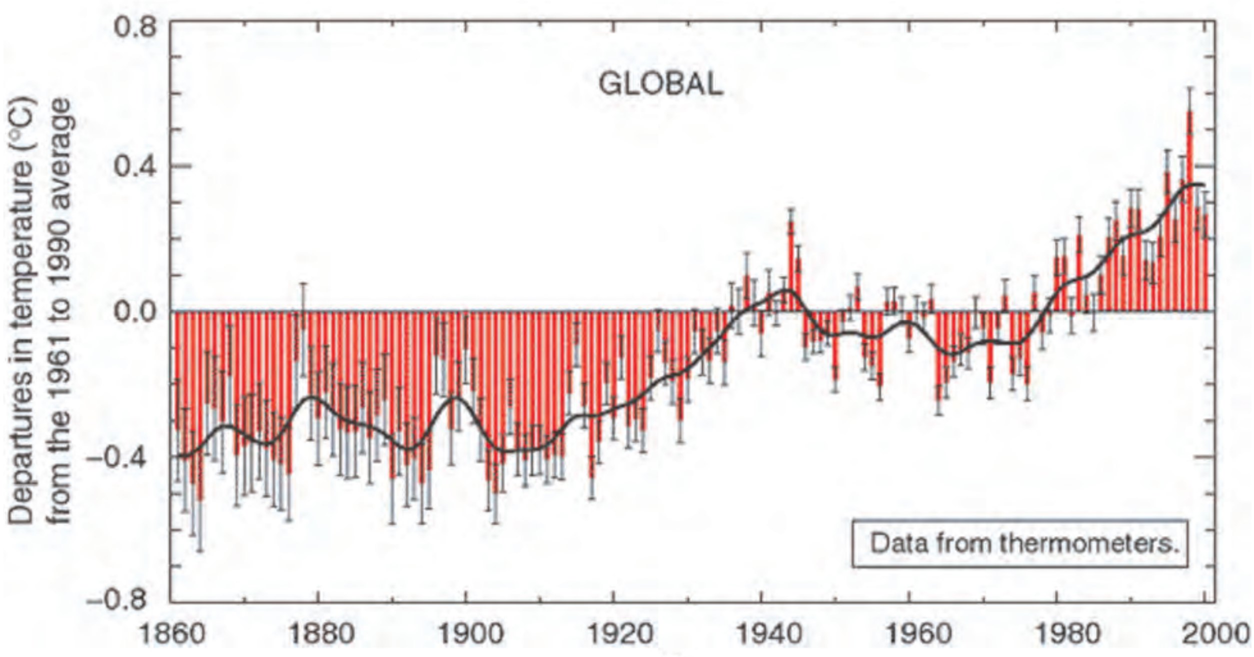
Climate encompasses the statistics of temperature, humidity, atmospheric pressure, wind, rainfall, atmospheric particle count and other meteorological elemental measurements in a given region over long periods of time. Climate can be contrasted to weather, which is the present condition of these same elements and their variations over shorter time periods. The climate of a location is affected by its latitude, terrain, and altitude, as well as nearby water bodies and their currents. Climates can be classified according to the average and the typical ranges of different variables, most commonly temperature and precipitation. The Intergovernmental Panel on Climate Change (IPCC) is a scientific intergovernmental body tasked with reviewing and assessing the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. It provides the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences, notably the risk of climate change caused by human activity. According to IPCC, climate is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization. These quantities are most often surface variables such as temperature, precipitation, and wind. But it may also include atmospheric moisture, snow cover, extent of land and sea ice, sea level and patterns in atmospheric and ocean circulation. Climatic projections identify long-term averaged status of these variables and hence these are one of the key inputs in planning.

This Appendix summarizes current published knowledge on climate change in India and unifies climate change studies being undertaken for our Technical Assistance by the National Institutes.

Climate Change

One of the major causes of global warming is the increased emission of greenhouse gases due to anthropogenic activities (IPCC, 2007). The consequences of global warming are seen globally and regionally. Figure 1 depicts the variation of the global temperature over a period of 140 years. The plot shows the average increase of 0.6º C in recent years. The global climatic change has serious implications for water resources and regional development (IPCC, 2001). Similarly, climate change has its impacts on the oceans and in turn the coasts, with the rising sea levels and intensive winds, cyclones and waves.

Figure 1. Variations of the Earth's surface temperature for the past 140 years



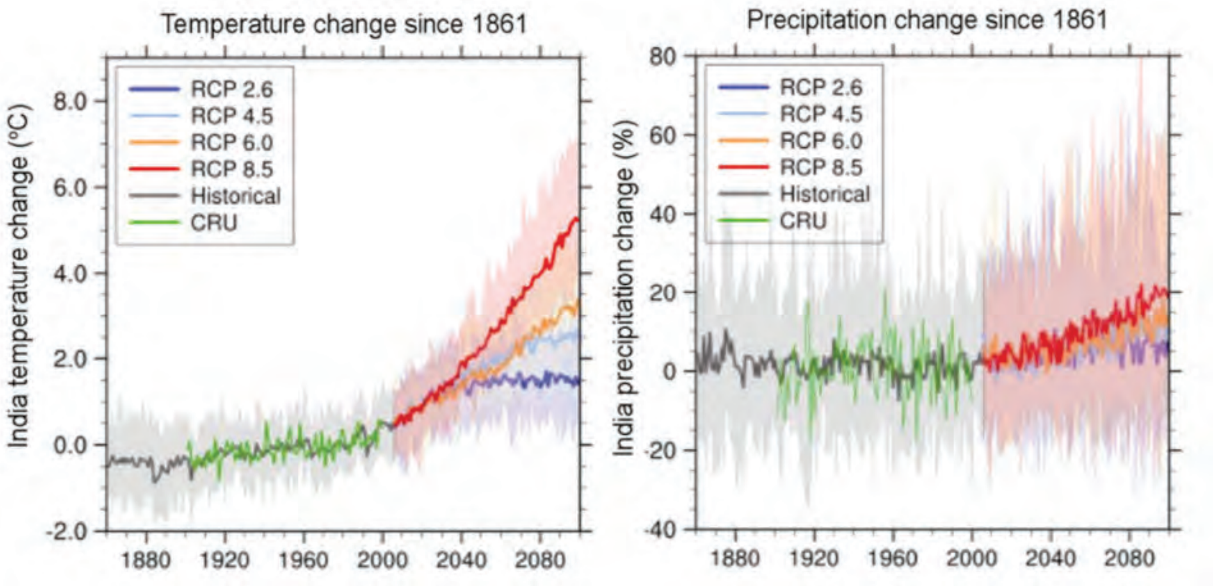
Source: IPCC (2007). Note: Red bars – Earth's surface temperature departures year by year. Black line – average temperature. Black bars – bias in temperature.

India is subject to a wide range of climatic conditions from the freezing Himalayan winters in the north to the tropical climate of the southern peninsula, from the damp, rainy climate in the north-east to the arid Great Indian Desert in the north-west, and from the marine climates of its vast coastline and islands to the dry continental climate in the interior. The Indian summer monsoon is the most important feature of the Indian meteorology and, hence, its influence on the broader economy. Almost all regions of the country receive their entire annual rainfall during the summer monsoon (also called the southwest monsoon), while some parts of the southeastern states also receive rainfall during early winter from the northeast monsoon. Rainfall increases by almost three orders of magnitude from west to east across the country. A detailed description of the current Indian climate and its variability is available in India's Initial National Communication to the United Nations Framework Convention on Climate Change (INC, 2004), India's Second National Communication to the United Nations Framework Convention on Climate Change – Work Program (INDNC2, 2008), and the Second National Communication on the Effects and Impacts of Climate Change for India (SNC, 2012). Climate change projections (Second Indian National Communication, 2012) show that there may not be a significant decrease in the monsoon rainfall in future except in some parts of the southern peninsula. However, the simulations mostly predict 9 to 16% rise in the monsoon rainfall towards the end of the 21st century.

Temperature

Simulations for 2020, 2050, and 2080 (PRECIS program SNC, 2012) indicate an all-round warming over the Indian sub-continent. The annual mean surface air temperature rise by the end of the century ranges from 3.5°C to 4.3°C. Chaturvedi et al. (2012) presented projections for the century for changes in temperature and precipitation. While a sharp increase in temperature is projected in the latter half of this century, the change in precipitation is not as large.

Figure 2. CMIP5 model-based time series of temperature and precipitation anomalies (historical and projections) from 1861 to 2099



Source: Chaturvedi et al. (2012)

Extreme Weather and Climate Events

In India, the climate and weather are dominated by the largest seasonal mode of precipitation in the world due to the summer monsoon circulation. Over and above this seasonal mode, the precipitation variability has predominant inter-annual and intra-seasonal components, giving rise to extremes in seasonal anomalies resulting in large-scale droughts and floods, and also short-period precipitation extremes in the form of heavy rainstorms or prolonged breaks on a synoptic scale. Indeed, rainfall during a typical monsoon season is by no means uniformly distributed in time on a regional / local scale, but is marked by a few active spells separated by weak monsoon or break periods of little or no rain. Thus, the daily distribution of rainfall at the local-level has important consequences in terms of the occurrence of extremes.

According to the climate change projections (SNC, 2012), the number of rainy days and the intensity of the rainy days may change in future. The rainy days in future appear to be less in number than the present. On the other hand, all the three simulations indicate an increase in the rainfall.

Extreme Temperatures

According to the climate change projections (SNC, 2012), the daily extremes in surface air temperature may intensify in the future. The spatial pattern of the change in the highest maximum temperature suggests warming of 1 to 4°C towards 2050, which may exceed even 4.5°C in most places towards the end of the present century. Rise of more than 4.5°C in night time temperature may be seen throughout India, except in some small pockets in peninsular India.

Defining Future Scenarios

Uncertainties surround the future responses of governments to climate change. Reductions in greenhouse gas discharges may occur or increasing populations and discharges may increase. Representative Concentration Pathways (RCPs) are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its fifth Assessment Report (AR5) in 2014. It supersedes Special Report on Emissions Scenarios projections published in 2000.

The pathways are used for climate modeling and research. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gas is emitted in the years to come. The four RCPs: RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W / m², respectively) (Weyant et al., 2009).

Climate Change Studies by Indian Institutes

The Coordinated Regional Climate Downscaling Experiment (CORDEX) climate change projections provided by the Indian Institute of Tropical Meteorology, Pune for wind, extreme wind events, temperature and rainfall for the Indian coast was further analyzed by Indian Institute of Technology (IIT), Mumbai. IIT Mumbai has conducted a thorough analysis of the available model data and relative uncertainty of the projections (by considering the different greenhouse gas emissions).
National Institute of Oceanography of Council of Scientific and Industrial Research (CSIR-NIO) carried out studies on wave climate changes in the near coastal region. The wave study analyses modeled wind waves for: (a) a historical period using hindcast reanalyzed winds; (b) climate change scenario period for medium greenhouse gas emission (7% increase in wind speeds), and; (c) climate change scenario period for high greenhouse gas emission (11% increase in wind speeds). State of the art spectral wind wave models are used in this study. Calculations are based on hindcast wave information available with CSIR-NIO at hourly intervals for a period of 46 years (1970 to 2015). Modeling is carried out to provide waves at 20m depth and at 50 km spatial resolution around the coastline for the return periods of 1, 10, 50 and 100 years.

CSIR-NIO has also analyzed the historic sea level data, trends during historical periods (tide gauge data) and recent periods (satellite altimetry). The climate change projections of the sea level with adjustments to vertical land movements are being computed by CLIMSystems, New Zealand.

Computation of probable maximum water level elevations generated by any tropical cyclones crossing maritime states of India and Andaman and Nicobar, and Lakshadweep islands is carried out by Centre for Atmospheric Studies of the IIT, Delhi. These projections include present (no climate change scenario) and two other scenarios based on climate change at different return periods of 10, 50 and 100 years. The finite-element advanced circulation (ADCIRC) model framework is applied with the maximum pressure-drop value for a set of synthetic tracks which are generated by composing actual tracks as well as from theoretical ones, ensuring that each coastal district is covered. Using different pressure-drop values for different return periods, the simulations of surges have been carried out. The model also incorporates the tides so that the non-linear interaction of tide and surge is comprehensively considered.

Climate Change Projections for West Coast

The analysis of IIT Mumbai with CORDEX RCPs provides multi-model ensembles (averages) for different climatic variables: precipitation; sea level pressure; wind fields; surface air temperature; maximum surface air temperature; minimum surface air temperature, and; specific humidity at surface for locations on the western coast of India.

Further the analysis of near surface temperature is carried out for a historical period and three time slices in future (2006 to 2035, 2036 to 2065 and 2066 to 2095) for both the RCP scenarios, i.e. 4.5 and 8.5. The analysis shows an overall increasing trend in mean near surface temperature at all the locations considered in this study from past to future in both scenarios. The intensity of extreme events tends to increase in future with maximum extreme events occurring towards the end of the century (2066 to 2095). Also, there is an increase in the mean maximum near surface temperature in both the scenarios. Notably, the increase in mean minimum near surface temperature is increasing in the future which implies a warmer climate. Near surface specific humidity shows a negative trend in annual maxima in future for both scenarios. Mean surface specific humidity shows a decreasing trend at all locations considered in this study.

The mean precipitation and standard deviation increases to the south along the west coast of India. Barring the Gujarat coastline, the mean precipitation is expected to increase in both scenarios. The extreme precipitation may decrease in future for all the three considered time slices, with the decrease being highest along Gujarat coast.

The annual maxima trend is observed to be positive along the Gujarat and Maharashtra coastline, but further south the trend changes to negative. The comparison of mean precipitation amongst the three time slices in future indicates a constant increase from 2006 to 2095.

The average of resultant wind along the Indian coastline is 3.71 m / s. No significant difference in mean wind is predicted in future. The annual maximum trend is observed to be decreasing to the south along the western coastline. Also amongst the three time slices no significant increase in the mean wind is observed from 2006 to 2095. However, the extreme wind speeds are expected to be order 35 to 40 m / s at some locations along Gujarat coast and there will be a constant increase from 2006 to 2095.

Cyclonic Storms

In the northern Indian Ocean, about 16 cyclonic disturbances occur each year, of which about six develop into cyclonic storms (INC, 2004). The annual number of severe cyclonic storms with hurricane force winds averages about 1.3 over the period 1891 to 1990. During the recent period 1965 to 1990, the number was 2.3. No clear variability pattern appears to be associated with the occurrence of tropical cyclones.

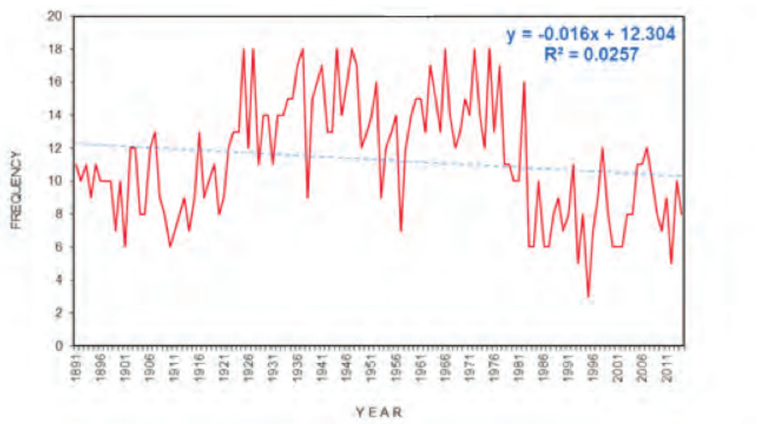
The annual frequency of cyclonic storms over the North Indian Ocean was analyzed by Mukhopadhyay (2015). The long-term trend shows a slight decrease in the frequency of occurrence of the cyclones. Climate change projections (SNC, 2012) report a decrease in the frequency of the cyclonic disturbances towards the end of the present century. The number of cyclonic disturbances over the Arabian Sea may be less in the future, as compared to the present simulations. However, the analysis indicates that it might be more intense in the future. There is, however, no predicted change in the track of cyclonic disturbances.

Table 1. Increase in extreme climate events for different return periods and scenarios

SI. N°	RETURN PERIOD	MOST LIKELY CLIMATE SCENARIO	EXTREME CLIMATE SCENARIO
1	10 years	7% increase	11% increase
2	50 years	7% increase	11% increase
3	100 years	7% increase	11% increase

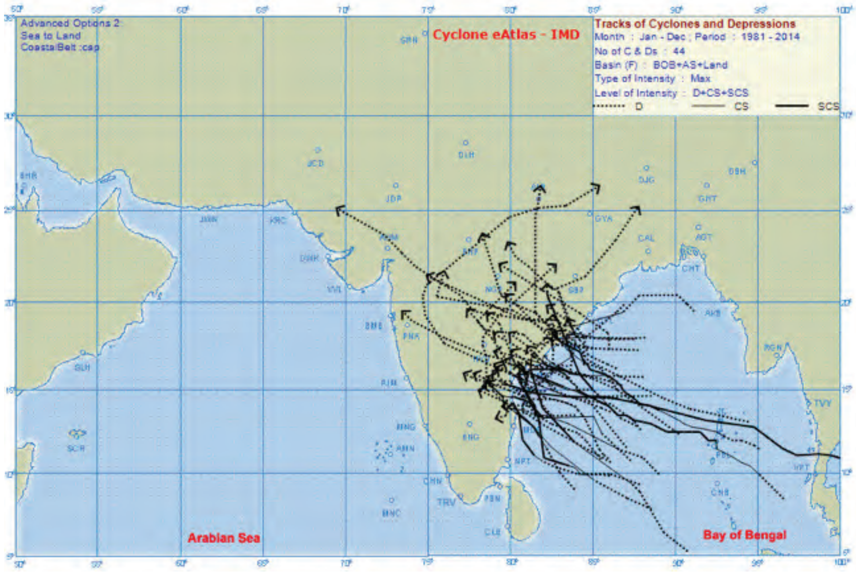
Source: Rao (2015)

Figure 3. Annual frequency of cyclonic storms over the North Indian Ocean (1981-2014)



Source: IITD (2016)

Figure 4. Tracks of cyclones and depressions that traversed Andhra Pradesh (1981-2014)



Source: Rao (2015)

Storm Surges

The occurrence of coastal flooding due to cyclones, known as "storm surge", causes havoc in coastal areas. The severity of the storm surge is primarily determined by the shallowness and orientation of the water body relative to the storm path, the barometric pressure and the wind speed. The Orissa super cyclone of October 1999 generated a maximum wind speed of 252 km / h with an ensuing surge up to 7 m. This caused unprecedented inundations up to 35 km from the coast (Mascarenhas, 2004). This 9 m measurement has substantial implications for the design water levels to be adopted for coastal protection structures.

A 10% increase of the current 1 in 100 year storm surge level combined with an assumed 1 m sea level rise could affect around 7.6 million people in India (Wheeler, 2011). Rao et al. (2015) has carried out simulations of maximum possible total water elevation and associated inundation for all the districts in Andhra Pradesh. They adopted climate change scenarios based on the IPCC recommendations.

Storm Surge Projections for the Indian Coast

Indian coasts are frequently affected by the extreme sea levels generated by the tropical cyclones which have tremendous impact on human life and coastal infrastructure. Quantitative risk analysis of consequence of a tropical cyclone is important for planning, preparedness and mitigation processes by the coastal authorities. The ADCIRC model is used for computing maximum possible total water elevation (TWE) along the entire Indian coast considering the non-linear interaction of local high tide. This is also known as the storm tide. The TWE is computed at every 10 km interval along the coast, except for the southern west coast of India. Since occurrence of cyclones in this region are uncommon, the TWE is provided for every 50 km along this coast. The information of past cyclone data (1891 to 2016) that includes cyclone track along with its intensity (strength of the wind stress or pressure-drop) and surges are used in this study from various sources (India Meteorological Department, Joint Typhoon Warning Center, etc.). This data is reconciled to make a uniform data base for cyclones and its surges. The finite-element ADCIRC model framework is configured for the entire Indian coast with very high resolution near the coast. The model bathymetry is obtained from the General Bathymetric Chart of the Oceans 30-second global bathymetric grid. The tidal solution in the ADCIRC model is generated by prescribing tidal elevations along the open boundaries. The cyclonic wind distribution is computed using the wind scheme described in Jelesnianski and Taylor (1973) by considering pressure-drop and uniform radius of maximum winds of 30 km. The model is initially extensively validated for tides and storm surges for the recent cyclones.

Using the cyclone data base, the return periods of the cyclone intensity (pressure-drop) for every 10, 50 and 100 years is calculated for each maritime state along the east and west coasts of India (IIT Delhi, 2017) (Table 1). The 10-year return period is considered to be the present scenario. Synthetic tracks are generated by composing actual tracks as well as from theoretical ones, ensuring that each coastal district is covered. The synthetic track for a particular district is moved parallel for every 10 km / 50 km along the coast to compute the extreme sea levels within the district. Using these cyclonic tracks for a given pressure-drop, the TWE is computed for all the return periods.

The latest IPCC report provides change in seasonal mean tropical cyclone potential intensity for end of the century which is RCP8.5 (2081 to 2100) minus historical control (1986 to 2005) in Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model ensembles (August to October, 10°S to 40°N) (AR5-IPCC, 2013). Accordingly, in the North Indian Ocean, the changes in wind speed increases by 2 m / s to 8 m / s. This increase is covered in our simulations by providing 2 to 11% increase in winds as mentioned in Knutson (2010) in which future projections based on theory and high resolution dynamical models consistently indicate that greenhouse warning will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with intensity increases of 2 to 11% by 2100. There are no near-term tropical cyclone intensity projections given for the North Indian Ocean in the latest IPCC report. In order to study the climate change scenario in our simulations, the cyclonic wind stress is increased by 7% (an average value) and of 11% (extreme value) over the present (normal) scenario. These experiments are carried out for all the return periods for east and west coasts of India. This study, being first of its kind for the entire coastal stretch of India, provides the surge, tide and its combined effect of total water levels at every 10 km along the coast. The detailed information of storm tides along the coast is an important component used to create sustainable local-level development action plan for preparedness and mitigation.

East coast of India: On the basis return period analysis on the cyclone intensity, Odisha followed by Andhra Pradesh coasts are more prone to the high intensity cyclones for any return period (Table 2). The simulations are provided for every 10 km stretch along the coast from south of Tamil Nadu to north of West Bengal. In general, the surges / storm tides (surge + tide) increase from south to north. The present scenario (10-year return period) infers that the higher surges of about 4.6 m are simulated along the north Odisha coast except a small coastal stretch near Ramanathapuram where the surge rises up to about 5.6 m owing to the effect the local coastal geometry. The surge simulations made for different climate change scenarios follow a similar trend along the coast. In the case of extreme scenario for 100-year return period, the surges are enhanced to about 10m along the entire coast north of Balasore (Figure 5). The reason for generation of high surges along this coast, particularly in the climate change scenarios, is due to shallowness of the head bay region. The rise of storm tide in the case of extreme climate change is noticed all along the coast of about 13% over the present scenario (Figure 6). The computations are also made for Andaman and Nicobar Islands where the surges are found to be very small compared to the local tides ranging from 1 to 1.5 m.

West coast of India: Along the west coast, Gujarat is the state most affected by the cyclones. Accordingly, the simulations are provided at every 50 km for Kerala, Karnataka and south Maharashtra, while it is at every 10 km for north of Maharashtra and Gujarat. The cyclone intensity based on return period analysis for each maritime state along the west coast infers that the pressure-drop is about 10 mb in the present scenario. Hence, the surge simulations are about 1 m all along the coast up to Maharashtra and beyond, the surge increases to about 3.0 m along the Gujarat coast. However, the tides along the southern part of the coast, up to Maharashtra, varies from 0.5 m to 2.5 m and hence the storm tide ranges from 0.5 m to 3.5 m along this stretch. As the tide increases further north to about 4.2 m, the surge as well as the storm tide increases all along the Gujarat coast. The maximum storm tide of about 5.6m is simulated in the Gulf of Khambhat region. The simulations in the extreme climate change scenario for 100-year return period suggest that the maximum water level increases up to 8.5m along the Gujarat coast (Figure 5). About 13% rise of water levels over the present scenario are also seen in this region due to climate change effect as noticed along the east coast (Figure 6).

The Lakshadweep islands are not directly influenced by any tropical cyclones, however, some passing cyclones may produce water levels which are about 50 to 70 cm including local tides. A combined picture of maximum and minimum surges state-wise is presented in Figure 7.

Table 2. Values of pressure-drop by return period for the west coast of India

SI. N°	RETURN PERIOD (YEARS)	PRESSURE-DROP ΔP (mb)			
		Kerala	Karnataka	Maharashtra	Gujarat
1	10	5	8	8	12
2	50	12	15	15	40
3	100	29	29	37	66

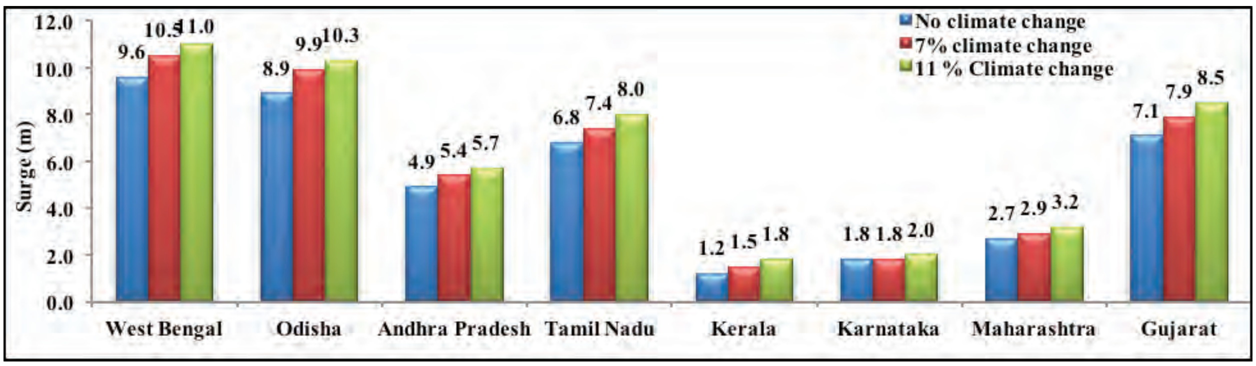
Source: IITD (2017)

Table 2. Values of pressure-drop by return period for the west coast of India

SI. N°	RETURN PERIOD (YEARS)	PRESSURE-DROP ΔP (mb)			
		West Bengal	Odisha	Andhra Pradesh	Tamil Nadu
1	10	25	45	48	26
2	50	51	78	70	47
3	100	75	98	82	66

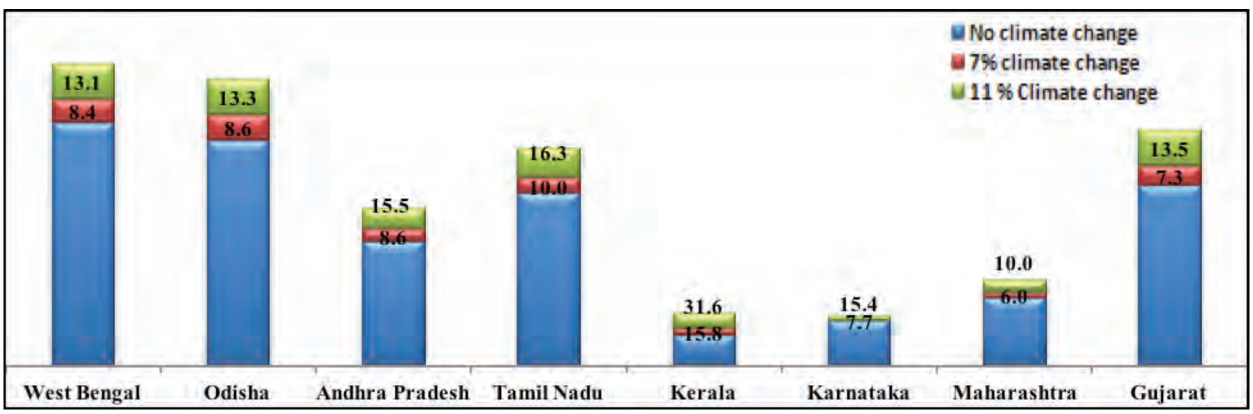
Source: IITD (2017)

Table 2. Values of pressure-drop by return period for the west coast of India



Source: IITD (2017)

Table 2. Values of pressure-drop by return period for the west coast of India

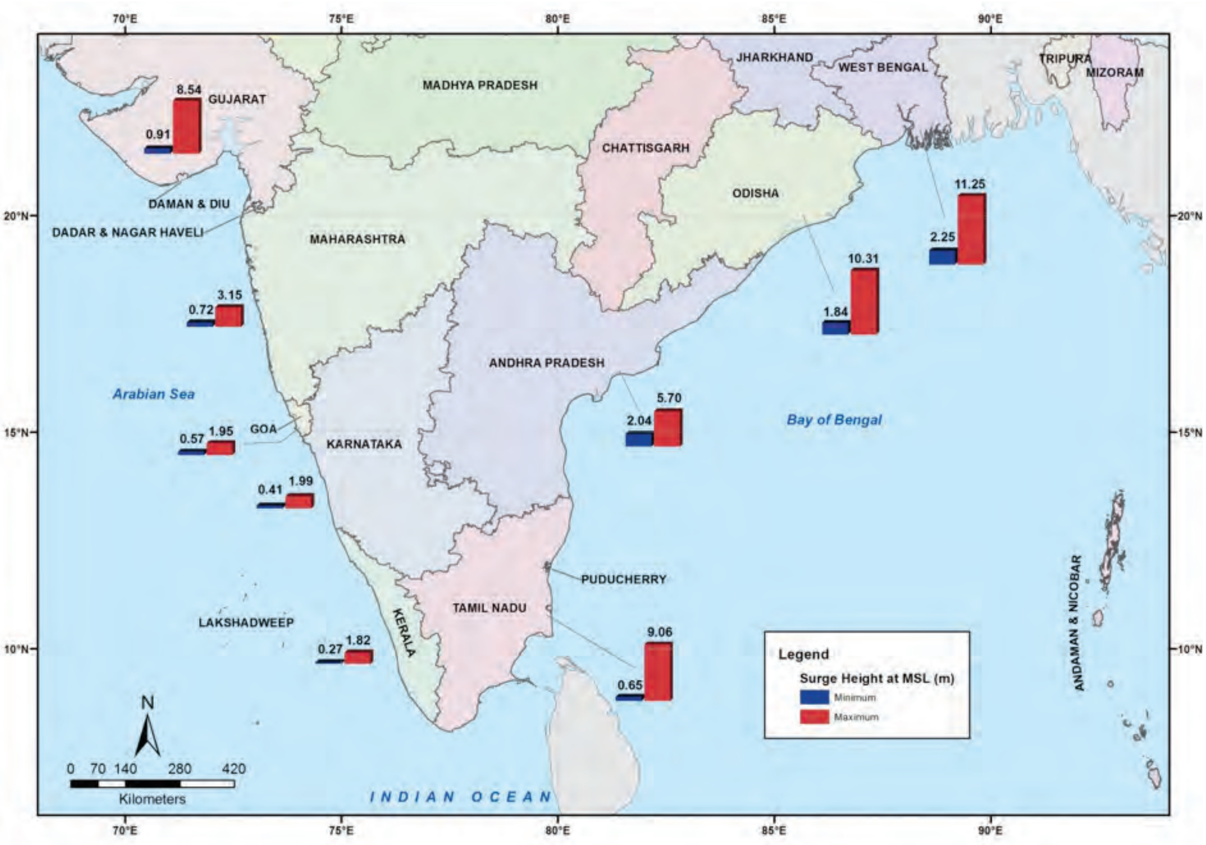


Source: IITD (2017)

The simulations for Kerala coast for 10-year return period in the normal scenario suggest that the surge varies from 0.5 m in the south to 0.81 m in the north. However, in the extreme scenario (100 year return period and 11% climate change scenario), the range may vary from 1.80 m to 2.50 m respectively. These ranges increase north in Karnataka. The maximum possible surge for the extreme scenario for Karnataka coast varies from 2.58 m to 2.95 m.

The Maharashtra coast experiences a minimum surge of 1.35 m in the south to 3.55 m in the north in the normal scenario. However, the corresponding values may rise to 2.95 m and 5.50 m respectively for the extreme scenario.

Figure 7. Maximum and minimum surge predicted for each state



Waves

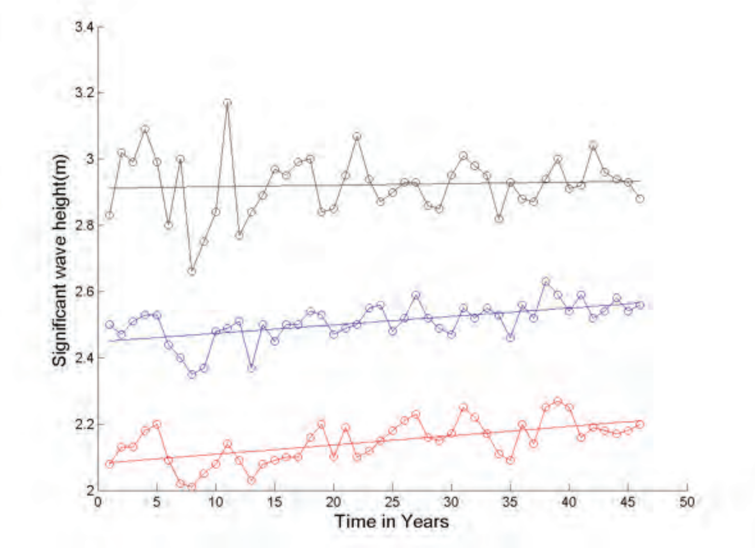
The wave modeling was carried out (NIO, 2017) with wind inputs obtained from National Center for Environmental Prediction (NCEP) / National Center for Atmospheric Research (NCAR) reanalysis data (Kalnay et al., 1996). The wind parameters over the domain shown were extracted from the NCEP/NCAR wind database and were used in forcing the MIKE-SW, a state of the art spectral wind wave model, to obtain wave parameters along the coast of India.

The winds for the climate change scenario were considered by enhancing the wind speeds by 7% and 11% which is considered for the cyclone induced storm surge studies as part of this project by IIT Delhi. All the three wind case scenarios viz., hindcast winds, and increased winds were used in the MIKE21-SW spectral wind wave model and the significant wave height (Hs), mean wave period (Tm) and mean wave direction along the 20 m contour water depth is extracted approximately at 50 km spacing for the mainland coast. Whereas, for Lakshadweep and Andaman and Nicobar Islands, the data is extracted at 100 m water depth contour and at varying spatial resolution surrounding the islands. The model results for the hindcast scenario were compared with available wave data on either side of the coast and in deep as well as shallow waters and found to be in good correlation with measurements.

The wave parameters are further analyzed to obtain: (a) joint distribution of Hs vs Tm and Hs versus wave direction; (b) extreme Hs for 1 in 50 and 1 in 100 return periods, and; (c) Hs trend analysis. The joint distribution of Hs and Tm is carried out to know the variation of Hs with respect to the wave period. Similarly, the variation on Hs and direction is also carried out. Extreme value analysis of Hs is carried out using statistical methods to obtain 1 in 1, 1 in 50 and 1 in 100 year return period Hs estimates. The Weibull-3 statistical method results are provided for all the locations. Linear regression of the wave heights is carried out and the slope of the regression line is provided as the trend of wave heights. A typical wave height trend plot is shown in Figure 8. The trends are plotted for annual maxima, annual mean and annual 90th percentile of Hs.

In general, the measured wave heights in the Arabian Sea are observed to be higher than those measured in the Bay of Bengal. The return period estimates reflect the same. Figure 9 shows the Hs for 1 in 10, 1 in 50 and 1 in 100 year return periods plotted for locations 1 to 100 along the main land coast. Gujarat state locations are from 1 to 18, Maharashtra locations are from 19 to 28, Goa locations are between 29 and 31, Karnataka locations are from 32 to 36, Kerala locations are from 37 to 48, Tamil Nadu locations are from 49 to 68, Andhra Pradesh locations are from 69 to 87, Odisha locations are between 88 and 94 and West Bengal locations are from 95 to 100.

Figure 8. Typical wave height trend



Source: NIO (2017)

Note: Top line refers to the annual maxima wave height, the middle line refers to the annual mean wave height and the bottom line refers to the annual 90th percentile wave height.

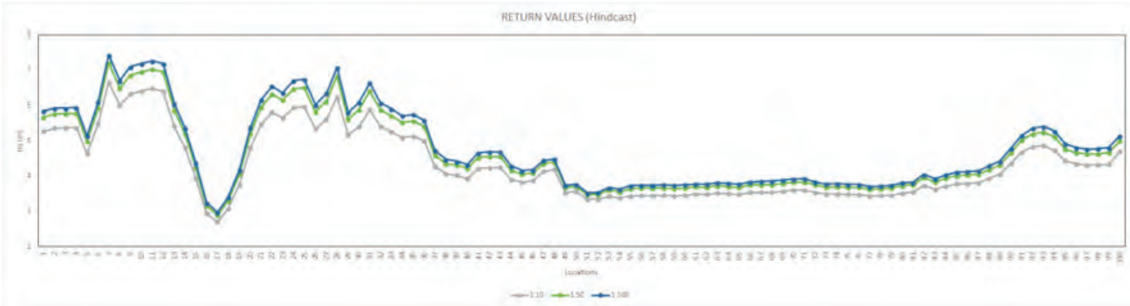
Wave Projections for the Indian Coast

The variation of Hs along locations 1 to 100 for the hindcast, medium case (7% increase winds) and extreme case (11% increase winds) are presented in Figure 9. The top panel (Figure 9a) show the Hs variation for 1 in 10, 1 in 50 and 1 in 100 for hindcast study. The middle panel (Figure 9b) shows the Hs variation for 1 in 10, 1 in 50 and 1 in 100 for medium wind increase study. And the bottom panel (Figure 9c) shows the Hs variation for 1 in 10, 1 in 50 and 1 in 100 for extreme wind increase study.

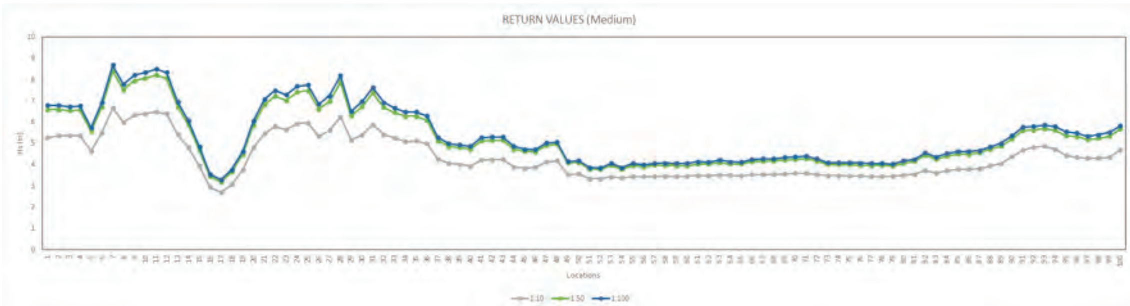
The variation of Hs along mainland locations 1 to 100 for the hindcast study showed that the Hs for 100 year return period varies between 2.98 m and 7.44 m while for the extreme case of 11% increase in winds the 100 year Hs varied between 3.46 m and 9.41 m. All the maximum wave heights occurred in Gujarat state.

Figure 9. Significant wave heights for 100 locations along the main land coast starting from Gujarat and ending at West Bengal Figure 8. Typical wave height trend

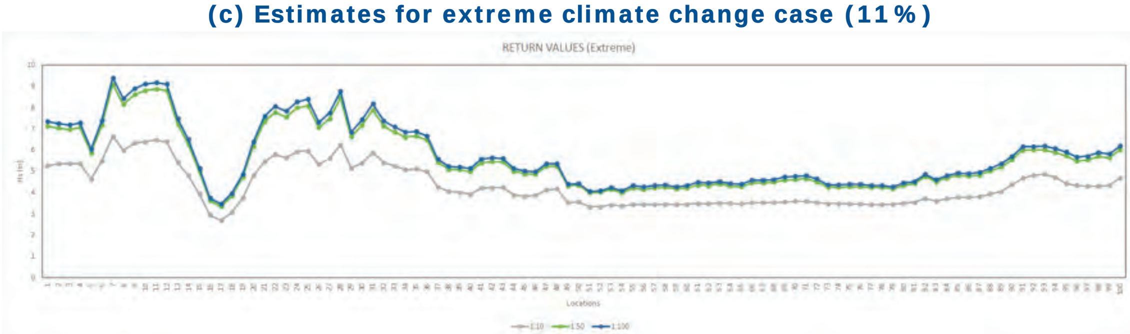
(a) Hindcast estimates



(b) Estimates for medium climate change case (7%)



(c) Estimates for extreme climate change case (11%)



Source: NIO (2017)

For the Lakshadweep Islands the variation of Hs from the hindcast study showed that the Hs for 100 year return period varies between 3.85 m and 9.04 m while for the extreme case of 11% increase in winds the 100 year Hs varied between 4.55 m and 11.24 m. And for the Andaman and Nicobar Islands the variation of Hs from the hindcast study showed that the Hs for 100 year return period varies between 4.16 m and 7.13 m while for the extreme case of 11% increase in winds the 100 year Hs varied between 4.77 m and 9.14 m.

A comparison of the 100 year Hs values between hindcast, medium and extreme case scenarios is made. The difference in the 100 year return period Hs between the hindcast case and the extreme case is ranging between 12.4% and 26.7% and difference in the 100 year return period Hs between the medium case and the extreme case is between 3% and 9.3%.

Figure 10 shows the Hs trends for the hindcast (a), medium case (b) and for the extreme case (c). Each panel contains the trend for annual maxima, annual mean and annual 90th percentile estimates. From the hindcast study, the mean Hs trend shows high variability along the coast wherein along the mainland majority of the northern regions along the west coast show negative trends whereas the last four locations in the northern regions of east coast show positive trend (Table 4). The west coast (except north Gujarat) predominantly show positive trend for mean Hs while the east coast (except the last four locations) generally showed negative trend. The mean Hs and the annual maxima showed opposite trends (e.g., locations 6 to 14; 28 to 57; 62 to 72) for most of the mainland coast. The mean Hs trends under medium and extreme case more or less follow that of the hindcast study, except for the magnitudes being different. The range of mean and maxima Hs trends for the different regions are presented in the table below. The values presented are m / year.

Table 2. Values of pressure-drop by return period for the west coast of India

	HINDCAST		MEDIUM (7%)		EXTREME (11%)	
	Min	Max	Min	Max	Min	Max
Annual Mean Hs for mainland coast	-0.0014	0.0019	-0.0017	0.0019	-0.002	0.0017
Annual Hs Maxima for mainland coast	-0.01	0.0046	-0.01	0.0047	-0.011	0.0042
Annual Mean Hs for Lakshadweep coast	-0.0019	0.0061	-0.0027	0.0087	-0.0037	0.0054
Annual Hs Maxima for Lakshadweep coast	-0.01	0.0089	-0.014	0.017	-0.015	0.006
Annual Mean Hs for Andaman coast	0.0012	0.0076	0	0.0042	-0.00018	0.0041
Annual Hs Maxima for Andaman coast	-0.014	0.006	-0.016	0.0045	-0.018	0.0037
Annual Mean Hs for mainland coast	-0.0014	0.0019	-0.0017	0.0019	-0.002	0.0017
Annual Hs Maxima for mainland coast	-0.01	0.0046	-0.01	0.0047	-0.011	0.0042

Source: IITD (2017)

Figure 10. Significant wave height trends along the mainland coast

(a) Hindcast trend

(b) Medium case trend (7%)

(c) Extreme case trend (11%)

Source: NIO (2017)

Mean sea level data from the Coastal tide gauges in India show sea level estimates between 1.06 to 1.75 mm per year with a regional average of 1.9 mm per year (Table 5) when corrected for global isostatic adjustment (GIA) using model data (Unnikrishnan et al., 2006). These estimates are consistent with the 1 to 2 mm per year global sea level rise estimates reported by IPCC.

Table 5. Relative sea level trends along Indian coast

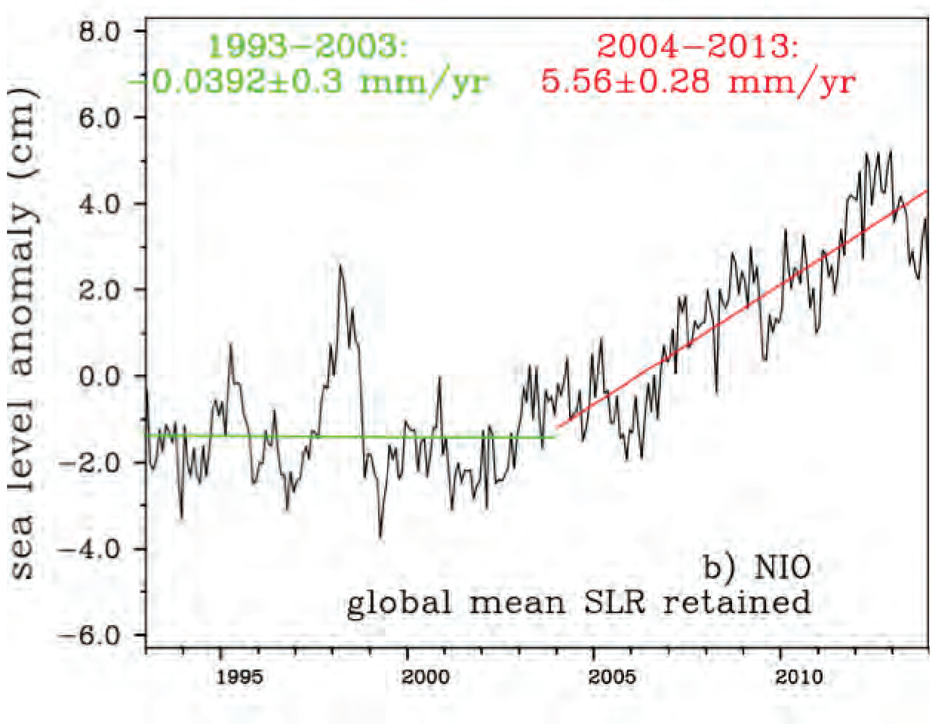
STATION	PERIOD OF ANALYSIS	NUMBER OF YEARS OF DATA AVAILABILITY	TRENDS IN RELATIVE SEA LEVEL (MM / YR)
Mumbai	1878-1993	113	0.77+/-0.08
Kochi	1939-2003	54	1.31+/-0.23
Vishahapatnam	1937-2000	53	0.70+/-0.28
Diamond Harbor (Kolkata)	1948-2004	55	5.22+/-0.43

Source: Unnikrishnan et al. (2006)

The sea level data show considerable inter-annual and inter-decadal variability (Unnikrishnan and Shakar, 2007). These changes are forced primarily by large-scale winds and changes in salinity (Shankar and Shetye, 2001).

During the 20th century, sea level rose by about 1.5 to 2.0 mm yr-1. In the last decade, the rate of sea level change for the north Indian Ocean is ~ 3.00 mm yr-1. However, for the northern and eastern Bay of Bengal it is greater than 5.00 mm yr-1 (Shenoi, 2015). Satellite and in situ observations, together with ocean reanalysis products show a distinct decadal reversal of sea level change over in the past two decades (Figure 11). Sea level fell from 1993 to 2003 (period-I) but rose sharply from 2004 to 2013 (period-II). This decadal reversal is part of the long-term decadal climate variability.

Figure 11. Sea level anomaly in the North Indian Ocean from 1993-2013



Source: Unnikrishnan et al. (2006)

Sea Level Trends for the Indian Coast

The monthly altimeter data based on the gridded (0.33 x 0.33 grid) sea level product from AVISO (Archiving, Validation, and Interpretation of Satellite Oceanographic data) for the period 1993 to 2015 is used by NIO for the estimation of mean sea level trend along the coast of India. Apart from the altimeter data, tide gauge data at different stations along the east and west coast of India are also used. These tide gauge records are more reliable near to coast compared to altimeter sea level data and are available for period earlier to period of satellite data availability. Particularly at Mumbai, the tide gauge data are available since 1880. The monthly-mean sea level data at few stations on either coast are analyzed, for example, on the west coast of India, tide gauge data at Okha, Mumbai, Kochi stations. Similarly, along the east coast of India - Paradip, Vishakhapatnam and Chennai tide gauge locations. Data at Port Blair (Andaman Islands) and also at other stations along the eastern and northern Bay of Bengal such as Ko Taphao Noi, off Thailand and Hiron Point, off Bangladesh. These tide gauge data are obtained from the archives of the Permanent Service for Mean Sea Level (PSMSL) are also used.

A monthly sea level climatology is removed from the sea level data (for both tide gauge and satellite data) to filter out the seasonal variations within a year. These seasonal variations in sea level would affect the estimation of long-term sea level trend. Then residual sea level signal is smoothened with a five-month running mean to remove all the variations at intra-seasonal periods. Similar analysis is done for the tide gauge data for all the aforementioned stations. NIO used tide gauge data which are uncorrected for the Inverse Barometer (IB) effect for the analysis because the effect of atmospheric pressure on sea level at periods greater than inter-annual time scales is not significant (Ponte, 1993; Shankar et al., 2010; Aparna et al., 2012). It must be noted that the altimeter sea level data used in this study are corrected for both IB and GIA. Hence the spatial map of sea level trend in Figure 12 shows the net sea level trend. Since past tide gauge records often do not have global positioning system (GPS) measurements to account for the temporal evolution of land movements, the tide gauge sea level used in this study are not corrected for GIA and the trends shown from gauge records are the relative sea level trend. The period of data availability is different at different locations. As some of the tide gauge records are having large data gaps (missing data), NIO considered the continuous time series data available at different locations (NIO,2017).

Tide gauge and altimeter sea level trends were estimated using a linear regression of respective time series (Figure 12). The slope of the "best-fit line" of the sea level time series is considered as the sea level trend.

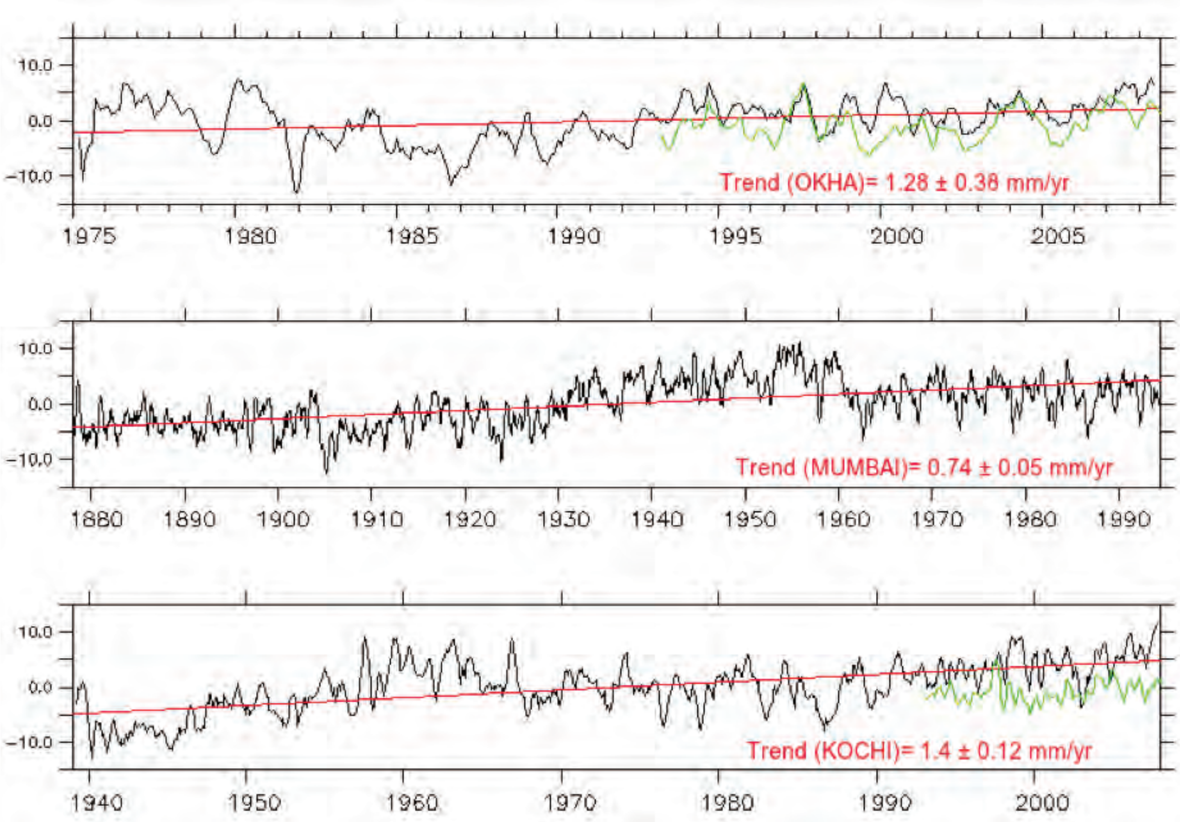
Table 6. Tide gauge data availability at different stations along the east and west coast of India, and comparison between trends calculated using the tide gauge and altimetry data

SR. N°	STATION NAME	PERIOD OF DATA AVAILABILITY (TIDE GAUGE)	PERIOD OF DATA AVAILABILITY (ALTIMETER)	SEA LEVEL TREND USING TIDE GAUGE DATA (mm / yr)	SEA LEVEL TREND USING ALTIMETER DATA (mm / yr)
ARABIAN SEA (WEST COAST OF INDIA)					
1	Okha	January 1975 to August 2008	January 1993 to December 2012	1.28 ± 0.38	2.81 ± 0.58
2	Kochi	January 1939 to December 2007	January 1993 to December 2012	1.40 ± 0.12	2.39 ± 0.39
3	Mumbai	January 1878 to June 1994	January 1993 to December 2012	0.74 ± 0.05	2.96 ± 0.64
BAY OF BENGAL (EAST COAST OF INDIA)					
4	Paradip	January 1966 to December 2011	January 1993 to December 2014	1.79 ± 0.42	2.00 ± 1.05
5	Vishakhapatnam	January 1937 to December 2011	January 1993 to December 2014	0.96 ± 0.17	3.35 ± 0.9
6	Chennai	September 1952 to December 2011	January 1993 to December 2014	0.4 ± 0.19	2.62 ± 0.75

ISLANDS (NORTH AND EASTERN BAY OF BENGAL)					
7	Port Blair	January 1916 to December 1964	January 1993 to December 2014	2.09 ± 0.13	3.62 ± 0.54
8	Ko Taphao Noi (Thailand)	January 1940 to December 2012	January 1993 to December 2014	1.07 ± 0.31	3.2 ± 0.85
9	Hiron Point (Bangladesh)	January 1983 to December 2003	January 1993 to December 2014	2.93 ± 1.47	2.41 ± 0.91

Source: Unnikrishnan et al. (2006)

Figure 12. Mean sea level trend at three locations along the west coast of India using tide gauge sea level data



Source: NIO (2017)

Note: Trends are written in red color in each panel, and the green line shows satellite data at nearest location to the tide gauge station.

The details of the tide gauges used, the data availability and the comparison between trends calculated using altimeter data and tide gauge data are shown in Table 6. It varies from 2.00 (at Paradip) to 3.62 mm / yr (for Port Blair) and the trend estimates from the satellite are higher than those estimated from tide gauge records over longer periods (fifth column in Table 6). A study by Unnikrishnan et al. (2014) also pointed out that the trends using altimetry data is higher than that estimated using tide gauge data.

Trend and error values are listed along 50 m and 100 m depth contour both the coasts (Figure 13 and Figure 14). Along the west coast of India, these contours are not very near to coast and hence are more reliable, but along the east of India, because of narrow shelf region, these contours are very near to coast. At certain places (for example, off Cuddalore), the 50 m depth contour is just 20 km away from the coast. Such values are not very reliable from the satellite data.

Recent studies using tide gauge data show that since the 1930s the global mean sea level rose by an average of approximately 1.8 mm / yr ± 0.3 mm / yr (Church and White, 2011), with the lowest trend being observed at Mumbai (Veit and Conrad, 2016).

The results (Figure 13) also show the similar trend with the mean sea level trend at Mumbai (0.74 mm / yr) being less than the sea level trend at Kochi (1.4 mm / yr) and Okha (1.28 mm / yr).

Figure 13. Sea level trends based on tide gauge data at 50 m depth state-wise

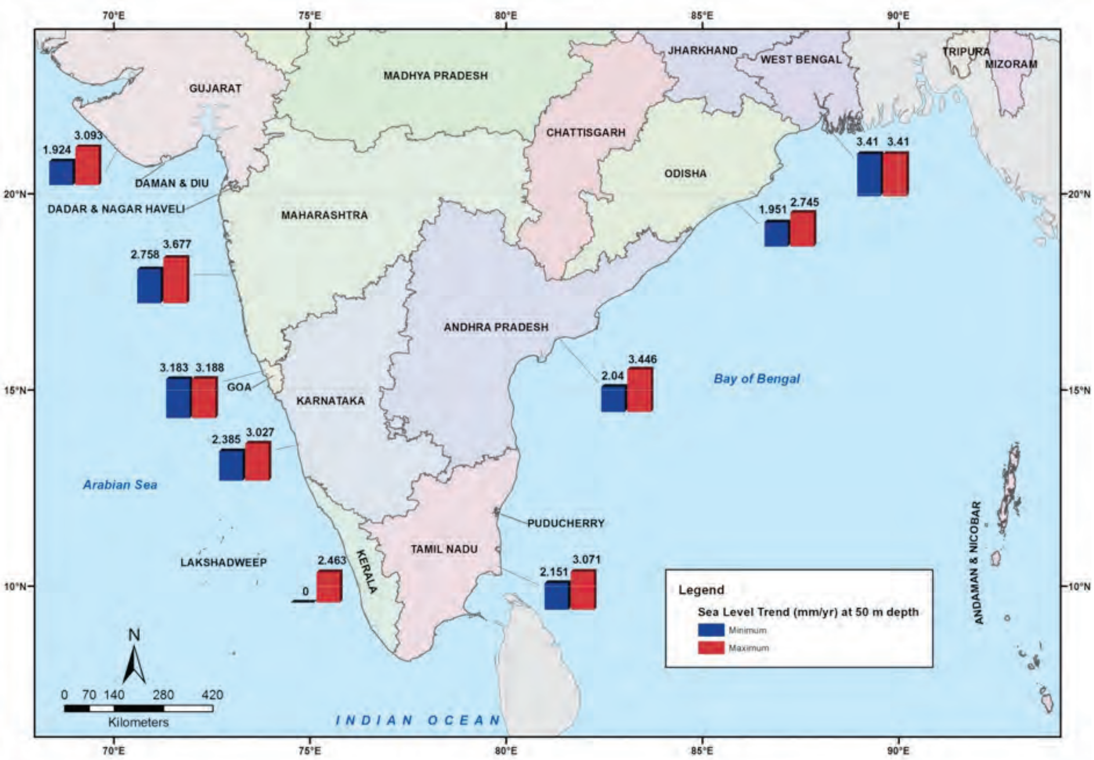
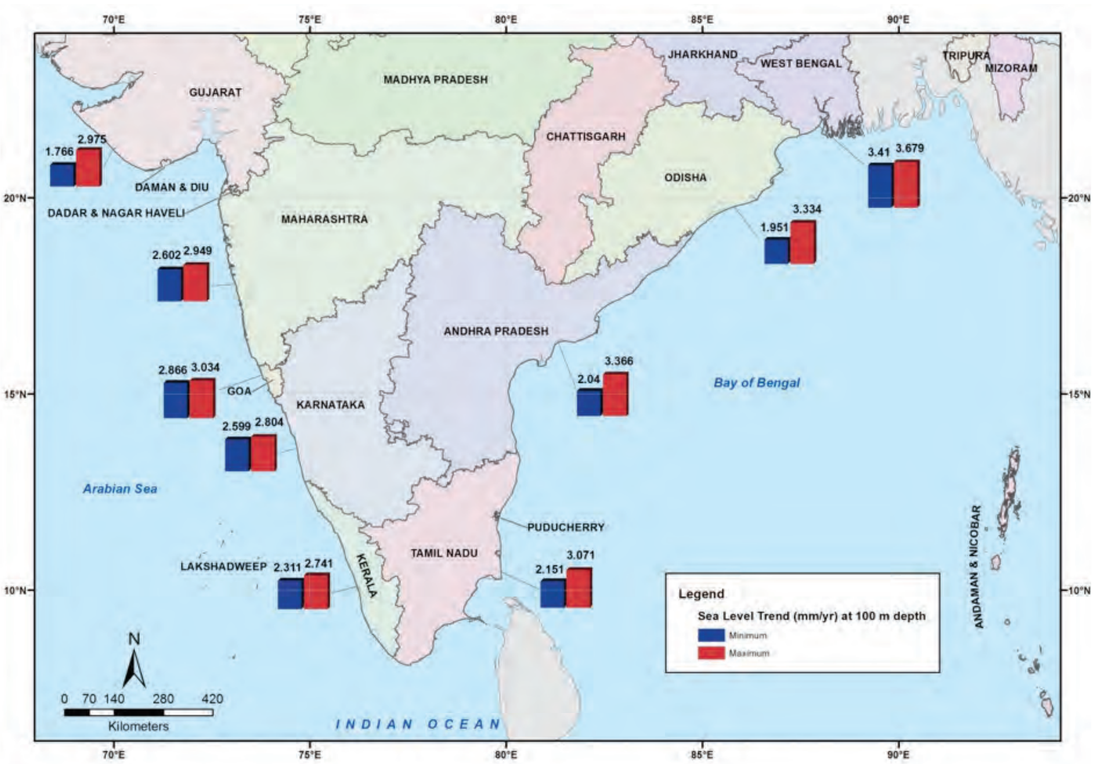


Figure 14. Sea level trends based on tide gauge data at 100 m depth state-wise



A second analysis of sea level projections under climate change scenario was undertaken by CLIMSystems (2016). The analysis incorporated vertical land movement along the Indian coast as well.

Global mean sea level rise scenarios are readily available and are regularly updated by the IPCC. To date, most coastal impact and adaptation assessments have ignored regional variations in sea level scenarios, largely due to a lack of technical guidance and access to the necessary data in a usable form. This has been rectified by the publishing of the IPCC Report in 2011 that includes sea level rise outputs generated using the SimCLIM modeling system (Nicholls et al., 2011). Nevertheless, regional and local assessments would benefit from considering the components of sea level change on a more individual basis, since the uncertainty for sea level change during the 21st century at any site is very likely to be larger than the global mean scenarios suggest.

The relative change in sea level at specific locations is attributable to factors at global, regional and local levels. To enable robust coastal vulnerability and adaptation assessment, sea level change scenarios should integrate these factors in an internally consistent fashion. One method that accomplishes this task is the sea level scenario generation approach as applied in the SimCLIM software package that is an integrated modeling system for assessing impacts and adaptation resulting from climate variability and change (Warrick, 2009; Warrick et al., 2005). The overall method features a separate consideration of three components: (1) global mean sea level projections; (2) regional departures from the global mean value due largely to thermal expansion effects; and (3) local non-climate change trends in relative sea level due largely to local land movements. The method is designed to permit the generation of high, mid and low projections for sites by selecting amongst a range of uncertainty for each.

For global mean projections, the system contains high, mid and low projections for the four RCP which are consistent with the values given in IPCC AR5. The SimCLIM method also takes into account of uncertainties in ice melt contributions due to ice sheet melt. For any user-selected location, the global mean projections are adjusted by the regional variations in sea level change, which are due largely to differences in thermal expansion as produced by atmosphere-ocean general circulation models (AOGCMs). The SimCLIM method uses pattern-scaling techniques in which the spatial patterns of thermal expansion from an AOGCM for a future time period are “normalized” by dividing by the global mean thermal expansion for the same period. For any given location, therefore, there is a ratio indicating whether the local thermal expansion will be greater than, equal to, or less than the global mean value and by how. The SimCLIM method applies twenty-eight patterns from AOGCM runs carried out for AR5. These AOGCM patterns could be used individually, however in this case a combination of all twenty-eight were applied as a multi-model ensemble with a median value presented.

The local pattern of thermal expansion under RCP forcing can be approximated using a pattern-scaling method similar to that previously applied for other climate variables (Santer et al., 1990). In applying the pattern-scaling method to sea level, “standardized” (or “normalized”) patterns of regional thermal expansion change, as produced by coupled AOGCMs, are derived by dividing the average spatial pattern of change for a future period (e.g. 2081 to 2100) by the corresponding global mean value of thermal expansion for the same period. The resulting standardized sea level pattern is thereby expressed per unit of global mean sea level rise. The pattern-scaling approach has been formalized within an integrated assessment modeling system called SimCLIM 2013.

We employed the following equation to calculate the normalized sea surface elevation patterns, (or sea surface height above the geoid, ZOS), termed DZOS (unit: cm/cm ΔGSLR):

$$DZOS_{ij} = \{(ZOS_{ij2090} - ZOS_{ij1995}) + \Delta GSLR\ \}/\Delta GSLR$$

$$\Delta GSLR = ZOSGA_{2090} - ZOSGA_{1995}$$

Where,

ΔGSLR is the global mean annual sea level change due to thermal expansion

Where,

ZOSGA is the global sea level change

i, j denote the latitude and longitude position;

2090 is the average of 2080-2100; 1995 is the average of 1986-2005.

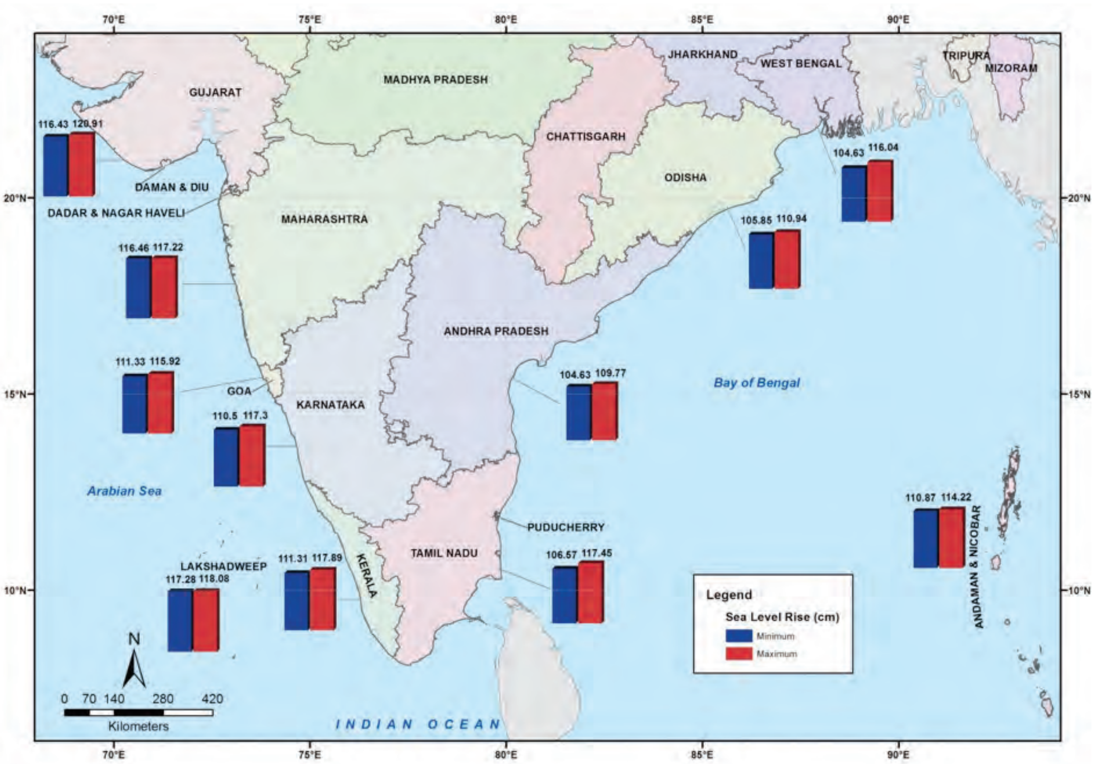
24 general circulation models (GCMs) (RCP45) runs, which have both local ZOS and ZOSGA data, are used in SimCLIM 2013.

The variable "zosga" is not available for four GCMs (CCSM4, HADGEM2-CC, HADGEM2-ES, INMCM4), so "zostoga" (global average thermosteric sea level change) is applied instead. Given the multiple source of uncertainty in sea level rise GCM data, these four GCMs are not outliers amongst other GCMs, so user can still use these GCM in ensemble study. However, the patterns for these four GCMs are optional for user applications.

For the local land movement component, we input a value for the local sea level trend. If the trend from relative sea level change from vertical land movement is known as derived from tidal and the SONEL database, and we simply added the derived value (in mm / yr) to the future projection. Often, however, only the total undifferentiated trend is known (as estimated, for example, from tide gauge data). This total trend cannot simply be added onto the future projection because it would "double-count" the effect that global warming has already had on observed sea level rise and would therefore inflate the future projected rise.

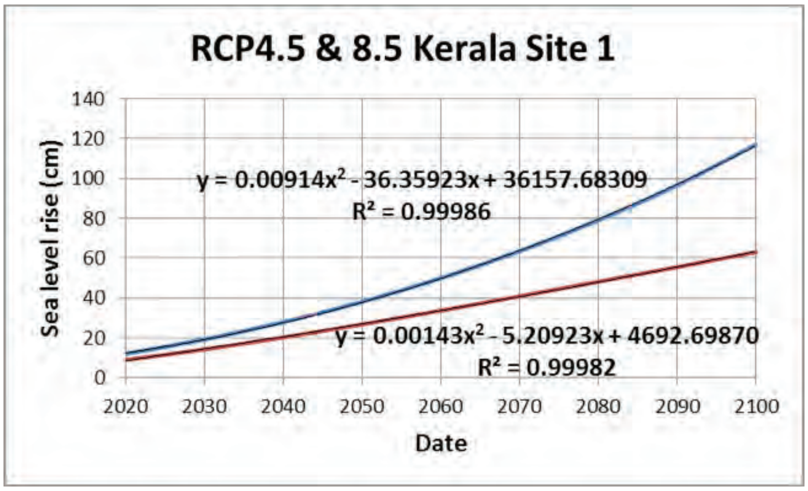
The results (Figure 13) also show the similar trend with the mean sea level trend at Mumbai (0.74 mm / yr) being less than the sea level trend at Kochi (1.4 mm / yr) and Okha (1.28 mm / yr).

Figure 15. Sea level projections due to the impact of climate change state-wise



The sea level rise values around the coast of India are relatively consistent as vertical land movement of the sub-continent is relatively slow and the open ocean conditions around much of the coastline is not conducive to wide variations in ocean salinity, temperature and near shore bathymetry that can influence local sea level rise. In general, the coast of India is experiencing slightly greater than global average sea level rise with most area under an RCP 8.5 medium sensitivity assessment including vertical land movement of between 1.10 and 1.20 m possibly by 2100 (Figures 13.14 and 13.15). As sea level rise is a non-linear phenomenon the values around the coast under the same RCP conditions and sensitivity could be between 0.35 and 0.38 m by 2050.

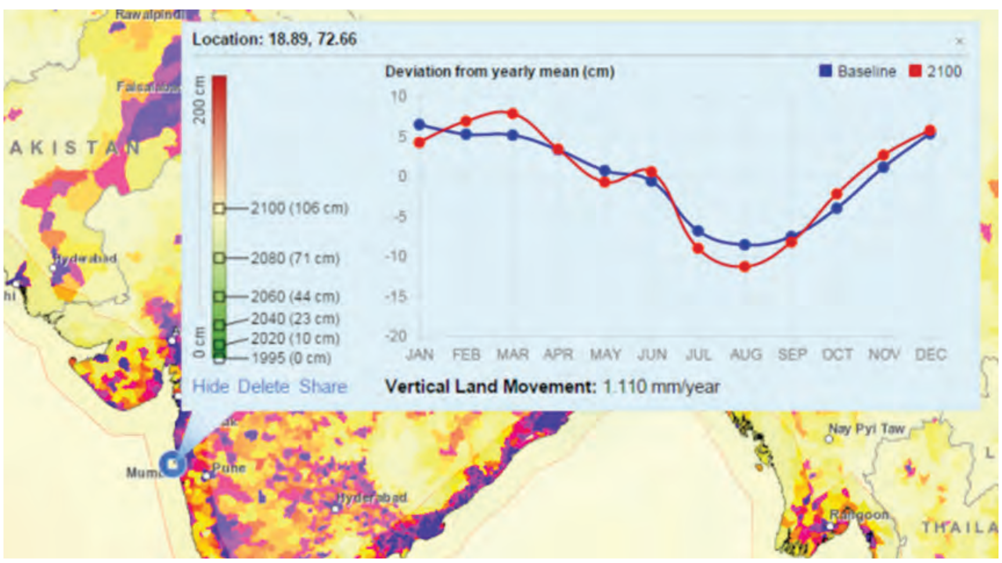
Figure 16. Sea level rise with time from CLIMSystems after incorporating vertical land movements



Note: The offset of around 13 cm at 2020 mostly shows the rises that have already occurred.

Focusing solely on the local relative sea level rise and the IPCC guidance documents on sea level scenarios, the impact and adaptation requirements in coastal areas can be estimated (Nicholls, 2011). An example for the sea level rise near Mumbai is shown here. In the Arabian Sea, the seasonal weather patterns cause an annual signal. On top of this, in the period between July and August the sea level is approximately 10 cm lower than the yearly average, while during the period between January and March, the level is approximately 5 cm higher. Additionally, the land is sinking at Mumbai by +1.11 mm / year. The total projected sea level rise by 2100 could be more than a meter (106 cm), based on an ensemble of 28 GCMs and a high climatic sensitivity (RCP8.5).

Figure 16. Sea level rise with time from CLIMSystems after incorporating vertical land movements



Source: CLIMSystems (2015)

Conclusions

The analysis has summarized quantitative changes to the climate around India. Further increases in water level will be devastating. The predicted weather and wave changes form the basis for our analysis of design water levels, and consideration of the optimal methods to make the Indian coast more resilient to climate change.

The analysis for the west coast of India indicates storm surges in Gujarat are as much as 11 m, making these the dominant impact on coastal flooding, even without sea level rise. Storm surges around Kerala are predicted to be 1.75 to 2.5 m. At the same time, the wave analyses of NIO indicate that wave heights will increase.

Structural levels need to be substantially above the high tide level to cope with such large storm surges and sea level rises. The Guidelines suggest a very conservative level of 3 m, but further analysis will provide levels for each state. The level will be much higher for the northern coasts.

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CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 2

APPENDIX 14

USING THE INDIA-WRIS DATABASE FOR CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT

ADB TA-8652 IND:

CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

APPENDIX 14
Using the India-WRIS Database for Climate Resilient Coastal Protection and Management

Water Resources Information System of India

Water Resources Information System of India (India-WRIS) is a joint venture of the Central Water Commission (CWC), Ministry of Water Resources, Government of India and Indian Space Research Organization, Department of Space, Government of India. India-WRIS Web geographic information system (WebGIS) was launched on 10 December 2009. This application is being hosted by National Remote Sensing Centre (NRSC) Hyderabad while the generation of database development and software development is being taken care by Regional Remote Sensing Centre, Jodhpur and WRIS project team of CWC.

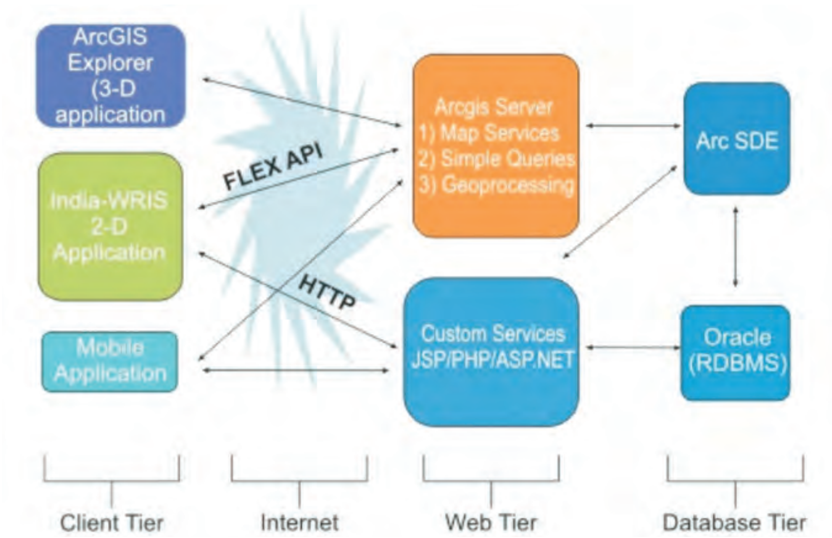
India-WRIS WebGIS aims as a “single window” solution for comprehensive, authoritative and consistent data and information of India’s water resources along with allied natural resources in a standardized national GIS framework tools to search, access, visualize, understand and analyze the data for assessment, monitoring, planning, development and finally integrated water resources management. The current version of India-WRIS WebGIS (Version 4.1) has spatial layers and attributes as per data collected until July 2015. The application is being maintained at a scale of 1:50,000. The data is useful for planning coastal protection projects and understanding the local environment and physical context for a project. The website can be accessed through www.india-wris.nrsc.gov.in

This Appendix explains how to access the data, where information is held and the format of that data. Some helpful software tools are described which allows the operator to gain easier access to the site and information.

The three major components of India-WRIS WebGIS application are: (i) database design and generation; (ii) web application and user interface technology, and; (iii) database storage and web hosting. In the user-interface, the main menu of WRIS has six modules namely, WRIS Info Discovery, WRIS Explorer, WRIS Connect, Input Data Builder, Share Success Story and Create Your WRIS. WRIS Explorer is the core module of India-WRIS WebGIS where all the data can be explored and viewed using the customized tools. Again, the Explorer module is divided into three sub-modules namely, Geo-Visualization, Sub-Information Systems, and Temporal Analyst. It is significant to mention that based on the data type and availability, the Sub-Information System module is divided into 12 major information systems such as base data, surface water, ground water, hydro-met, water quality, snow-cover / glacier, inland navigation waterways, inter-basin transfer links, hydro-met extremes, land resources, water tourism and socio-economic. The major information system is further divided into 35 sub-info systems having 108 spatial layers along with large attribute data of the water resources assets and temporal data of 5 to 100 years. This application complies with National Map Policy of 2005 and CWC data dissemination guidelines.

The India-WRIS WebGIS application uses ArcGIS server as publishing engine whereas the relational database is being maintained through Oracle 11g and MySQL.

Figure 1. India-WRIS web application architecture



Note: The offset of around 13 cm at 2020 mostly shows the rises that have already occurred.

Water Resources Information System of India

The data to be ported in the WRIS will be prepared by the knowledge institutions involved in the Climate Resilient Coastal Protection and Management Project (CRCPMP). The data will be made available at every 50 km interval all along the maritime states and Andaman and Nicobar and Lakshadweep Islands.

Indian Institute of Technology, Mumbai (IITB): The Coordinated Regional Downscaling Experiment (CORDEX) climate projections downscaled at 50 km interval for wind, extreme wind events (cyclones), temperature, humidity and rainfall for the Indian coast are generated. Downscale projection matrices for Indian coast in GIS platform will form a database of point files compatible with India-WRIS. The following parameters are included: rainfall, surface air temperature, surface air temperature maximum, surface air temperature minimum, sea-level pressure, surface specific humidity, surface zonal wind – (cyclones are covered here and in storm surges and waves) and surface meridional wind.

Indian Institute of Technology, Delhi (IITD): Probable maximum water level elevations generated by any tropical cyclones crossing maritime states of India and climate change projections include present (no climate change scenario) and two other scenarios based on climate change at different return periods on 10, 50 and 100 years.

National Institute of Oceanography (NIO), Goa: NIO is making use of the historic wave analysis available, where necessary calculate historic trends as wave climate characteristics. Calculate projections for wave characteristics due to climate change using the wave output from the Coupled Model Intercomparison Project Phase 5 (CMIP-5) database. The output envisaged under this scope is a database of the projected waves based on historic data along the Indian coast and changes to wave characteristics due to climate change. NIO also provides the historic sea levels data, estimate trends during historical (tide gauge data) and recent periods (satellite altimetry).

Water Resources Information System of India

The data to be ported in the WRIS will be prepared by the knowledge institutions involved in the Climate Resilient Coastal Protection and Management Project (CRCPMP). The data will be made available at every 50 km interval all along the maritime states and Andaman and Nicobar and Lakshadweep Islands.

Coastal Data Proposed to Port in Water Resources Information System as Part of the Climate Resilient Coastal Protection and Management Project

The following are the key data proposed to port in the WRIS as part of this project:

- Projected climate parameters such as rainfall, temperature, pressure, humidity and wind at different return periods of 10, 50 and 100 years for present, representative concentration pathways (RCPs) 4.5 and 8.5;
- Wave characteristics of height, period and direction at different return periods of 10, 50 and 100 years for present, RCPs 4.5 and 8.5;
- Maximum possible storm surge along with tide at observation points all along the coast for three scenarios - present (no change in climate), 7% climate change and 11% climate change scenario, and;
- Sea level trends based on measured data and climate change projections at different return periods of 10, 50 and 100 years for present, RCPs 4.5 and 8.5.

Data Format in Water Resources Information System

- The data will be in standard GIS format (point / line / polygon) shapefile with data sorted in the .dbf format;
- Project system - to make the present data combatable to the existing data in WRIS all GIS data will be prepared in Lambert Conical Conformal projection and WGS84 datum;
- The data is available every 50 km and for storm surge at 10 km along Gujarat, Odisha and West Bengal.

A separate module for coastal climate data called "Coastal Climate Information System" (CCIS) will be developed in the WRIS portal. WRIS development team is working on a beta version which was ready to access to user by end of November 2016 for stakeholder review and comments. The key modules and screen design of CCIS is as presented below:

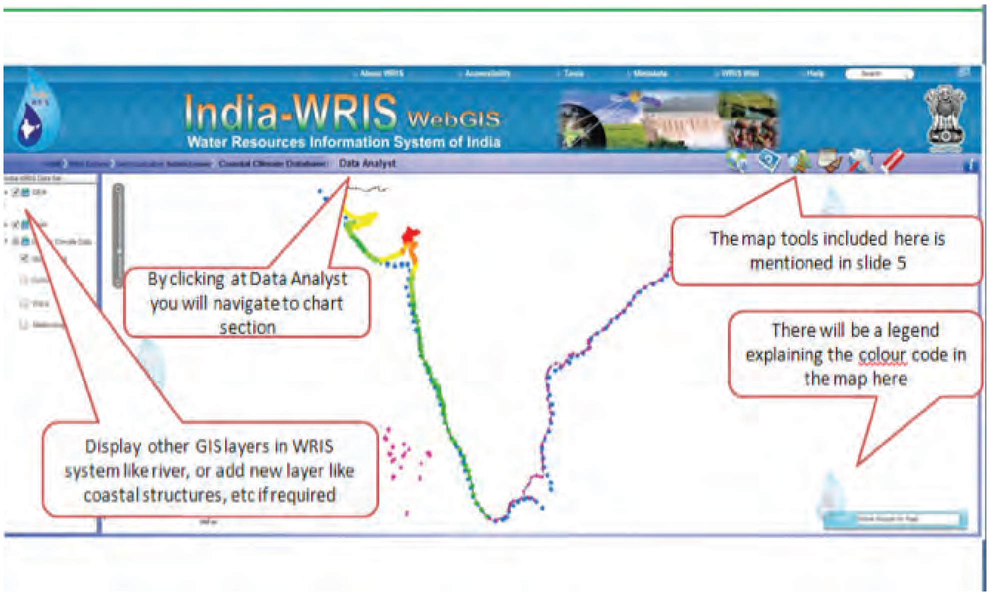
Figure 1. India-WRIS web application architecture

Source: India-WRIS Wiki (2017)
Note: See callout to the added text of CCIS in WRIS

Figure 3. Introductory page of CCIS

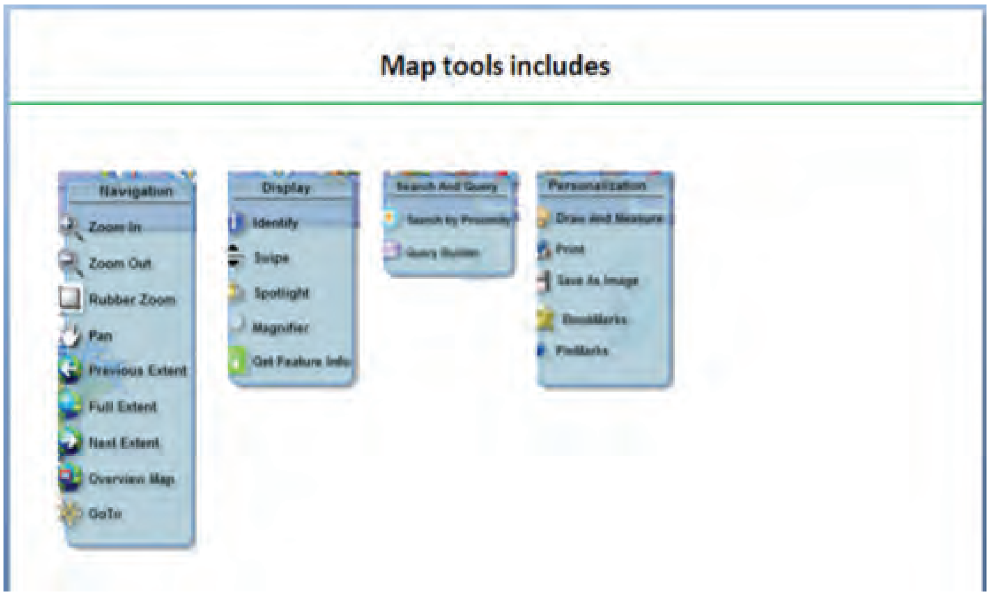
Source: India-WRIS Wiki (2017)
Note: CCIS opening page will have an introduction of the database along with brief methodology used and data sources.

Figure 4. Map display page of CCIS



Source: India-WRIS Wiki (2017)
Note: Left side will have display of layers, central section will have map display with basic map tools of GIS on top right corner.

Figure 5. GIS Map tools with sub menu

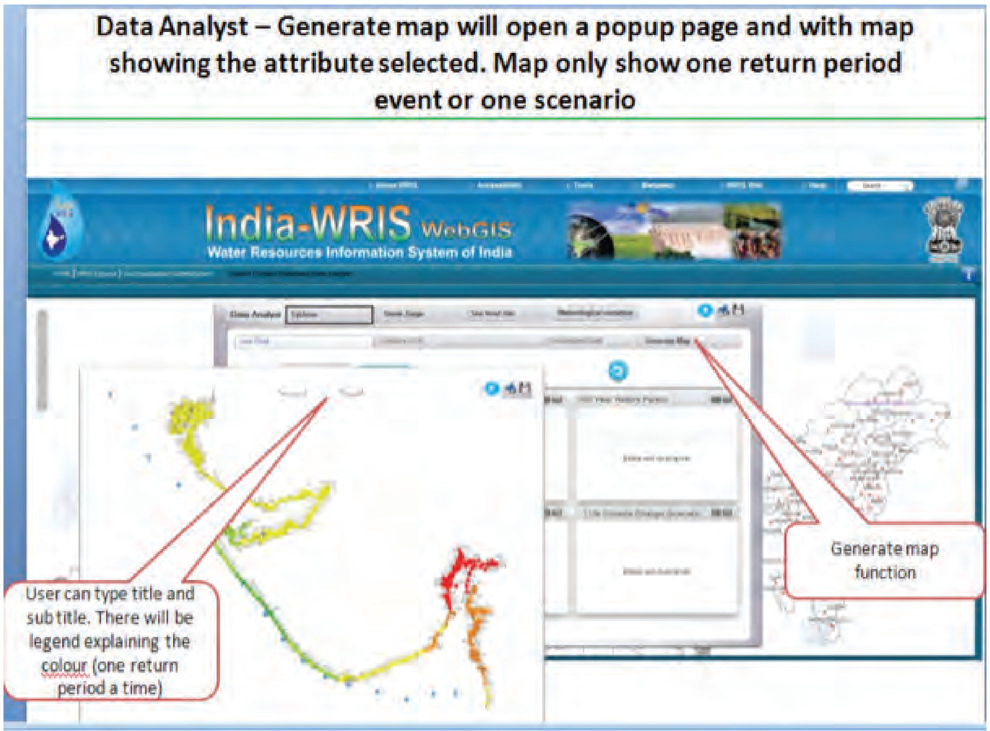


Source: India-WRIS Wiki (2017)
Note: The map tools come under respective tools and pull down menu.

Figure 6. Data analyst module which aids users to define variables and generate charts and tablets

Source: India-WRIS Wiki (2017)

Figure 7. Data analyst module with map window which can display the user defined variable in the map



Source: India-WRIS Wiki (2017)
Note: The map can only show one scenario or return period at a time but will help to analyze the spatial variation of the selected variable.

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CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 2

APPENDIX 15

ECONOMICS AND LIFE-CYCLE COSTING

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CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

APPENDIX 15
Economics and Life-Cycle Costing

Introduction

Coastal protection projects have both direct and indirect (or hidden) costs and benefits. The direct costs relate to the initial project capital development cost of the works, i.e. the direct cost of building a coastal intervention, and the ongoing operation and maintenance costs over the life of project, for example the cost of the periodic nourishment of the beach. Hidden costs relate to unforeseen downstream impacts or the need for unforeseen maintenance, e.g. the cost of repairing a downstream beach impacted by the works, or the extra maintenance arising when rocks used in the project are dislodged by waves.

Direct benefits relate to the value of assets protected by the coastal work, like land, houses and roads. The indirect benefits may be elements such as improved access to the beach for fishing, impact on public health, tourism or development of coastal resorts for income generation, protection of cultural heritage, etc.

In India, the costing of projects for coastal protection generally has only considered the direct costs. There has been no attempt to analyze the hidden costs and no specific consideration of both direct and hidden benefits over the whole life of the project. While a seawall may be built to protect houses, no calculations are done to estimate the value of those houses being protected, or to examine the total cost compared with the benefits of the project. Many of the decisions to protect a coast have arisen from residents applying political pressure or engineers planning works which they believe to be worthwhile, but are not subject to an impartial economic evaluation.

When capital is limited, as is likely to be the case for developing coastal protection measures when the effects of sea level rise (SLR) and climate change (CC) become more apparent, it will be necessary to direct the investment to projects where the economic benefits are highest.

This Appendix shows how to undertake:

- Full life-cycle costing of a project, that is, allowing for all costs of a project including the initial capital costs of construction, maintenance and replenishment and the costs of negative external impacts downstream or outside of the project;

- Identifying and quantifying the benefits resulting from the project over its full life, including methods of valuing benefits that are not easily expressed in monetary values; and

- The application of cost benefit analysis (CBA) to indicate if a project is economically viable and to allow the comparison of projects relative economic performance through the indicator of the internal rate of return (IRR), and net present value (NPV) and benefit: cost ratio (BCR) at a stipulated opportunity cost of capital (OCC).

Cost Benefit Analysis

The Guidelines document (Volume I) is self-contained, with adequate information to understand the Guidelines and put them into practice. It is supported by appendices provided in Volume II for users wanting to take a more in-depth approach. Technical references are provided where further information can be found.

Economic analysis, usually referred to as cost benefit analysis (CBA), is a method of appraising projects used by economists and planners to help decide if a project is economically viable and a worthwhile investment. It is also used to compare the economic performance of different projects to a common yardstick to indicate their priority for investment. CBA involves quantifying annual cost and benefits over the project life and discounting the resulting net annual flows to obtain a present value. This type of analysis is carried out from the point of view of society as a whole. Indicators such as the NPV, the economic internal rate of return (EIRR) and the BCR are used to evaluate whether a project should be carried out.

CBA uses full life-cycle cost analysis, not just construction costs, which incorporates ongoing maintenance, environmental restoration costs, downstream impacts and other costs that may arise due to the project over its full life-cycle of thirty years or more. Similarly, the benefits of environmental beach restoration and coastal protection that occur over the full life-cycle to offset costs are valued and included in the evaluation, e.g. protection of infrastructure, land, agriculture, fisheries, livelihoods public amenities, tourism, heritage, social and historical features, etc.

In relation to these Guidelines, the goal of economics is to ensure the following:

- Development of a CBA model that accounts for all economic, environmental and social costs and benefits of coastal management strategies.

- Enable planners to use the CBA model to rationalize the allocation of resources, and to make decisions about the appropriate strategy for sites. The development of interventions to ensure the most efficient allocation and beneficial use of capital resources in the coastal zone for the management and adaptation to coastal erosion and the future impact of climate change.

Time Value of Money

The costs and benefits (cashflows) of projects occur at various times over the project's life. Capital investment costs usually are front-loaded over the initial years, operations and maintenance (O&M) costs may be spread equally every year, or require periodic inputs. On the other hand, the benefits usually build up more slowly, or occur at some time in the future triggered by the build-up of coastal erosion. To put all projects on a level playing field for comparison, economists adjust the costs and benefits to Present Value allowing for the time value preference of money: by discounting future costs and benefits at a set discount rate. This is done because the value of a certain amount of money depends on when it is received. Money spent or earned in the future has a lesser value compared to expenditure and income now, (due to inflation, interest and the loss of future alternative uses of the money being used for the project). To consider the "time value" of money the present value of a future disbursement (or benefit) is computed by using a factor called the discount rate. The "discount rate" is a percentage change in the value of the money each year into the future. At a 10% discount rate $1.0 received one year away has a present value of $0.90, money that is spent or earned two years away has a present value of $0.81 (1*(1-10%)*(1-10%)), and so on at a compounding lower value into the future.

Opportunity Cost

The discount rate is representative of the OCC, which is the general return on the money that can be obtained if invested in other sectors of the economy. This rate considers the global profitability of all other investment projects within the society. It is the rate of return at which the Government can invest its scarce resources. It is not the same as the interest rate or cost of capital if money is invested or borrowed by a private entity. In the current financial environment, the OCC to a country is usually higher that the cost of capital for the private sector. From the national viewpoint undertaking a project below the OCC rate would financial environment, the OCC to a country is usually higher that the cost of capital for the private sector. From the national viewpoint undertaking a project below the OCC rate would not serve national interests and society would be poorer as a result. Projects with a return above this rate, all other things been equal, indicate that the government should be ready to go ahead with the project because the other projects (the alternatives) are less profitable. Given the choice between two projects, the government should always select the project with the highest rate of return that exceeds the OCC. In a society, the OCC tends to be more or less stable across time.

Usually international development agencies, such as the World Bank and Asian Development Bank (ADB), require that the discount rate should be 10% to 12% representing the OCC. However, for projects, such as those building resilience to climate change and protecting the environment, with a longer gestation period before the full benefits are achieved and longer time-scales with inter-generational aspects to be considered, a lower discount rate is generally considered to be more realistic[1].

For the purpose of these guidelines it is recommended that a discount rate of 5% is used for the CBA as representative of the opportunity cost of capital.

Indicators of Economic Performance

Economic Internal Rate of Return

This is the rate of interest (discount rate) which discounts the net cashflows over time for the revenue and costs generated by an investment) so that the present value of the revenue flows is equal to the discounted value of the cost flows over the project life. The result is called the economic internal rate of return (EIRR)[2] : the discount rate at which the NPV equals zero.

The NPV and the EIRR are considered as reliable indicators for project selection and decision.

The NPV and the EIRR are calculated as follows:

$$\sum_{t=0}^{n} \frac{Benefit_t}{(1+r)^t} - \sum_{t=0}^{n} \frac{Cost_t}{(1+r)^t} = NPV$$

$$\sum_{t=0}^{n} \frac{Benefit_t}{(1+ERR)^t} - \sum_{t=0}^{n} \frac{Cost_t}{(1+ERR)^t} = 0$$

Where:

n= Period of analysis

r= Discount rate

t= Year

Benefit, Cost t = Benefit or cost for year t.

The functions in Microsoft Excel allow the EIRR and NPV to be calculated easily without the need to apply these calculations.

1 The Asian Development Bank has reviewed its benchmark for the OCC and is moving to allowing a lower OCC of 6% for projects with significant environmental and poverty alleviation benefits.

2 Called the Economic Internal Rate of Return because for the economic analysis the costs and benefits are adjusted for the effects of transfer payments, (taxes and subsidies), shadow value of labor and other distortionary effects in the economy.

Benefit Cost Ratio

Project economic performance can also be measured by the BCR which is the ratio between the PV of benefits and the PV of costs at the stipulated discount rate representing the OCC. A BCR of greater than 1.0 results when the PV of benefits is greater than the PV of costs and is often used as the indicator of a satisfactory economic performance. However, the EIRR is usually used as the main indicator of economic performance and feasibility.

The BCR is heavily influenced by the discount rate, particularly long-term BCRs, such as those involved in climate change, are very sensitive to the discount rate used in the calculation of NPV, and there is often no consensus on the appropriate rate to use. Stipulating that a coastal protection project must achieve a BCR of 3:1, or 5:1, is meaningless unless the discount rate applied is clearly defined. Except at very low discount rates of 1% to 2% achieving these levels of BCRs would impose an unrealistic hurdle for the project. For example, the recent economic evaluation of the nine subprojects of the ADB-funded Sustainable Coastal Protection and Management Investment Program (SCPMIP) in Karnataka State indicates that only one subproject, (which has an EIRR of 38%) would achieve a BCR of greater than 3:1 at a discount rate of 12% and only two projects would exceed 3:1 at a 5% discount rate, while eight and the nine subprojects have an EIRR exceeding 6% which would meet the ADB's updated criteria.

Net Present Value

The net present value (NPV) at a stipulated discount rate (representing the OCC) is an indicator of the order of economic performance as the higher the economic returns at the chosen discount the higher the NPV. The NPV is also an indicator of the scale or size of the project; a bigger project in terms of the capital investment and benefits will have a higher NPV than a smaller project that has a similar economic performance.

Project Life-Cycle

Typically, CPA assumes a project life of 25 years, even though the costs and benefits may continue for a longer period, or almost indefinitely. The reason for the cut-off is twofold: it is increasingly difficult to predict costs and benefits far into the future; and also, the impact of costs and benefits occurring after 25 years on the PV and economic returns are negligible at the discount rates used.

Assessing Costs

Assessing the costs is the easier part of preparing a CBA. Coastal protection project costs are made up of the initial capital investment costs (Capex) and the O&M costs, also called Opex needed to maintain the assets that occur over the life of the project. The capital costs are defined during project preparation and typically will be incurred over the first years of project implementation, which for coastal protection projects can be expected to be implemented over a one to three-year time frame depending on the size and complexity of the project.

Annual O&M costs can be expressed as a percentage of the initial capital cost, and vary according to the category of costs. Hard assets such as roads, seawalls, and buildings typically have annual O&M of between 0.5% to 3% of the initial capital cost, while equipment and moveable assets such as pumps, control gates have a higher rate – 5% to 10% of their capital cost per year and a shorter economic life requiring replacement during the project life-cycle. Vehicles have a higher annual cost of maintenance and fuel, proportional to the amount of usage. Some operation and maintenance costs occur as irregular lumps every so many years over the life of the project, for example the replenishment of sand in a beach / dune nourishment project every five years, or major repairs to protection infrastructure that may be required after an exceptional storm or climatic event.

Sometimes the introduction of protection measures in one location may have an unintended negative impact on another location off-site, for example, when the construction of a groyne, seawall or an artificial reef to protect an area of coastline may change the morphology of another location leading to accelerated beach erosion. The impact of this should be included as a cost, or negative benefit, of the project. The cost on the environment when rocks and sand are mined and transported to the location site for the construction of protection measures should also be considered and included as a cost to the project when there are significant impacts.

Assessing Benefits

Assessing the benefits arising from coastal protection measures is a more complicated and diverse exercise than assessing the costs. Coastal protection projects are designed to protect the coast and increase resilience to climatic events. Most of the benefits are in the form of saved losses: saving the loss of land due to coastal erosion, prevention of the destruction of roads and infrastructure, protecting land from losses in productivity due to salt water intrusion, and so on. Assessing the benefits requires both information about the likely impacts (saved loss) and the timing of when the loss may occur over the life of the project. Both of these aspects require local knowledge of the extent of the coastal land and infrastructure affected and detailed analysis of the impacts supported by field investigation. The likely benefits can be divided into several categories, as given in Table 1.

Table 1. Benefit categories that accrue from coastal protection measures

BENEFIT CATEGORY	DESCRIPTION
Loss of land	Physical loss of coastal land due to coastal erosion.
Loss of land productivity	Impact on quarry and borrow sites for sourcing rock and sand when other alternatives are used for coastal protection
Damage to assets	Loss of agricultural production from coastal land due to inundation with sea water and saline water intrusion
Loss of livelihood	Damage and destruction of coastal assets including housing, buildings, roads, port facilities, etc. due to coastal erosion
Saved protection costs in without project situation	Impact on agriculture, local fishing activities, tourism due to the loss of the beach and access to fish landing facilities
Increase in economic output	Savings in the cost of emergency and remedial works that would have to be incurred if the project did not exist
Impact on cultural and heritage sites	Impact of coastal protection measures on promoting economic activity such as investment in tourism infrastructure, intensified agricultural production, local fishing and fish landing facilities, etc.
Impact on cultural and heritage sites	Damage and destruction to cultural assets, such as places of worship, heritage buildings, graveyards etc. through coastal erosion

A first step in the benefit assessment is to define the boundaries and extent of the land that is affected and that will be protected through the project. This requires a projection of the rate of coastal erosion and land loss in the situation without the project. In a typical situation along the coast in Karnataka, this land may be divided into the beach frontage that has no economic use other than to provide access to the sea for fishing, a desirable location for tourist operations, and providing protection to the back slope. Then there is land that is used for infrastructure and housing close to the beach, and thirdly productive land that is used for agriculture and which will be threatened by coastal erosion. Quantifying these benefits required an estimate of the annual net production from the land and the loss in income through the impact on its use, or the need to change to a less productive use.

Quantifying the saved cost of damage to assets (category 3) requires an estimation of the saved cost of the repairs, and a valuation of the replacement cost in the event that the asset is destroyed. In extreme cases, the local residents may have to relocate to a location in which case there will be the cost of establishing a new home. Relocation may also lead to a loss of livelihood and the need to take up an alternative livelihood, as would be case when coastal residents are no longer able to work as fishermen. The net loss in their livelihood can then be counted as a benefit.

The installation of an effective coastal protection measure means that there will be a saving in the costs that would have been incurred in the without project situation in dealing with emergencies to protect essential infrastructure and remedial works. The saving in this cost can also be counted as a benefit in the CBA. This requires the analyst to estimate what the annual average costs of protection would be without the project, and how effective this work might have been in protecting the coastline.[3]

Effective coastal protection measures can act as a stimulus for increased economic production in the coastal area when investors and landholders have more confidence to develop resources for tourism and more intensive agricultural production. The net increase in national tourism can be counted as a benefit to the economy, i.e. an increase in international tourism rather than a relocation of tourists from another tourist area. Coastal protection interventions can also enhance people's livelihoods and resilience to natural disasters in a positive way, not only through the avoided costs of damage. The benefits of these types of projects can be valued as the increase in income, or income-in-kind over the life of the project.

The coastal protection works may also protect locations and infrastructure with a particular cultural and heritage value that cannot be easily expressed in monetary terms, such as the case for the destruction of a building, or loss of productivity from land. The value of the saving of these assets can also be included as a benefit, but they usually require other techniques to arrive at their value to the society (as discussed later in this Appendix).

Methodologies for including subsistence and non-market values, ecological functions and non-use benefits in the economic valuation of benefits are considered. The Appendix also highlights issues concerning the appropriate discount rate, valuation of benefits and costs, inter-generational equity, direct values, indirect values, option values and non-use values, etc.

Assessing When Benefits Occur

The next step after defining the type and monetary value of the benefits is to decide when the benefits will occur over the life of the project. In the situation without the coastal protection provided by the project there will be annual accumulation of impacts as the coastal land is eroded away and productive land is subject to more frequent inundation with seawater. In most of India's coastal erosion occurs during the annual monsoon period when increased storms and rainfall cause heightened wave action and flooding in coastal areas contributing to a gradual landward progression of the coastline. Unlike other situations where coastal erosion is caused by extreme climatic events such as a cyclone the situation in India is a more gradual annual process. In this case, the analyst must estimate the extent of the land loss and associated damage and impact on economic activity each year over the life of the project. This should also allow for the partial protection provided in the without project situation by the unplanned and less effective coastal protection measures.

Economic Analysis Case Study: Maravanthe Subproject

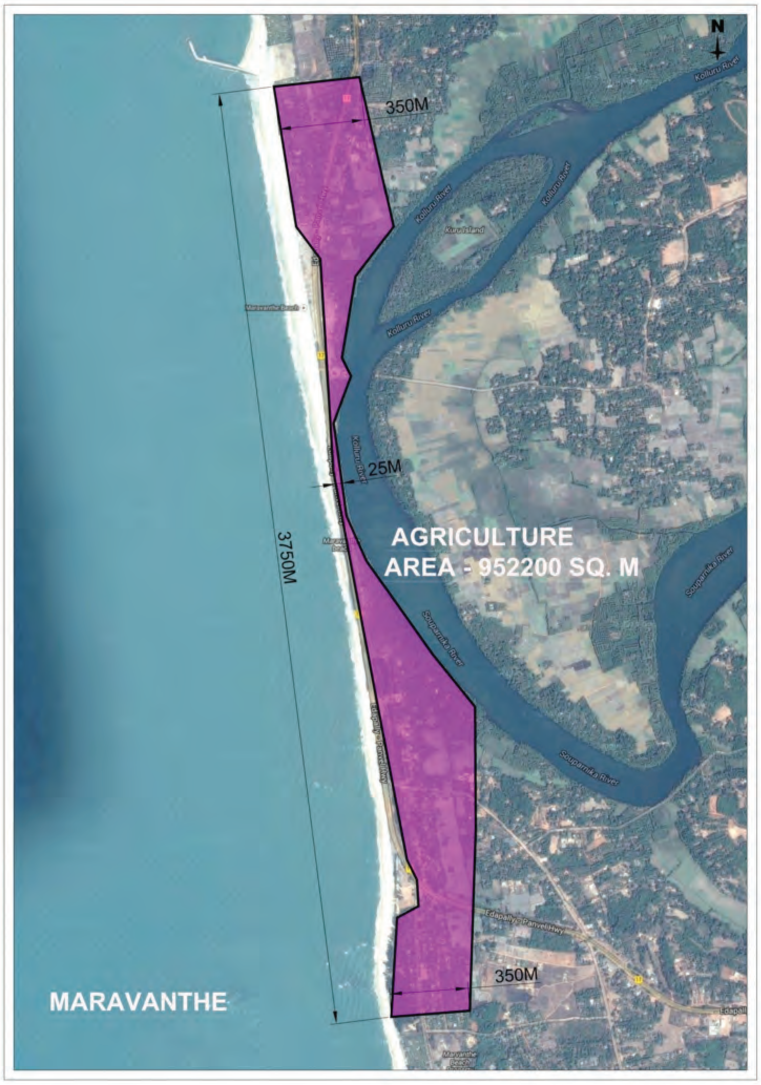
The economic analysis of two of the nine subprojects included in the SCPMIP, which is being implemented in Karnataka is used as an example of the application of CBA for coastal protection investment.[4]

The Maravanthe subproject is located in Udupi district of Karnataka state with the Arabian Sea on the west and the Souparnika River on the east forming a narrow isthmus on which the National Highway 66 (NH-66) connects Mumbai in the north to Kochi in Kerala towards the south (Figure 1).

3 Analysts use the logic of Future With Project (FWP) minis Future Without Project (FWOP) in assessing the net effect and benefit, or cost, resulting from the project. In a typical coastal conservation project the FWOP situation would be x meters of coastline eroded away after y years, and the resultant negative impact. In the FWP situation this negative benefit would be abated.

4 The Asian Development Bank (ADB) in October 2010 approved a Multitranche Financing Facility (MFF) for $250 million for the three coastal states of Maharashtra, Karnataka and Goa for the Sustainable Coastal Protection and Management Investment Program (SCPMIP). The investment program aims to address immediate coastal protection needs and coastal instability using environmentally and socially appropriate solutions in the three states. Under Tranche 2 the SCPMIP will develop coastal protection at nine sites in Karnataka state involving a range of design methodologies in consideration of the site-specific requirements and directed as far as possible towards soft options which will maintain the integrity of the natural beach with minimum impact on the natural shoreline processes.

Figure 1. Maravanthe Coastal Protection Project



Source: Google Earth

The proposed scheme involves protecting a shoreline length of 3.5 km through establishing 15 shore normal groynes on the south and northern ends of the project site and nine T-groynes at the middle section where the National Highway 66 runs along the very narrow stretch sandwiched between the sea and river. Sand nourishment is proposed to enhance the beach width at critical sections. T-Groynes would protect the beach and hold the beach nourishment in place and stabilize the beach. The height of the groynes would be set low to not significantly affect the natural littoral drift.

The project area and the land affected by coastal erosion and flooding are shown in the figure above. The pink shaded area is the area of coastal land that is threatened by coastal erosion and inundation over a 25-year period. The greatest risk is to National Highway 66, which in the event that the narrow isthmus is breached would have to be reconstructed over the breached section. Without adequate protection, this section is expected to fail within a relatively short time frame, despite ongoing emergency protection works.

The impact of coastal erosion on this project was thoroughly evaluated during feasibility studies for the ADB project.

Projected Coastal Erosions

Figure 2. Coastal road in Maravanthe

Source: Subramanian (2009)

The projected rate of coastal erosion for the site is calculated based on the predicted rate of sea level rise and the historical rate of erosion as determined from historical photographs and satellite imagery. The results of this simulation are shown in the table below. (For the SCPMIP this calculation was performed for each of the nine subprojects).

Table 2. Projected coastal erosion at Maravanthe

YEAR	SEA LEVEL RISE (mm / yr)	RETREAT VALUES (m / yr)	CUMULATIVE LAND LOST TO EROSION (m^2)	SALINE VULNERABLE LAND LOST CUMULATIVE (m^2)
2015	3.10	2.06	7,201	-
2016	3.22	2.14	14,681	-
2017	3.34	2.22	22,440	-
2018	3.46	2.30	30,478	-
2019	3.58	2.38	38,794	-
2020	3.70	2.46	47,389	-
2021	3.76	2.49	56,112	-
2022	3.81	2.53	64,963	-
2023	3.87	2.57	73,941	-
2024	3.92	2.60	83,048	-
2025	3.98	2.64	92,282	-
2026	4.03	2.67	101,643	2,400,000
2027	4.09	2.71	111,133	2,400,000
2028	4.14	2.75	120,750	2,400,000
2029	4.20	2.78	130,495	2,400,000
2030	4.25	2.82	140,368	2,400,000
2031	4.31	2.86	150,368	2,400,000
2032	4.36	2.89	160,497	2,400,000
2033	4.42	2.93	170,753	2,400,000
2034	4.47	2.97	181,137	2,400,000
2035	4.53	3.00	191,648	2,400,000
2036	4.58	3.04	202,288	2,400,000
2037	4.64	3.08	213,055	2,400,000
2038	4.69	3.11	223,950	2,400,000
2039	4.75	3.15	234,972	2,400,000
2040	4.80	3.19	246,123	2,400,000

This table shows the projected loss of land (retreat rate) each year over 25 years from 2015 to 2040 allowing for the projected rate of SLR. The retreat value is increasing each year due to SLR. This is the situation in the "future without project" in the absence of effective coastal protection measures.

Over the 25-year period the total area of coastal land lost to coastal erosion is estimated to be 246,123 m² or 60.8 acres made up of 42.6 acres of agricultural land used for the production of coconut and 18.2 acres of non-productive land. In addition, a further 2.4 M m² or 495 acres of land would be affected by flooding and inundation with seawater and rendered unproductive. The loss of this land would be triggered when the rate of coastal erosion and SLR has progressed to the point when the protecting bund on the seaward side is overtopped and the backland subject to flooding during the monsoon. This land is currently being used for the production of coconut, cashew and rice and pulses.

Costs of Coastal Protection Works

The total costs of the coastal protection work for this project is estimated to be $13.5 million (INR 922.4 million), which when converted to economic prices allowing for the removal of tax is equivalent to $12.12 million (INR 830.15 million). Implementation of the project would take place over three years. O&M costs for the project over the 25-year project life are estimated at INR 8.3 million ($0.12 million) per year. This cost allows for the periodic replenishment of the sand.

Benefits

The benefits of the project are assessed on a "future with project minus future without project" basis. Most of the benefits are in the form of saved costs and losses as in the future situation without adequate protection against coastal erosion the land would be progressively eroded away and agricultural land flooded and rendered useless. The main identified benefits for this site are noted as follows and how they are quantified explained.

Emergency Protection Works

In the project situation, there will be a saving in the annual cost of emergency rock dumping to protect vulnerable parts of the coastline near the highway (Figure 3). On an average 100 m coast is required to be protected each year at a cost of INR 36,000 per m representing a total cost of INR 3.6 million per year. This saved cost is counted as a benefit to the project for each year of its life.

Figure 3. Rock dumping to protect coastline

Source: Rahul (2014)

National Highway 66 Realigned and Reconstructed

NH-66 which runs along the narrow spit of land is vulnerable to be broken if the narrow isthmus is broken. Based on the projected loss of land without adequate protection is estimated that the breach could occur within ten years, by 2024. The estimated cost of reconstructing and realigning two km of the four-lane highway plus additional bridges is INR 1,676 million. In addition to this cost there would be disruption to the traffic on this part of the highway necessitating a 28-km detour for two years while the highway is being rebuilt. The extra cost to the vehicles and trucks can be estimated based on the representative cost per kilometer for each type of vehicle. The extra cost of this item increases to total saved cost of not having to rebuild the highway to INR 4,058 million equivalent to almost $60 million.

Figure 4. Maravanthe coastline

Source: Bhandary (2016)

Damage to Houses

Houses that are located close to the coastline are vulnerable to damage as the coastline is progressively eroded. The cost of the damage depends on the type of house – pucca or katcha, (for this site it is shown from census data that 78% are pucca and 22% katcha). An increasing number of houses get damaged every year at an average cost of INR 14,000 for pucca houses and INR 30,000 for katcha houses.

Resettlement of Houses

Eventually as more land is lost to coastal erosion the houses will be destroyed and the residents will have to relocate to a new house elsewhere away from the coast. A total of 304 houses would have to be relocated at a cost of INR 700,000 per house including land and relocation expenses.

Loss of Coconut Area

The area of coastal land that is projected to be lost to coastal erosion that is being used for coconut production is estimated to amount to 46.2 acres. The value of the loss of coconut production is valued at the net return per acre for coconuts based on the representative economic value of coconuts and allowing for the direct costs of production. The net loss per acre is assessed as being INR 46,064 per acre per year.

Loss of Fishing Livelihood

A total of 304 families are recorded as having fishing as their main livelihood in this area. With the progressive loss of the beach frontage to coastal erosion and the destruction of their houses, these families will be forced to relocate to a different area and take up a new livelihood that is less productive than fishing. The net loss in annual income to these fishermen can be included as a benefit as in the situation with the project and coastal protection their livelihood would not be threatened. The average annual household income from fishing is assessed as INR 135,000 per year, which after allowing to the income received from an alternative livelihood results in a net loss of income of INR 122,586 per year.

Loss of Land due to Saline Ingress

A total of 495 acres of land would be subject to saline ingress after 2026 when the combination of coastal erosion and SLR triggers the flooding of the backland. This land is being used for growing cashew, coconut, rice and pulses. Some of the area is built-up used for housing. An area of 26 acres of land that is being used for cashew trees that will become unproductive as the land is lost due to flooding with seawater from 2026. The average net return from cashew production is estimated at INR 77,408 per acre per year. Coconut production takes place on 95 acres with an annual net return of INR 46,064 per acre. Rice is grown on 190 acres with a second crop of pulses on 10% of the area at an annual net benefit of INR 17,591 per acre.

The 84 acres of built-up and barren land in this category that will be lost due to flooding can be valued at an annual rental value INR 364,363 per acres per year as indicated by the Public Works Port and Inland Water Transport Department (Citizen Charter-2014) Schedule-F.

Loss of Tourism Income and Potential Tourism

The loss of the net income from the existing number of tourists and the potential loss of future increases in tourism in the without project situation can also be included as a benefit to the project. Based on the recorded number of tourist to the project area and an assumed loss of the beach tourist numbers are assumed to decrease by 70% when 50% of the beach had been eroded. 10% of the tourist numbers are projected to remain after the beach is eroded. In the future situation with the project, tourist numbers for this beach are projected to increase by five times after five years following implementation of the project. However, there would be no net economic benefit from the change in domestic tourists, as they would only relocate to other locations with no gain to the national economy. For international tourists, it can be assumed that 30% of the increase in tourists is a net gain to the economy and that 15% of their average daily expenditure of INR 3,788 is a net benefit, allowing for input costs and capital investment.

A summary of the physical impact of the project on the factors noted above and the projected build-up over the 25-year period is shown in Table 3 below.

Table 3. Physical impact and build-up for the Maravanthe Project

Year	Shoreline retreat rate (m/yr) with SLR	Vulnerable											Per annum loss of livelihood / fishing (families)	Built up area (acres)
				Infrastructure										
		Land lost (m^2/yr)	Cumulative land lost to erosion (m^2)	Saline vulnerable land cumulative (m^2)	Emergency protection works (rock dump) (m)	Fishers roads to be realigned and constructed (m)	Annual repair to fisheries road (m)	NH-66 to be realigned and constructed (m)	N° of pucca houses damaged	N° of katcha houses damaged	Resettlement of houses	Coconut plantations (acres)		
2015	2.06	7,201	7,201	-	100	0	0	-	0	0	0	1.25	0	0.53
2016	2.14	7,480	14,681	-	100	0	0	-	0	0	0	1.29	0	0.55
2017	2.22	7,759	22,440	-	100	0	0	-	0	0	0	1.34	0	0.57
2018	2.30	8,038	30,478	-	100	0	0	-	0	0	0	1.39	0	0.60
2019	2.38	8,316	38,794	-	100	0	0	-	0	0	0	1.44	0	0.62
2020	2.46	8,595	47,389	-	100	0	0	-	0	0	0	1.49	0	0.64
2021	2.49	8,723	56,112	-	100	0	0	-	0	0	0	1.51	0	0.65
2022	2.53	8,851	64,963	-	100	0	0	-	0	0	0	1.53	0	0.66
2023	2.57	8,978	73,941	-	100	0	0	-	0	0	0	1.55	0	0.66
2024	2.60	9,106	83,048	-	100	0	0	-	0	0	0	1.58	0	0.67
2025	2.64	9,234	92,282	-	100	0	0	2,000	0	0	0	1.60	0	0.68
2026	2.67	9,362	101,643	2,400,000	100	0	0	-	12	3	18	1.62	18	0.69
2027	2.71	9,489	111,133	2,400,000	100	0	0	-	13	4	19	1.64	19	0.70
2028	2.75	9,617	120,750	2,400,000	100	0	0	-	14	4	19	1.66	19	0.71
2029	2.78	9,745	130,495	2,400,000	100	0	0	-	16	4	19	1.69	19	0.72
2030	2.82	9,873	140,368	2,400,000	100	0	0	-	17	5	20	1.71	20	0.73
2031	2.86	10,001	150,368	2,400,000	100	0	0	-	19	5	20	1.73	20	0.74
2032	2.89	10,128	160,497	2,400,000	100	0	0	-	21	6	20	1.75	20	0.75
2033	2.93	10,256	170,753	2,400,000	100	0	0	-	23	6	20	1.77	20	0.76
2034	2.97	10,384	181,137	2,400,000	100	0	0	-	25	7	21	1.80	21	0.77
2035	3.00	10,512	191,648	2,400,000	100	0	0	-	28	7	21	1.82	21	0.78
2036	3.04	10,639	202,288	2,400,000	100	0	0	-	30	9	21	1.84	21	0.79
2037	3.08	10,767	213,055	2,400,000	100	0	0	-	33	10	21	1.86	21	0.80
2038	3.11	10,895	223,950	2,400,000	100	0	0	-	37	10	22	1.88	22	0.81
2039	3.15	11,023	234,972	2,400,000	100	0	0	-	40	12	22	1.91	22	0.82
2040	3.19	11,150	246,123	2,400,00	100	0	0	-	45	12	22	1.93	22	0.83

The various benefits that occur over the life of the project are combined into a table showing the timing of the cash flow each year and the total of the costs and benefits each year. The net cash flow is obtained by subtracting the costs from the benefits, resulting in a negative cash flow in the initial years during the construction period. The example for the Maravanthe subproject is shown below:

The net cash flow can be discounted using the IRR function in Microsoft Excel to indicate the EIRR, and the NPV function can be used to calculate the NPV at the OCC.

In the Maravanthe example the EIRR is 23%, which comfortably exceeds the normal cutoff of 10 to 12%. This is largely due to the big benefits that occur through providing protection to the NH-66 highway and the saved costs of not having to reconstruct and realign this highway in the event the isthmus is breached. The NPV at a discount rate of 10% indicates the scale of the project and can be used to compare the NPV with other projects of a similar nature.

The BCR at a discount rate of 12% is 2.4. At a discount rate of 5% the BCR increases to 3.9. (This illustrates the impact the discount rate has on the BCR).

Table 4. Summary cash flows and results of the cost benefit analysis for Maravanthe

Year	Emergency protection works (rock dumping) (m)	NH-66 realigned and constructed	Damage to pucca houses	Damage to katcha houses	Resettlement of houses	Net loss of fishing livelihood	Coconut land lost	Cashew plantations lost	Other agri land loss due to saline intrusion	Other land lost due to saline intrusion	Tourism (loss without project)	Tourism (potential gained with project)	Value of built up land & barren land lost to erosion	Total benefits	Costs (Capex & Opex 1%)	Net cash flow
2015	-	-	-	-	-	-	-	-	-	-	-	-	-	-	830.2	-830.2
2016	36.0	-	-	-	-	-	1.8	1.4	-	-	5.6	-	6.1	50.9	5,811.1	-5,760.2
2017	36.0	-	-	-	-	-	2.4	1.9	-	-	7.0	-	8.2	55.6	1,660.3	-1,604.7
2018	36.0	-	-	-	-	-	3.1	2.5	-	-	8.4	-	10.5	60.4	-	60.4
2019	36.0	-	-	-	-	-	3.8	3.0	-	-	11.2	-	12.8	66.7	83.0	-16.3
2020	36.0	-	-	-	-	-	4.5	3.6	-	-	12.6	-	15.2	71.7	83.0	-11.3
2021	36.0	-	-	-	-	-	5.2	4.1	-	-	14.0	-	17.5	76.8	83.0	-6.2
2022	36.0	-	-	-	-	-	5.9	4.7	-	-	15.4	10.1	20.0	91.9	83.0	8.0
2023	36.0	-	-	-	-	-	6.6	5.3	-	-	14.7	20.1	22.4	105.1	83.0	22.0
2024	36.0	28,667.8	-	-	-	-	7.4	5.8	-	-	15.4	30.2	24.9	28,787.5	83.0	28,704.5
2025	36.0	11,907.8	16.8	0.9	129.5	20.8	8.1	6.4	33.4	394.3	19.0	40.2	27.5	12,640.8	83.0	12,557.8
2026	36.0	-	18.2	1.1	131.3	41.9	8.9	7.0	33.4	394.3	20.6	60.3	30.0	783.0	83.0	700.0
2027	36.0	-	19.6	1.2	133.0	63.3	9.6	7.6	33.4	394.3	19.5	80.4	32.6	830.8	83.0	747.8
2028	36.0	-	22.4	1.2	134.8	85.0	10.4	8.3	33.4	394.3	20.2	80.4	35.2	861.7	83.0	778.7
2029	36.0	-	23.8	1.5	136.6	107.0	11.2	8.9	33.4	394.3	20.9	80.4	37.9	891.9	83.0	808.9
2030	36.0	-	26.6	1.5	138.3	129.2	12.0	9.5	33.4	394.3	21.6	80.4	40.6	923.6	83.0	840.6
2031	36.0	-	29.4	1.7	140.1	151.8	12.8	10.2	33.4	394.3	22.3	80.4	43.4	955.7	83.0	872.7
2032	36.0	-	32.2	1.9	141.9	174.6	13.6	10.8	33.4	394.3	23.0	80.4	46.1	988.2	83.0	905.2
2033	36.0	-	35.0	2.1	143.6	197.7	14.4	11.5	33.4	394.3	23.7	80.4	48.9	1,021.2	83.0	938.2
2034	36.0	-	39.2	2.2	145.4	221.1	15.3	12.1	33.4	394.3	25.1	80.4	51.8	1,056.3	83.0	973.3
2035	36.0	-	42.0	2.7	147.2	244.8	16.1	12.8	33.4	394.3	25.1	80.4	54.6	1,089.4	83.0	1,006.4
2036	36.0	-	46.2	2.9	148.9	268.7	17.0	13.5	33.4	394.3	25.1	80.4	57.5	1,124.1	83.0	1,041.1
2037	36.0	-	51.8	3.0	150.7	293.0	17.8	14.2	33.4	394.3	25.1	80.4	60.5	1,160.3	83.0	1,077.3
2038	36.0	-	56.0	3.5	152.5	317.5	18.7	14.9	33.4	394.3	25.1	80.4	63.5	1,195.8	83.0	1,112.8
2039	36.0	-	63.0	3.6	154.2	342.3	19.6	15.6	33.4	394.3	25.1	80.4	66.5	1,234.1	83.0	1,151.1
2040	36.0	-	63.0	3.6	154.2	342.3	19.6	15.6	33.4	394.3	25.1	80.4	66.5	1,234.1	83.0	1,151.1

Economic Analysis Case Study: Someshwara Subproject

The Someshwara subproject is in Dakshina Kannada district in the south of Mangalore in Karnataka state. The proposed coastal protection measures to be installed at this site are revetments using geotextile containers filled with sand, for a length of about 2 km along the coast. The proposed scheme provides protection to the communities and infrastructure adjacent to the shoreline. The estimated cost of the proposed scheme at Someshwara is $4.7 million (INR 322 million).

Figure 5. Someshwara Project site plan

Source: Google Earth

It is estimated that a 234 m wide strip of coastline along the 2,000 m frontage making a total of 116 acres is vulnerable to loss to coastal erosion and an additional area of 54 acres will eventually be lost to inundation with seawater when the protective bund is overtopped. The main economic impact is the loss of infrastructure and houses and cost of resettlement, loss of livelihood from fishing, loss of agricultural production and a small net economic loss of tourism.

Projected Coastal Erosion

The projected rate of coastal erosion for this site is calculated based on the predicted rate of sea level rise and the historical rate of erosion as determined from historical photographs and satellite imagery, similar to the calculation for each of the nine subprojects in SCPMIP. A summary is shown in Table 5.

Table 5. Projected coastal erosion in Someshwara

YEAR	SHORELINE RETREAT RATE (m / yr) WITH SLR	LAND LOST (m² / yr)	CUMULATIVE LAND LOST TO EROSION (m²)	SALINE VULNERABLE LAND LOST CUMULATIVE (m²)
2015	6.86	13,717	13,717	-
2016	7.12	14,248	27,965	-
2017	7.39	14,779	42,743	-
2018	7.65	15,310	58,053	-
2019	7.92	15,841	73,894	-
2020	8.19	16,372	90,265	-
2021	8.31	16,615	106,881	-
2022	8.43	16,858	123,739	-
2023	8.55	17,102	140,841	-
2024	8.67	17,345	158,186	-
2025	8.79	17,588	175,774	-
2026	8.92	17,832	193,606	220,000
2027	9.04	18,075	211,681	220,000
2028	9.16	18,319	230,000	220,000
2029	9.28	18,562	248,562	220,000
2030	9.40	18,805	267,367	220,000
2031	9.52	19,049	286,416	220,000
2032	9.65	19,292	305,708	220,000
2033	9.77	19,535	325,243	220,000
2034	9.89	19,779	345,022	220,000
2035	10.01	20,022	365,044	220,000
2036	10.13	20,265	385,310	220,000
2037	10.25	20,509	405,819	220,000
2038	10.38	20,752	426,571	220,000
2039	10.50	20,996	447,566	220,000
2040	10.62	21,239	468,805	220,000

This table shows the projected loss of land (retreat rate) each year from 2015 to 2040 in meters per year allowing for the projected rate of SLR. The retreat value, and the area of land lost, is increasing each year due to SLR. This is the situation in the “without project” in the absence of effective coastal protection measures.

Over a 25-year period from 2015 to 2040, the total area of coastal land lost to coastal erosion is estimated to be 468,805 m² or 115.79 acre made up of 34.7 acre of build-up land used for housing, and non-productive land, and 81.1 acre of agricultural land used for the production of coconut. In addition, a further 54.3 acre of land would be affected by flooding and inundation with seawater and rendered unproductive. The loss of this land would be triggered when the rate of coastal erosion and SLR has progressed to the point when the protecting bund on the seaward side is overtopped and the back land subject to flooding during the monsoon rendering it unproductive. This land is currently being used for the production of coconuts.

Costs of Coastal Protection Works

The total cost of the coastal protection works for this project is estimated to be $4.693 million (INR 321.5 million), which when converted to economic prices allowing for the removal of tax, etc. is equivalent to $4.22 million (INR 289.35 million). Implementation of the project would take place over three years. O&M costs for the project over the 25-year project life are estimated at INR 3.21 million per year (US $47,000), allowing for the periodic replenishment of the sand.

Benefits

The benefits of the project are assessed on a "future with project minus future without project" basis. Most of the benefits are in the form of saved costs and losses as in the future situation without adequate protection against coastal erosion the land would be progressively eroded away, houses and infrastructure destroyed and agricultural land flooded and rendered useless. The main identified benefits for this site are noted as follow and how they are quantified explained. A summary of the physical amounts and timing of the impact and progressive build-up is shown in Table 6 at the end of this section.

Emergency Protection Works

In the with project situation there will be a saving in the annual cost of emergency rock dumping to protect vulnerable parts of the coastline. On average 30 m is required to be protected each year at a cost of INR 36,000 per meter representing a total cost of INR 1.08 million per year. This saved cost is counted as a benefit to the project for each year of its life.

Fisheries Road Realigned and Reconstructed

The fisheries access road that runs parallel to the coast is vulnerable to progressive coastal erosion and without effective protection this road will have to be realigned further inland and reconstructed. The total length of 2,000 m would be affected within five years at an estimated cost of INR 7.5 million per kilometer, including the cost of having to relocate utilities – power and water. The total benefit of this saved cost is INR 150 million.

Damage to Houses

Houses that are located close to the coastline are vulnerable to damage as the coastline is progressively eroded. The cost of the damage depends on the type of house – pucca or katcha[5] . An increasing number of houses get damaged every year at an average cost of INR 14,000 for pucca houses and INR 30,000 for katcha houses.

Resettlement of Houses

Eventually as more land is lost to coastal erosion the houses will be destroyed and the residents will have to relocate to a new house elsewhere away from the coast. In the absence of effective coastal protection, a total of 336 families would eventually have to be relocated at a cost of INR 700,000 per house including land and relocation expenses.

Loss of Coastal Coconut Land

The area of coastal land that is projected to be lost to coastal erosion that is being used for coconut production is estimated to amount to 81.1 acres by 2040. The value of the loss of coconut production is valued at the net return per acre for coconuts based on the representative economic value of coconuts and allowing for the direct costs of production. The net loss per acre is assessed as being INR 46,064 per acre per year.

Loss of Coastal Built-up Land

The 34.7 acres of built-up and barren land along the coast that will be progressively lost due to coastal erosion can be valued at an annual rental value INR 364,363 per acre per year as indicated by the Public Works Port and Inland Water Transport Department (Citizen Charter-2014) Schedule-F. The total value of this benefit over the life of the project is INR 213.2 million.

5 The 2011 census records 76% pucca and 24% katcha houses in this area.

Loss of Fishing Livelihood

A total of 336 families are recorded as having fishing as their main livelihood in this area. With the progressive loss of the beach frontage to coastal erosion and the destruction of their houses, these families will be forced to relocate to a different area and take up a new livelihood that is less productive than fishing. The net loss in annual income to these fishermen can be included as a benefit as in the situation with the project and coastal protection their livelihood would not be threatened. The average annual household income from fishing is assessed as INR 135,000 per year, which after allowing to the income received from an alternative livelihood results in a net loss of income of INR 122,586 per year per family.

Loss of Land due to Saline Ingress

A total of 81.1 acres of land would be subject to saline ingress after 2026 when the combination of coastal erosion and SLR triggers the flooding of the back land. This land is being mostly used for growing coconuts with an annual net return of INR 46,064 per acre for the land when it becomes unproductive.

Loss of Tourism Income and Potential Tourism

The Someshwara area currently attracts almost 300,000 domestic tourists per year as well as a small number of international tourists. In the "future without project situation" this number can be assumed to progressively decrease as the beach and supporting infrastructure is eroded. The loss of the net income from the existing number of tourists and the potential loss of future increases in tourism can also be included as a benefit to the project. Based on the recorded number of tourists to the project area and the progressive loss of the beach, tourist numbers were assumed to decrease to 10% of the current level by 2040.

In the future situation with the project, tourist numbers, domestic and international, for this beach are projected to increase by five times after five years following implementation of the project. However, there would be no net economic benefit from the change in domestic tourists, as they would only relocate to other locations with no gain to the national economy. For international tourists, it can be assumed that 30% of the increase in tourists is a net gain to the economy and that 10% of their average daily expenditure of INR 3,788 is a net benefit, allowing for input costs and capital investment.

A summary of the physical impact of the project and the build-up over the project life of 25 years is shown in the next table.

Table 6. Physical impact and build-up for Someshwara

Year	Shoreline retreat rate (m/yr) with SLR	Vulnerable									Per annum loss of livelihood / fishing (families	Built up area (acres)
		Land lost (m^2/yr)	Cumulative land lost to erosion (m^2)	Saline vulnerable land cumulative (m^2)	Infrastructure					Coconut plantations (acres)		
					Emergency protection works (rock dump) (m)	Fishers roads to be realigned and constructed (m)	No. of pucca houses damaged	No. of katcha houses damaged	Resettlement of houses			
2015	6.86	13,717	13,717		30		3	1	4	2.4 2.37	4	1.02
2016	7.12	14,248	27,965		30		5	1	6	2.5	6	1.05
2017	7.39	14,779	42,743		30		5	2	11	2.6	11	1.09
2018	7.65	15,310	58,053		30		6	2	11	2.7	11	1.13
2019	7.92	15,841	73,894		30		7	2	12	2.7	12	1.17
2020	8.19	16,372	90,265		30	400	8	2	12	2.8	12	1.21
2021	8.31	16,615	106,881		30	1,600	8	3	12	2.9	12	1.23
2022	8.43	16,858	123,739		30		9	3	12	2.9	12	1.25
2023	8.55	17,102	140,841		30		10	3	13	2.9	13	1.27
2024	8.67	17,345	158,186		30		11	3	13	3.0	13	1.28
2025	8.79	17,588	175,774		30		11	4	13	3.0	13	1.30
2026	8.92	17,832	193,606	220,000	30		13	4	13	3.1	13	1.32
2027	9.04	18,075	211,681	220,000	30		14	5	13	3.1	13	1.34
2028	9.16	18,319	230,000	220,000	30		16	5	14	3.2	14	1.36
2029	9.28	18,562	248,562	220,000	30		17	6	14	3.2	14	1.37
2030	9.40	18,805	267,367	220,000	30		19	6	14	3.2	14	1.39
2031	9.52	19,049	286,416	220,000	30		21	7	14	3.3	14	1.41
2032	9.65	19,292	305,708	220,000	30		24	7	14	3.3	14	1.43
2033	9.77	19,535	325,243	220,000	30		26	8	14	3.4	14	1.45
2034	9.89	19,779	345,022	220,000	30		28	9	15	3.4	15	1.46
2035	10.01	20,022	365,044	220,000	30		31	10	15	3.5	15	1.48
2036	10.13	20,265	385,310	220,000	30		34	11	15	3.5	15	1.50
2037	10.25	20,509	405,819	220,000	30		38	12	15	3.6	15	1.52
2038	10.38	20,752	426,571	220,000	30		42	13	15	3.6	15	1.54
2039	10.50	20,996	447,566	220,000	30		46	15	16	3.6	16	1.55
2040	10.62	21,239	468,805	220,000	30		51	16	16	3.7	16	1.57

Presentation of Cash Flows

The various benefits that occur over the life of the Someshwara project are combined into a table showing the timing of the cash flow each year and the total of the costs and benefits each year. The net cash flow is obtained by subtracting the costs from the benefits, resulting in a negative cash flow in the initial years during the construction period. The summary of the cashflows is shown in Table 7 below.

The net cash flow can be discounted using the IRR function in Microsoft Excel to indicate the EIRR, and the NPV function can be used to calculate the NPV at the OCC.

For this project, the EIRR is 11.4%, which is within the normal cut-off of 10 to 12%, and exceeds the 5% OCC by a comfortable margin.

The BCR at a discount rate of 12% is 1.0. At a discount rate of 5% the BCR increases to 1.83. (This illustrates the impact the discount rate has on the BCR).

Table 7. Summary cash flows and results of the cost benefit analysis for Someshwara Project

Year	Emergency protection works (rock dumping) (m)	Fisheries roads to be realigned and constructed	Damage to pucca houses	Damage to katcha houses	Resettlement of houses	Net loss of fishing livelihood	Plantation lost (coconut)	Other land lost due to saline intrusion	Tourism loss (existing)	Tourism loss (potential)	Value of built up land & barren land lost to erosion	Total benefits	Costs (Capex & Opex 1 %)	Net cash flow
2015	10.8	0.0	4.2	0.3	28.0	4.5	1.1	-	-	-	4.9	53.8	-	-
2016	25.2	0.0	7.0	0.3	42.0	11.3	2.2	-	0.02	-	10.1	98.1	-	-
2017	10.8	0.0	7.0	0.6	77.0	23.6	3.4	-	0.03	-	15.4	137.9	-868.0	-868.0
2018	10.8	0.0	8.4	0.6	77.0	36.0	4.6	-	0.04	-	20.9	158.4	1,736.1	-1,577.7
2019	10.8	0.0	9.8	0.6	84.0	49.5	5.9	-	0.05	-	26.6	187.3	289.3	-102.1
2020	10.8	30.0	11.2	0.6	84.0	63.1	7.2	-	0.07	-	32.5	239.4	28.9	210.5
2021	10.8	120.0	11.2	0.9	84.0	76.6	8.5	-	0.07	-	38.5	350.5	28.9	321.6
2022	10.8	0.0	12.6	0.9	84.0	90.1	9.9	-	0.08	-	44.5	252.8	28.9	233.9
2023	10.8	0.0	14.0	0.9	9.1	104.7	11.2	-	0.09	0.1	50.7	283.5	28.9	254.5
2024	10.8	0.0	15.4	0.9	9.1	119.4	12.6	-	0.09	0.1	56.9	307.2	28.9	278.2
2025	10.8	0.0	15.4	1.2	9.1	134.0	14.0	-	0.09	0.2	63.2	329.9	28.9	301.0
2026	10.8	0.0	18.2	1.2	9.1	148.6	15.4	25.0	0.11	0.2	69.7	380.3	28.9	351.4
2027	10.8	0.0	19.6	1.5	98.0	163.3	16.9	25.0	0.12	0.4	76.2	404.7	28.9	375.8
2028	10.8	0.0	22.4	1.5	98.0	179.0	18.3	25.0	0.12	0.5	82.8	438.4	28.9	409.5
2029	10.8	0.0	23.8	1.8	98.0	194.8	19.8	25.0	0.12	0.5	89.4	464.1	28.9	435.1
2030	10.8	0.0	26.6	1.8	98.0	210.6	21.3	25.0	0.12	0.5	96.2	490.9	28.9	462.0
2031	10.8	0.0	29.4	2.1	98.0	226.3	22.8	25.0	0.13	0.5	103.1	518.1	28.9	489.2
2032	10.8	0.0	33.6	2.1	98.0	242.1	24.4	25.0	0.13	0.5	110.1	546.6	28.9	517.7
2033	10.8	0.0	36.4	2.4	98.0	257.8	25.9	25.0	0.14	0.5	117.0	574.0	28.9	545.1
2034	10.8	0.0	39.2	2.7	105.0	274.7	27.5	25.0	0.14	0.5	124.1	609.7	28.9	580.8
2035	10.8	0.0	43.4	3.0	105.0	291.6	29.1	25.0	0.15	0.5	131.3	639.9	28.9	611.0
2036	10.8	0.0	47.6	3.3	105.0	308.5	30.7	25.0	0.15	0.5	138.6	670.2	28.9	641.3
2037	10.8	0.0	53.2	3.6	105.0	325.4	32.3	25.0	0.15	0.5	146.0	702.0	28.9	673.1
2038	10.8	0.0	58.8	3.9	105.0	342.3	34.0	25.0	0.15	0.5	153.5	733.9	28.9	705.0
2039	10.8	0.0	64.4	4.5	112.0	360.3	35.7	25.0	0.15	0.5	161.0	774.4	28.9	745.4
2040	10.8	0.0	71.4	4.8	112.0	378.3	37.4	25.0	0.15	0.5	168.7	809.0	28.9	780.1

Simplified Economic Analysis Template

The economic analysis and screening of coastal protection projects identified and proposed for inclusion in a program may require a relatively simple and cost-effective methodology that can be applied by planners and engineers who may not be skilled in economic analysis. Application of a simplified model will assist in the screening a number of potential projects covering a wide range of activities to whittle down the list to a short-list of projects, which would then be subject to a more detailed economic analysis by professional staff with capacity in the application of CBA and skills in the economics of coastal protection. Another important application of the economic model will be to evaluate between several options to achieve the same output to determine the most cost-effective and least cost option for a particular location. This is called least cost analysis.

Simple Economic Template

For relatively straightforward projects, a template could be used for the economic analysis based on simplified CBA using the BCR as the main indicator for assessing economic viability, as discussed above. The benefits 'B" side of the equation represents the avoided cost of damage under climate change which "C" represents the costs – capital and O&M - over the life of the project. A BCR of more than 1.0 (at the stipulated OCC) indicates that the project is economically viable.

For a simple economic analysis used as an initial screening instrument and to indicate the likely economic performance, the BCR is a convenient means of assessing project viability. The present value (PV) of a constant stream of costs or benefits over a period (PV of an annuity) can be expressed by multiplying the yearly amount by a common factor (the "annuity factor"), which depends on the discount rate that is applied, as illustrated in Table 4.

Table 8. Present value of annuity factor according to discount rate

DISCOUNT RATE	PRESENT VALUE OF ANNUITY FACTOR		
	20 YEARS	30 YEARS	50 YEARS
10%	8.5	9.4	9.9
7 %	10.6	12.4	13.8
5 %	12.5	15.4	18.3
1 %	18.0	25.8	39.2

Table 8 shows the PV of $1.0 received each year at the end of each year of the period, 20, 30 and 50 years. It also illustrates how a lower discount rate has a higher PV of annuity factor and gives greater weight to benefits occurring further into the future. This means that a spend of $1 per year over 30 years (i.e. $30) for a nourishment project with discount rate of 10% would be equivalent to spending $9.40 today. On the other hand, the PV of the same amount at a discount rate of 1% has a much higher PV of $25.80.

The capital costs as they occur can be expressed as a PV by using a discount factor for each year and summed to represent the total PV of capital costs. The PV factors for various discount rates for years 1 to 5 are shown in Table 9.

Table 9. Present value factor for years 1-5 according to discount rate

YEAR	DISCOUNT RATE			
	1 %	5 %	7 %	10%
1	0.990	0.952	0.935	0.909
2	0.980	0.907	0.873	0.826
3	0.971	0.864	0.816	0.751
4	0.961	0.823	0.763	0.683
5	0.951	0.784	0.713	0.621

The proposed template for these types of projects is shown in Table 10 below. If necessary the template could be adapted to suit a particular location with a different mix of costs and benefits.

An example of an economic evaluation using the template is shown in Attachment 1. This is based on one of the proposed projects in SCPMIP, Parvin Kurve, which involves the establishment of a plantation supported by the local community to provide coastal protection.

Table 10. Economic Evaluation and Screening Template

Economic Evaluation Template for Coastal Protection Projects

Project Name ________________________________ Project No.__________
Location (Village) ________________________________ Date __________

Project Description

____
____
____

Project Category

Local Infrastructure
Road / Culvert ☐, Seawall ☐, Building ☐, Community Asset ☐, Cultural Asset ☐, Relocation ☐

Ecological
Beach Protection ☐, Hard Structures ☐, Mangrove Planting ☐, Reef Conservation ☐

Sectoral / Livelihoods support / Resilience

Agriculture ☐, Fisheries ☐, Forestry ☐, Tourism ☐, Other ☐ ____________________

Village Population__________ Number of Beneficiaries __________

Project Costs (itemize the estimated costs and implementation schedule)

Item	Total cost	Implementation program (% of costs)			
CAPITAL COSTS	**(INR'000)**	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Civil works					
Equipment & materials					
Personnel					
Training					
Other					
TOTAL INVESTMENT					
O&M Costs	**(Estimate the annual O&M costs for the project)**				
Item	% of cost	Annual cost			
Civil works	1%				
Equipment	10%				
Sand replenishment (ave / yr)					
Other	5%				
Total O&M per year					

Project Benefits (List the expected impact / benefits of the project. Expand as necessary)

ITEM	IMPACT	Value INR'000
Value of assets affected	(Housing, roads, buildings, tree crops etc.)	
Estimated average annual value of avoided damage	(Based on degree of protection and return period for destructive events)	
Estimated average annual value of improved production / livelihoods	(Value of production from agriculture, fisheries, forestry, tourism resulting from the project)	

PV of COSTS		Total
Investment Costs (from above adjusted for timing)		
O&M (as above)	PV = Annual value times 15	
TOTAL (A)		

PV of BENEFITS		Total
Avoided damage	PV = Annual average value x 15	
Livelihood Benefits	PV = Annual average value x15	
TOTAL (B)		

BENEFIT COST RATIO1		B:C Ratio
PV Benefits (B) ÷ PV Costs (A)		
Benefits		
Costs		

1. Benefit Cost Ratio (based on discount rate of 5% and 30-year project life)

CONCLUSION / RECOMMENDATION

Excel-Based Template

For more complex projects, and where there is greater range of potential coats and benefits an economic analysis template model which uses Microsoft Excel to derive the ERR and BC ratio could be used. This has the advantage that it is more flexible and can be adapted to capture a variety of benefit flows which may not be regular over the life of the project making it more difficult to analyze using the discount factors. An example of this type of template, which is similar to that used for the analysis of the Maravanthe and Someshwara project examples, is shown in Table 11.

The template can be adapted to include any number of types of benefit cash flows over the life of the project, and will also calculate the sensitivity of the results to changes in the main parameters and assumptions.

The application of this type of template would usually entail a more detailed and thorough economic evaluation than that needed for the simpler screening template. The analyst will need more capacity and experience in the application of CBA. It could be used after the initial screening to prepare a more detailed evaluation of a short-list of projects as part of due diligence for getting approval for funding. It would usually require more data analysis and field investigation to substantiate and quantify the costs and benefits.

Table 11. Microsoft Excel-based economic evaluation template

Coastal Protection Economic Evaluation Template

Year	Capital costs INR'000	O&M costs INR'000	Total INR'000	Benefits: Infrastr. INR'000	Benefits: Housing INR'000	Benefits: Ag land INR'000	Benefits: Ag prodtn. INR'000	Benefits: Livelihood INR'000	Benefits: Tourism INR'000	Benefits: Total Bnft INR'000	Net Benefit (Cost): Base Case INR'000	Net Benefit (Cost): Investmt 10% INR'000	Net Benefit (Cost): O&M 10% INR'000	Net Benefit (Cost): Infrastr. -20% INR'000	Net Benefit (Cost): Ag prodtn. -20% INR'000	Net Benefit (Cost): Livelihood -20% INR'000	Net Benefit (Cost): Tourism -20% INR'000
2016	7,637	0	7,637	0	0	0	0	0	0	0	-7,637	-8,400	-7,637	-7,637	-7,637	-7,637	-8,400
2017	26,475	0	26,475	0	0	0	0	0	0	0	-26,475	-29,123	-26,475	-26,475	-26,475	-26,475	-29,123
2018	18,669	0	18,669	0	0	0	0	0	0	0	-18,669	-20,536	-18,669	-18,669	-18,669	-18,669	-20,536
2019	10,688	0	10,688	840	0	0	0	0	610	1,450	-9,238	-10,307	-9,238	-9,406	-9,238	-9,238	-10,429
2020	3,006	651	3,657	1,426	600	2,315	381	133	4,344	9,198	5,541	5,241	5,476	5,256	5,422	5,078	4,372
2021	199	1,181	1,380	1,701	600	4,647	396	133	4,344	11,821	10,441	10,421	10,323	10,101	10,321	9,512	9,552
2022	0	1,151	1,151	1,706	600	5,654	396	133	4,344	12,833	11,682	11,682	11,567	11,341	11,562	10,551	10,813
2023	0	1,912	1,912	1,711	600	7,094	396	133	4,344	14,277	12,365	12,365	12,174	12,023	12,245	10,947	11,497
2024	0	2,172	2,172	1,715	600	7,119	396	133	4,344	14,307	12,135	12,135	11,918	11,792	12,015	10,711	11,266
2025	0	2,342	2,342	1,720	600	7,143	396	133	4,344	14,336	11,994	11,994	11,759	11,650	11,874	10,565	11,125
2026	0	2,342	2,342	1,888	600	7,167	396	133	4,344	14,528	12,185	12,185	11,951	11,808	12,065	10,752	11,317
2027	0	2,342	2,342	1,892	600	7,189	396	133	4,344	14,555	12,212	12,212	11,978	11,834	12,092	10,775	11,344
2028	0	2,342	2,342	1,897	600	7,211	396	133	4,344	14,581	12,238	12,238	12,004	11,859	12,119	10,796	11,370
2029	0	2,342	2,342	1,901	600	7,233	396	133	4,344	14,606	12,264	12,264	12,030	11,884	12,144	10,817	11,395
2030	0	2,342	2,342	1,905	600	7,254	396	133	4,344	14,631	12,289	12,289	12,055	11,908	12,169	10,838	11,420
2031	0	2,342	2,342	1,909	600	7,275	396	133	4,344	14,656	12,314	12,314	12,080	11,932	12,194	10,859	11,445
2032	0	2,342	2,342	1,913	600	7,296	396	133	4,344	14,682	12,339	12,339	12,105	11,957	12,220	10,880	11,471
2033	0	2,342	2,342	1,917	600	7,318	396	133	4,344	14,708	12,365	12,365	12,131	11,982	12,245	10,902	11,496
2034	0	2,342	2,342	1,921	600	7,340	396	133	4,344	14,733	12,391	12,391	12,157	12,007	12,271	10,923	11,522
2035	0	2,342	2,342	1,925	600	7,362	396	133	4,344	14,760	12,417	12,417	12,183	12,032	12,297	10,945	11,549
2036	0	2,342	2,342	1,925	600	7,362	396	133	4,344	14,760	12,417	12,417	12,183	12,032	12,297	10,945	11,549
2037	0	2,342	2,342	1,925	600	7,362	396	133	4,344	14,760	12,417	12,417	12,183	12,032	12,297	10,945	11,549
2038	0	2,342	2,342	1,925	600	7,362	396	133	4,344	14,760	12,417	12,417	12,183	12,032	12,297	10,945	11,549
2039	0	2,342	2,342	1,925	600	7,362	396	133	4,344	14,760	12,417	12,417	12,183	12,032	12,297	10,945	11,549
2040	0	2,342	2,342	1,925	600	7,362	396	133	4,344	14,760	12,417	12,417	12,183	12,032	12,297	10,945	11,549
2041	0	2,342	2,342	1,925	600	7,362	396	133	4,344	14,760	12,417	12,417	12,183	12,032	12,297	10,945	11,549
2042	0	2,342	2,342	1,925	600	7,362	396	133	4,344	14,760	12,417	12,417	12,183	12,032	12,297	10,945	11,549
2043	0	2,342	2,342	1,925	600	7,362	396	133	4,344	14,760	12,417	12,417	12,183	12,032	12,297	10,945	11,549
2044	0	2,342	2,342	1,925	600	7,362	396	133	4,344	14,760	12,417	12,417	12,183	12,032	12,297	10,945	11,549
2045	0	2,342	2,342	1,925	600	7,362	396	133	4,344	14,760	12,417	12,417	12,183	12,032	12,297	10,945	11,549
						Discount Rate @ 12%				EIRR	14.12%	12.9%	13.9%	13.7%	14.0%	12.7%	12.0%
										ENPV	9,477	4,496	8,534	7,591	8,875	3,187	59
						Sensitivity Indicator				EIRR		5.6	0.9	1.0	0.3	3.3	5.0
										ENPV		5.3	1.0	1.0	0.3	3.3	5.0
						Switching Value				EIRR		18%	106%	103%	326%	31%	20%
										ENPV		19%	100%	101%	315%	30%	20%

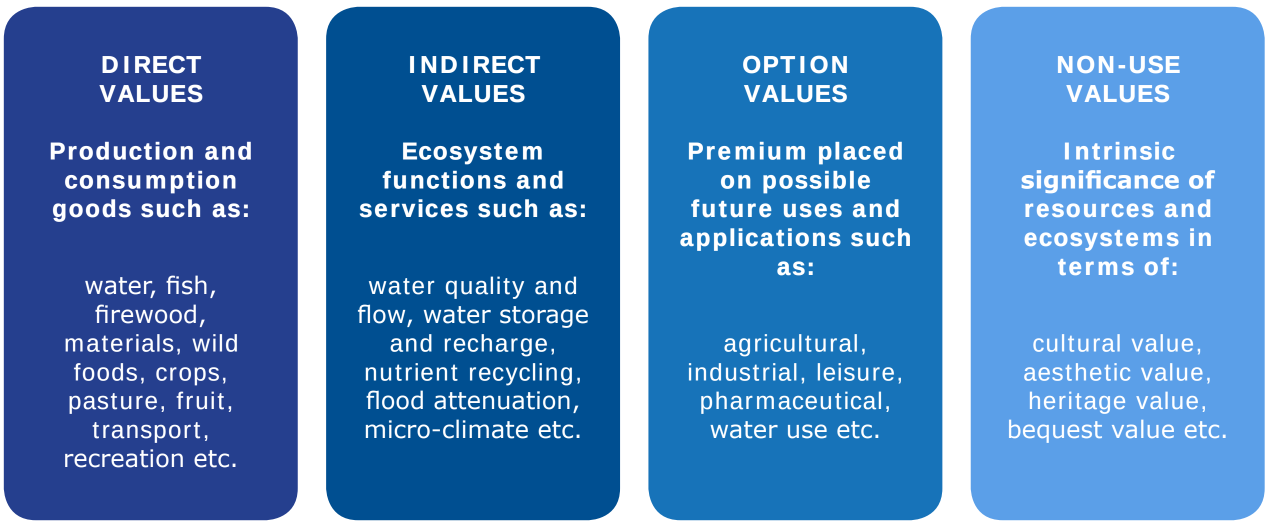
Not Quantified Costs and Benefits

Mainstream economic analysis has tended to use a narrow definition of the costs and benefits, ignoring many of the other negative and positive impacts associated with a project (also called externalities). For some projects, there are significant impacts of coastal erosion that are not easily expressed in monetary values and included in a conventional CBA. For example, when a coastal protection project may protect assets of high cultural and historical worth (invaluable assets), but for which it is not possible to easily quantify in monetary terms. In this situation economists may apply a broader economic evaluation taking account other factors in the environment. The essence of an environmental economic evaluation is that it goes beyond outputs (as measured in the market place) and also considers non-market values.

The concept of total economic value has become more widely accepted; using tools for identifying and categorizing all ecosystem benefits instead of focusing only on the direct natural resource, or commercial values. It also values the subsistence and non-market values, ecological functions and non-use benefits. Thus, it presents a more complete picture of the economic importance of ecosystems and demonstrates the often high and wide-ranging economic costs associated with degradation, which extends beyond the loss of direct use values. It tries to express in economic ($ values) terms the importance of other values which is not captured in a conventional or traditional economic analysis. This allows a more common framework for comparison and places a value of assets that otherwise may not be properly valued.

The total economic value of an ecosystem can be categorized into four components: direct values, indirect values, option values and non-use values, as is shown in Figure 6.

Figure 6. Economic value of an ecosystem



Source: IUCN (2005)

Considering the total economic value of an ecosystem, such as area given protection through coastal protection works, involves considering its full range of characteristic as an integrated system – its resource stock or assets, flows of environmental services and the attributes of the ecosystem as a whole. Broadly defined the total economic value of the ecosystem includes:

- **Direct values:** natural resources (raw materials and physical products) which are used directly for production, consumption, and sale, such as those providing energy, shelter, food, agricultural production, fish production, water supply, transport and recreational activities.

- **Indirect values:** the ecological functions which sustain and protect natural flora and fauna and human systems through services such as maintenance of water quality and flow, flood control, and storm protection, nutrient retention, macro and micro climate stabilization and the production and consumption activities they support.

- **Option values:** the premium placed on maintaining a pool of species and genetic resources for future possible uses, some of which may not be known now, such as leisure, commercial, industrial, agricultural and pharmaceutical application and water based developments.

- **Existence values:** the intrinsic value of ecosystems and their component parts, regardless of their current or future use possibilities, such as their cultural, aesthetic, heritage and bequest significance.

Methods of Valuing Economic Environmental Values

Various methods can be used in valuing the outputs and existence values of the environmental aspects in economic terms. These include:

- **Market prices:** This is the most straightforward way of quantifying economic values where outputs are traded and market prices are available to indicate the value. In some cases, the market prices may need to be converted to economic values to allow for distorting effects of taxes, subsidies and where there is an imperfect market as a determinant of price or value.

- **Price of alternatives or substitutes:** This method involves valuing a product with no market value by comparing it to the value of a close substitute, for example kerosene as an alternative to firewood, and corrugated iron as a substitute to thatching grass.

- **Collection and production labor:** Where products have no market price they may be valued based on the amount of time and labor spent in collecting or preparing the goods at the prevailing wage rate. For example, the time spent on collecting products for consumption or firewood for own use. A problem can arise when there is no alternative employment to indicate the prevailing wage rate, so other methods of valuing time must be applied.

- **Contingent valuation (willingness to pay):** A more sophisticated valuation method for valuing environmental benefits that are not marketed or consumed directly by determining consumers' willingness to pay for a certain amount of the item, as determined through surveys and interviews.

- **Travel cost approach:** Determining the total cost of peoples' time, transport, accommodation and entrance fees for visiting a scenic or environmental attraction as a proxy of the value that they ascribe to the place or feature.

- **Participatory valuation:** A similar technique to contingent valuation but avoids potential distortion caused through using monetary values and instead asks people to value the resource in terms of locally important products or categories of value.

Despite the various methods of valuing the benefits some benefits cannot be quantified and are immeasurable, mostly because the necessary scientific, technical or economic data are not available to allow a meaningful and objective valuation. Other aspects of the valuation which relate to human life or cultural significance may involve ethical considerations, especially when they are used to argue that specific activities or people's needs are more important than others.

Application of these techniques usually requires specialist knowledge and skills and involves additional costs and time for surveys, participant interviews and analysis of the data. It may be applied when a location as assets or an environment of special significance that requires consideration of the non-monetary benefits to be included in the economic evaluation through the application of these techniques.

Where it is possible to ascribe a probability of occurrence of climatic events of varying severity leading to coastal erosion or flooding and its impact, a probability matrix can be developed to calculate the average annual loss. The methodology for assessing the benefits of installing coastal protection measures against climatic events (sea surges, wave overtopping, flooding etc.) is to calculate the expected damage that would occur in the absence of the protective measures and to express the cost of the damage avoided as an average annual benefit over the life of the project. For example, if the construction of a flood protection measure, say, ecology-based coastal protection is expected to reduce damage to an acceptable level for up to a 20-year event and the damage / cost expected in the without project situation is INR 100,000, then the average benefit would be INR 5,000 (100,000 / 20) per year, which can be discounted to a PV by applying the PV of an annuity factor. Floods with a more frequent occurrence but with a lower level of associated damage would also be included in the benefits.

Although the frequency of extreme climatic events may able to be predicted based on the historical records, the difficulty is in estimating the costs of the damage resulting from an event. This is dependent on the value of the infrastructure that is being protected by the protective measures and the expected damage that would occur to the assets related to the severity of the storm / event. The amount of damage usually depends on the depth and amount of time the location might be inundated, and the destructive force of the flooding and wind that occurs with an extreme climatic event destroying property and eroding the land. As noted above, predicting and quantifying the costs (benefits) requires a valuation of the assets and an assessment of the likely cost of the damage to property, personal injury, livelihoods etc., which usually requires intensive field investigation for each situation and project.

The probability of events with different return periods and their associated costs can be developed to show an overall annual average cost / saved damage cost as illustrated in Table 12, which relates storm severity to its associated cost of damage. The risk of a five-year storm happening in any year is 1/5 = 0.2, a ten-year storm has an annual risk of 1/10 = 0.1 and so on. The risk of a storm which is greater than a five-year storm but not as great as a ten-year storm is 1/5 – 1/10 = 0.1. Similarly, a storm greater than ten years but not greater than 20 years is 1/10 -1/20 = 0.05. The sum of all the probabilities of the events is 1.00.

Table 9. Present value factor for years 1-5 according to discount rate

RETURN PERIOD (YEARS) AND STORM PROBABILITY RANGE		ANNUAL PROBABILITY	ASSOCIATED DAMAGE	ANNUAL AVERAGE COST
<5	Storm less than 1:5 year	0.80	1,000	800
5-10	Storm greater or equal to 1:5 but less than 1:10	0.10	15,000	1,500
10-20	Storm greater or equal to 1:10 but less than 1:20 year	0.05	400,000	20,000
>20	Storm of 1:20 or greater	0.05	1,500,000	75,000
Total annual average cost		1.00		

The impact and cost of damage usually are proportionally much greater as the return period increases. The probability of damage from a five to ten-year storm is 0.10, and the damage cost if it occurs is $15,000, so the cost on average each year is 0.1 x $15,000 = $1,500. If for example a protective measure could provide protection up to a 20-year storm then the annual average benefit of the cost savings would be $22,300. As the protective measures do not provide protection for a storm with a return frequency greater than 20 years the average annual cost of these storms of $75,000 is not included.

In locations where there is not sufficient information available of the occurrence and frequency of storms and extreme events and the associated level of impact and damage to build a realistic probability matrix the impact must be assessed through the average annual cost based on the progressive rate of annual coastal erosion.

ATTACHMENT 1

Example of Application of Economic Evaluation and Screening Template

Economic Evaluation Template for Coastal Protection Projects

Project Name __________ Pavin Kurve Community Protection Project __________ Project No.______________
Location (Village) __________ Uttara Kannada district, Karanataka __________ Date ______ Dec 2016 ___

Project Description

The project area is divided into three sectors, where a 0.7-hectare plantation scheme is proposed with a combination of different species of plants. This scheme is proposed to protect a 1.5 km stretch of coastline. Implementation and maintenance of this scheme is proposed to be carried out by involving local communities. Total capital investment costs are INR11.7 million (US$170,800. The main benefits are preventing the loss of coastal land from coastal erosion and prevention of seawater flooding of productive agricultural land. There is also a saving of the costs of emergency protective works and a saving of the loss of tourism potential with protection of the beach.

Project Category

Local Infrastructure
Road / Culvert ☐, Seawall ☐, Building ☐, Community Asset ☑, Cultural Asset ☐, Relocation ☐

Ecological
Beach Protection ☐, Hard Structures ☐, Mangrove Planting ☑, Reef Conservation ☐

Sectoral / Livelihoods support / Resilience

Agriculture ☐, Fisheries ☐, Forestry ☐, Tourism ☐, Other ☐ ________________________

Village Population__________ Number of Beneficiaries ____________

Project Costs (itemize the estimated costs and implementation schedule)

Item	Total cost	Implementation program (% of costs)			
CAPITAL COSTS	**(INR'000)**	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Civil works					
Equipment & materials					
Personnel					
Training					
Other (saplings & grass)	11,700	10%	70%	20%	
TOTAL INVESTMENT	11,700	1,170.0	8,190.0	2,340.0	0.0
PV @ 5%	10,563	1,114	7,428	2,021	0.0
O&M Costs	**(Estimate the annual O&M costs for the project)**				
Item	% of cost	Annual cost			
Plantation maintenance	2%				234.0
Equipment	10%				
Sand replenishment (ave / yr)					
Other	5%				
Total O&M per year					234.0

Project Benefits (List the expected impact / benefits of the project. Expand as necessary)

ITEM	IMPACT	Value INR'000
Value of assets affected	(Housing, roads, buildings, tree crops etc.)	
Emergency protection works	Saving in rock protection works per year	
Coastal land loss prevented	Total of 26.1 acres saved of the life of the project, which is composed of 15.1 ac for built-up land and 10.9 ac of coconuts	
Saline intrusion prevented	Total of 67.4 ac prevented after 15 years. 8.6 ac is used for cashew and 58.8 for rice and pulses	
Estimated average annual value of avoided damage	(Based on degree of protection and return period for destructive events)	
Emergency protection works	Average saving per year for 30 years	180.0
Coconut production (land loss due to coastal erosion	10.9 ac coconut – average saving per year allowing for build-up of the area.	254.8
Cashew and rice land lost due to saline intrusion	Cashew production – average benefit per year	261.7
	Rice and pulses – average benefit per year with prevention of inundation with seawater	943.9
Estimated average annual value of improved production / livelihoods	(Value of production from agriculture, fisheries, forestry, tourism resulting from the project)	
Tourism	Loss of potential tourism income, average benefit per year	117.3

PV of COSTS		Total
Investment Costs (from above adjusted for timing)		117.3
O&M (as above)	PV = Annual value times 15[6]	3,510
TOTAL (A)		14,073

PV of BENEFITS		Total
Avoided damage	PV = Annual average value x 15	
Emergency protection works	180.0	2,700
Coconut production	254.8	3,822
Cashew production	261.7	3,925
Rice and pulses production	943.9	14,158
Livelihood Benefits	PV = Annual average value x15	
Tourism potential	117.3	1,759
TOTAL (B)		26,364

BENEFIT COST RATIO1		B:C Ratio
PV Benefits (B) ÷ PV Costs (A)		1.87
Benefits		26,364
Costs		14,073

1. Benefit Cost Ratio (based on discount rate of 5% and 30-year project life)

6 The PV of an annuity with regular payment over 30 years at a discount rate of 5% is equivalent to 15 times the annual annuity.

CONCLUSION / RECOMMENDATION
The project has an acceptable BCA of 1.87 at the 5% discount rate which exceeds the target return by a comfortable margin. It is recommended that this project be investigated further.

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CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 2

APPENDIX 16
INDIAN ISLAND TERRITORIES AND CLIMATE RESILIENT COASTAL PROTECTION

ADB TA-8652 IND:
CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

APPENDIX 16
Indian Island Territories and Climate Resilient Coastal Protection

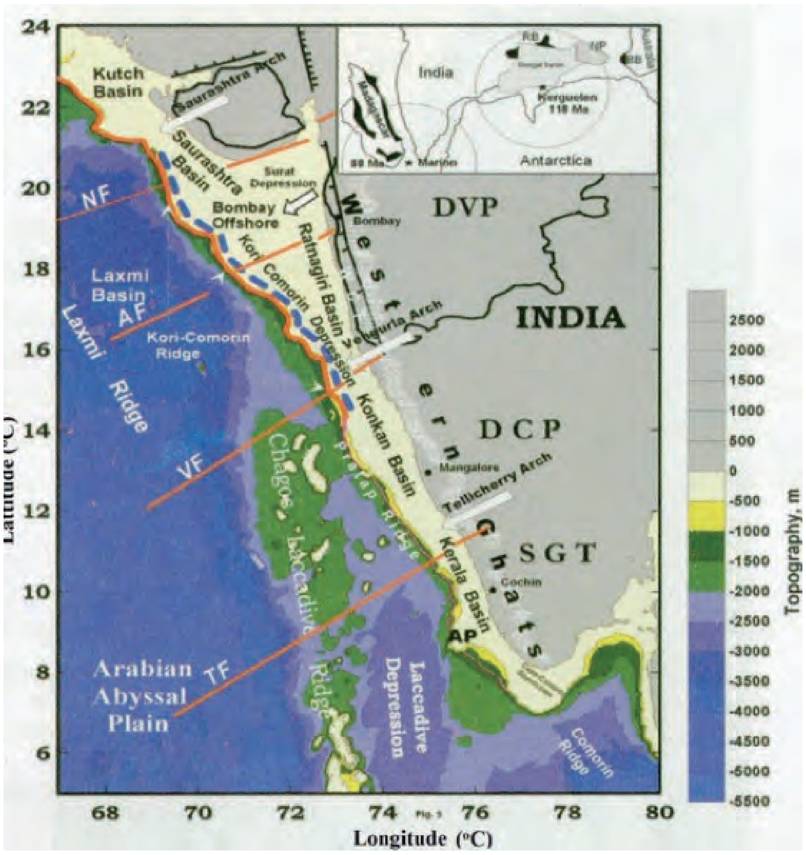
Introduction

The largest Indian island territories are the Lakshadweep Islands off the west coast and the Andaman and Nicobar chain off the east coast. These islands are tropical and relatively pristine. The coral islands among them may require shoreline protection solutions different from the mainland and hence this Appendix examines their morphology and dynamics in general and the coral islands in particular.

Lakshadweep Islands

The Union Territory of Lakshadweep consists of a group of 36 small islands in the Arabian Sea (of which only ten are inhabited) with a total land area of 32 km² (Figure 1).

Figure 1. Lakshadweep Islands and submarine geomorphology of the Arabian Sea



Source: Prakash et al. (2015)

The Lakshadweep archipelago (Figure 1) is distinct with corals islands, banks and shoals, topographic rises and mounts, inter mountain valleys and sea knolls. The seaward reefs of the atolls have several well-defined submerged terraces which have been attributed to the stand of sea level change during the Quaternary Period (Prakash et al., 2015). All the islands have a surface layer of approximately 1 to 2 m thickness of coral debris and below that a compact but porous crust of limestone conglomerate. Below this, there is a bed of fine sand which acts as permeable layer through which there is constant filtration of fresh water.

hese islands of Lakshadweep formed out of volcanic atolls are engulfed by protective natural lagoons (of area about 4200 km²). The islands have extensive formation of corals (in the form of polyps which secrete calcareous materials around them to form as reefs) and they have been reported in the lagoon, crest and outer slope of these islands (Figure 2). The corals have various shapes and sizes ranging from slender skeletoneous branching corals to hard large stony masses. The ten inhabited islands provide an overall population density of around 2,000 persons per square kilometer (in 2011) against a national average of less than 400.

Figure 2. The reef and lagoon of Kavaratti, Lakshadweep Islands

Source: Prakash et al. (2015)

Coastal Erosion and Protection

Out of about 152 km of coastline, considering the shoreline change rate, 21 km are categorized as medium risk, 5 km high risk and 10 km very high risk (INCOIS, 2012). Beaches erode at varying rates due to both natural processes and human activities. During the monsoon, due to the high wave activity and / or increased alongshore drift of sand the beaches erode and immediately after the reversal of the processes they regain their original profile. On the other hand, there are numerous examples where human activities have contributed to or caused coastal erosion by changing the sediment supply through poor coastal development and / or protection practices. A common belief among communities residing within erosion risk areas is that only hard engineering provides sufficient protection against coastal erosion. Hence structural works are often demanded and generally regarded as a socially and economically acceptable means of reducing the risk of coastal erosion. However, a thorough understanding of coastal processes was not applied to determine the need for protection measures or their design and construction. Indeed, the national goal of protecting these fragile environments is at odds with the relatively unfettered construction on the beaches being approved and undertaken by the Government of India.

Seawalls and groins are the common coastal protection structures along the islands' coasts. These are often constructed with rocks or other artificial blocks like tetrapods (Figure 3). Toe erosion and end erosion are the two commonly-observed drawbacks of the seawalls and these problems are common in Lakshadweep.

Figure 3. Coastal protection measures along the coast of Lakshadweep with hollow concrete blocks and tetrapods

Source: Prakash et al. (2015)

The seawalls halt the loss of the land, infrastructure and other property. However, at the same time, they exacerbate erosion in front of the walls and at the ends, they cause loss of beach and deny the desire to keep these islands looking and feeling pristine. They change the beautiful beaches of Lakshadweep into a desecrated shoreline filled with rocks dumped. Tourism impacts will be dramatic and the long-term future is not assured, noting that seawalls have been shown in the Guidelines to be unsuitable under a changing climate scenario.

Groynes trap sand that moves alongshore. They increase the beach width on the upstream side but severe erosion normally occurs on the downstream side. The jetties constructed for the harbor / port operations also, if constructed unscientifically, work as groynes obstructing the sand movement downstream and attracting erosion there. Better solutions are needed for these precious islands.

Understanding the Islands

The Lakshadweep Islands are morphologically sand 'cays' which are built by wave and current action pushing sand into parts of the reef crest where the wave and current action from all sides is essentially neutral. Sand cays are known to be mobile, moving with storms. Also, cay growth leads to different wave patterns and the cay responds accordingly. Of course, this movement is at odds with the human desire to have absolutely stable beaches. However, total stability can only be achieved at the expense of the environment, i.e. rock or concrete beaches. Cays are formed only when waves wash over the sand cay beaches (once again at odds with human habitation). Eventually vegetation can take hold and the cay achieves a level of stability. These islands are very sensitive to climate change. They can be easily overtopped as sea level rises, due to inundation and because bigger waves can reach the cays once the water level rises on the surrounding reefs.

Overall, the natural mobility of these cays is not concordant with human expectations of a beach which is stable; not shifting and not over-topping during storms. For example, tetrapod protection has been put on the southern tip of Kavaratti already, to stabilize that cay (Figure 4). Kavaratti is used as a case study here.

Kavaratti Island

Kavaratti Island has a total shore length of 14.72 km. The long-term shoreline changes in the Kavaratti island indicates that about 36% of Kavaratti is affected by erosion, 61% is accreting and the rest is stable. These statistics demonstrate that the island is: (1) accreting overall due to new sand coming from the coral reefs, and; (2) shifting with the weather and waves as on all sand cays. Thus, the "erosion" is actually movement of the cay and / or local effects of human habitation.

However, much of the beach on Kavaratti has been stabilized by structures using hollow concrete blocks and tetrapods (Figure A16-3). In some locations, low-cost coir bags filled with mixtures of concrete and shingle / pebbles have been placed along the low-tide line.

Figure 4. Southern tip of Kavaratti Island with tetrapod protection of the cay

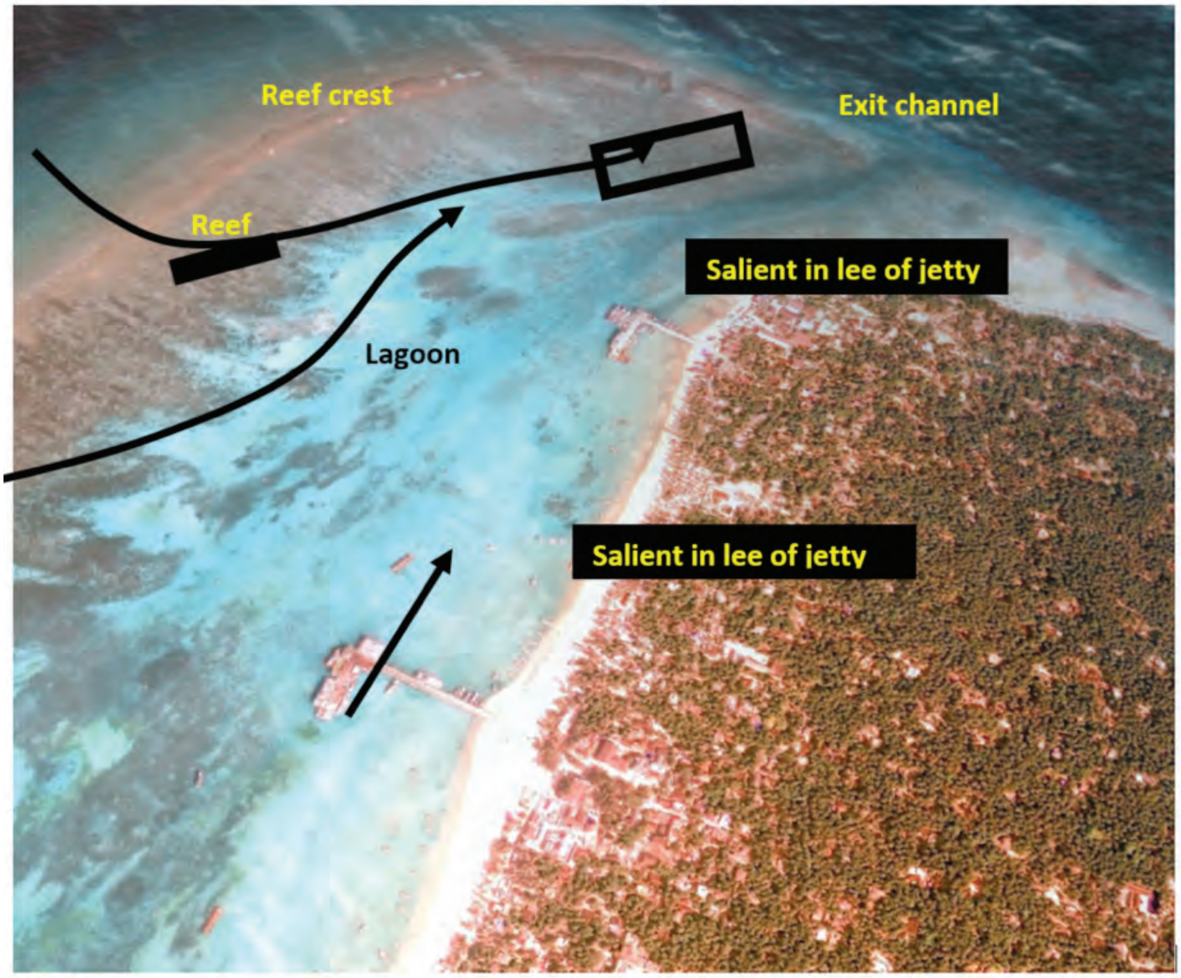
Source: Google Earth

Shoreline protection and sand sources for Lakshadweep

Breaking waves on the fringing reefs drive currents over the reef crest and into the lagoon. These bring coral debris and coral sands into the lagoon. On most cays, the water will exit from one or more channels that are often in a leeward zone which is protected from the waves. In Kavaratti, this channel can be seen at the north end of the island (Figure 4 and Figure 5). The arrows on the Figure 5 show the current patterns.

Sand exiting from the exit channel drops off the reef into deeper water and the sand is mostly lost. Thus, collection of sand from the channel has minor impact on the total sediment budget for the cay and island. Our Guidelines recommend that sand needed to build up the level of the cay and protect the shoreline can be collected from this channel. Strengthening of the reef artificially is also proposed by Prakash et al. (2015).

Figure 5. Northern tip of Kavaratti, Lakshadweep islands.



Source: Google Earth

In the above figure, the box on the exit channel shows a site suitable for sand collection for beach protection. The shaded square shows a small reef placed inshore of the reef crest that could be used to protect the coast. Note that the position, height and size of such reefs would need to be determined using field data collection and numerical model studies.

Two salients have formed in the lee of the jetties at Kavaratti, which locally shelter the beach from waves (Figure 5). These features demonstrate that accumulation can be encouraged using offshore structures. Figure 6 also shows that sand coming from the lagoon is being swept along the shore from the south. These sediment pathways should not be blocked by any works. However, low reefs offshore with a crest height that compensates for sea level rise can provide a solution for climate change. By placing the reefs shoreward of the natural reef crest (where waves are smaller due to breaking offshore), the size of the reef and construction cost can be reduced. Thus, to protect the cays from erosion under climate change, the following recommendation are made:

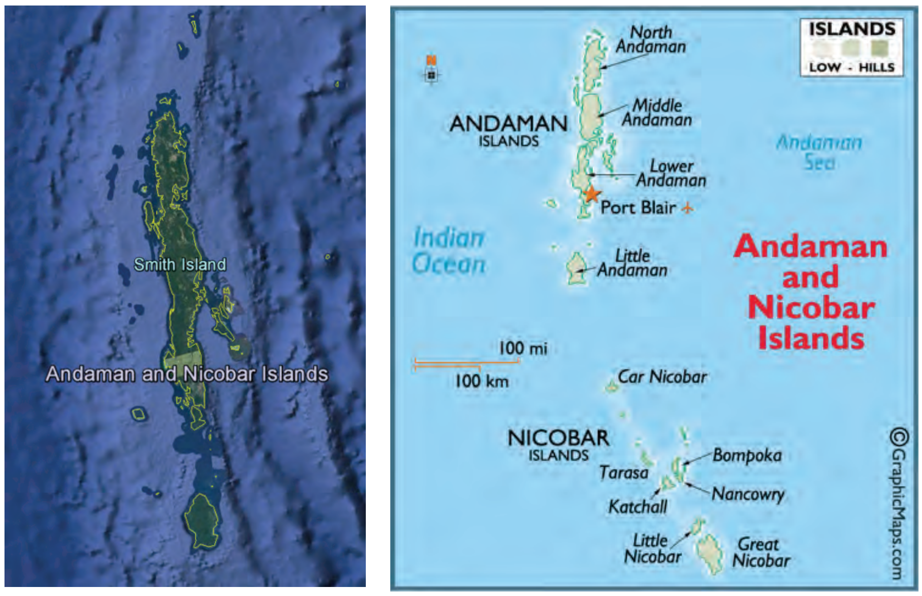
- Collection of sand from the exit channel for beach nourishment;
- Development of small reefs on the reef rest to reduce the wave energy reaching the beaches of the cay, and;
- Construction of sand dunes along the shoreline.

Notably, this assessment is generic and so no construction or projects should commence without detailed data collection and numerical modelling studies. The reefs must be designed so that sand coming to the lagoon from the reef crest is not blocked.

Andaman and Nicobar Islands

Andaman and Nicobar Islands are in the Bay of Bengal at latitude 60° to 140° N and longitude 92-94°E surrounded by Andaman Sea at its east and Bay of Bengal at its west. The Andaman and Nicobar Island group constitutes a total of 556 islands or rocks with 37 inhabited islands. It lies in a highly active seismic zone and experiences frequent earthquake shocks. The population of these Islands are moderate with a total population of about 4 lakh. But the forest cover is about 86%, endowed with evergreen tropical forests and availability of endemic species. From the strategic point of view, Andaman and Nicobar group of islands are very important for India.

Figure 6. Andaman and Nicobar Islands



Source: Google Earth and Graphic Maps (2017)

The Andaman group consist of 325 islands of which only 33 are inhabited, 94 are sanctuaries including six national parks (Figure 6). Out of about 2,400 km of coastline, considering the shoreline change rate, 429 km are categorized as medium risk, 220 km high risk and 161 km very high risk (INCOIS, 2012).

The Nicobar group in the south has 22 islands of various sizes, the largest being Great Nicobar. Out of about 800 km of coastline (considering the shoreline change rate), 121 km are categorized as medium risk, 43 km high risk and 123 km very high risk (INCOIS, 2012). The Andaman and Nicobar Islands are of volcanic origin. They exhibit many different geomorphological zones (Figure 7 and Figure 8): fringing reefs, steep and rocky cliffs, embayments with sandy beaches, tidal inlets, river discharges, lee beaches (which are sometimes muddier), offshore reefs and islands, sand cays, sand spits, salients, etc.

Figure 7. Islands in the South Andamans

Source: Holiday Birds (2017)

Figure 8. Andaman and Nicobar west coast embayment with arcuate beach and an offshore island in the north

Source: Google Earth

Coastal protection is carried out in Port Blair and other important areas mostly with seawalls, revetments and embankments (Figure 9). These islands are very much prone to natural calamities such as cyclones, storm surges, earthquakes and tsunami. Even the impact of global climate change on the island environment is very imminent.

The complex geomorphology means that shoreline protection will be site specific and so detailed solutions cannot be recommended here. However, the Guidelines are highly relevant to these islands, including the island Guidelines.

Figure 9. Coastal road with revetment at Port Blair

Source: Photo taken by individual Mishra (2015)

Conclusion

In the recent times, there is increased realization that 'working with nature' would be a better approach for cost-effective and sustainable coastal protection (Supreme Court of India, 2014). In this background, the recommendations given in the Guidelines, which are equally applicable to the islands, and those specifically made for islands may be followed.

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CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 2

APPENDIX 17
CALCULATING THE MINIMUM FLOOR LEVEL

ADB TA-8652 IND:
CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

APPENDIX 17
Calculating the Minimum Floor Level

Introduction

The Guidelines recommend following international practice whereby the floor level of buildings should be above a Minimum Floor Level (MFL).

> Minimum Floor Level (MFL) is the highest sea level that may occur at a coastal site (defined relative to mean sea level).

The Coastal Regulation Zone (CRZ) regulates horizontal regions relative to the High Tide Line. However, with sea levels rising, there is an urgent need to consider the vertical dimension. Many coastal areas are low-lying and while the environment needs to be protected under CRZ regulations, the elevation of these zones puts them at risk. At the same time, construction at current day levels denies the need for good future planning. The MFL is a key addition to coastal regulations recommended under the guidelines. Elevations are not considered by the current CRZ regulations. The MFL may be also used to define dune heights in beach nourishment projects.

To define MFL for each state, the following data is used:

- Tides, winds and waves around the Indian coast
- Storm surge, tidal and wave data provided by the Indian Institutes
- Surf zone parameters such as set-up and run-up

This appendix provides the background and application. The analysis is by way of example only for a region, rather than a single beach. Matters such as beach gradients, sheltering at beaches by headlands, localized effects of rivers and flooding etc. are not included. Individual states will need to make their own calculations. No MFL has been calculated for the Island Territories.

The Indian Research Institutes acknowledge that climate change will not be the same everywhere along the Indian shoreline and that localized refinement is important, rather than adopting a single water level or wave climate for all of India. Moreover, it is well understood that tides, wave climates and storm surge vary substantially from north to south and from east to west along the Indian coast. Even simple factors like the beach angle will greatly change the impacts of climate change. And sheltered beaches with small waves will be less impacted than beaches fronting major wave corridors.

Physical Environment

The sea is fluid and the forces that move the fluid up, down and sideways are numerous. We can think of the sea like a bathtub, rocking and rolling with myriad forces, including forces from space like the pull of the sun and the moon driving the tides.

Offshore in the coastal ocean, the key factors are:

- Tides
- Large-scale ocean circulation
- Oceanic gyres
- Coastal currents
- Coriolis deflection of currents
- Local wind set-up
- Cyclones
- Barometric pressure
- Sea level rise due to climate change

Inshore within and near the surf zone, the key factors include:

- Wave height
- Wave period
- Wave direction
- Surfzone width
- Beach gradient
- Sand grain size
- Sand bars
- Surfzone set-up
- Surf beat
- Swash and run-up
- Surf zone currents
- Rainfall

These parameters determine the level of the sea at the coast (Black, 1978; Lee and Black, 1978), and the ultimate re-sculpting or retreat of the coast in response to waves and storms. The science can identify what to expect in the future, e.g. what water levels to prepare for, whether cyclones will migrate more south as seas become warmer, or monsoon seasons get longer, wetter, shorter etc. All of these factors and many more determine outcomes at the coast.

In addition, waves play a dominant role. Any alteration to the direction or size of the waves due to climate change can be expected to dramatically alter beach alignments, change the direction or intensity of net sediment transport and ultimately lead to erosion or accretion adjustments that need to be forecast.

To answer these scientific questions, the technical assistance (TA) team has requested four of India's best research institutes to explain the future of water levels, cyclones and waves. These inputs can be incorporated into the guidelines in several ways. First, a design water level can be specified. Second, forecast changes in the weather can be utilized for improved design of beach protection methods and finally the values can be used to define the MFL. All data produced by the institutes has been transferred to the public water resources information system (WRIS) website (Appendix 14). Here, a subset has been extracted to define an MFL for each State.

This appendix first defines the MFL and shows how to make calculations. The more detailed scientific equations are later in the Appendix so that the key issue of MFL is presented first for the benefit of the less technical reader.

Finding the Minimum Floor Level

Buildings that are near the coast or a water body, such as a harbor or estuary will be subject to coastal hazards. Such hazards include coastal erosion and inundation. The purpose of this section is to identify a methodology for determining acceptable minimum floor levels for buildings at a coastal location in order that building permission may be granted by local self-governments (e.g. Panchayat, Municipality, City Corporation). The MFL proposed is for all coastal buildings.

While there are many factors which determine the sea level at the shoreline, we have focused on five key variables.

Tides

Maximum tide level which can be calculated by summing the tidal constituents. These are obtained by analyzing long water level time series and are available from ports and now they are also available from satellite observations of sea level. The maximum tide is higher than the mean spring tide.

Storm Surge

Storm surge occurs when strong winds blow over the ocean surface. The winds push water towards the coast. In addition, currents which occur during storms are subject to a factor called Coriolis Effect. The rotation of the Earth causes currents to turn to the right in the northern hemisphere. Longshore currents heading north on the west coast will set up the coastal water level. Currents heading south set up the water level on the east coast.

These processes are complex and so computer models are needed to determine the water level changes under a variety of storms. The TA requested the most experienced institute in India (Indian Institute of Technology (IIT) Delhi) to run these sophisticated models under the direction of Prof. A.D. Rao. His group modelled the sea levels under current day conditions and the predicted conditions at 2050 and 2100. The effects of barometric pressure are included in his modelling. These data have been stored on the public WRIS website and provided directly to this study in Figure 2. Surge height around India (years 2050 and 2100, under RCP 8.5).

Seasonal Ocean Levels

All oceans worldwide have different levels in the summer and winter. For the Indian Ocean, the levels are highest during the monsoon season (Figure 9 and Figure 10). While the level will vary annually, an allowance of 0.3 m has been made to account for these fluctuations.

Sea Level Change due to Climate Change

The sea level is predicted to rise in the future. The forecasts vary because no-one is sure what changes the global population will put in place to reduce the discharge of Greenhouse gases. Already, there are many countries aiming to shift from fossil fuels to renewable energy like solar power which is far less polluting. However, there is general agreement that the levels will rise by a substantial amount over the next 50 years. The predictions coming from the Indian Institutes are given in Figure 3. In many places, cities are also subsiding (e.g. Mumbai) and so the allowance does not include potential subsidence.

Surf Zone Set-up

When waves approach the beach, they cause the water level to set-down at the breakpoint and then set-up in the surf zone. Waves hold a lot of energy and so when the waves break some of this energy is converted to a pressure gradient at the shore. The set-up is always much greater than the set-down and so the net effect is a rise of the water levels at the shoreline under big wave conditions. The set-up not only depends on wave height, but it is also influenced by the offshore seabed gradients. This means that set-up needs to be calculated for each beach. Offshore extreme wave heights coming from the Indian institutes are given in Figure 4 while Figure 5 can be used to estimate the set-up on beaches. As the information is not available for all beaches, we have adopted a well-accepted equation (Eqn. 6, 7 and 8) which predicts set-up for most beaches. To make the calculation for near worst case conditions, the 50-year return period wave heights have been adopted. These were obtained by NIO (Appendix 14) and presented here in Figure 4. Typically, the set-up exceeds 1.0 m.

Surf beat is another factor which can elevate the set-up. When waves approach the beach they usually arrive in sets, i.e. periods of high waves and periods of low waves. This oscillates the surf zone water levels around the mean set-up causing greater temporary set-up at the shore.

Run-up

Run-up is what most people see when big storms overtop the beach crest and flood their houses. Run-up is the swash when the wave breaks on the beach and runs up and over the dune. Run-up is a natural and important process because the strong currents up the beach bring sand which can settle on the crest and behind the crest of the beach to build up the sand dune. However, most villagers will call this flooding because the run-up also brings water which can flood their houses, particularly in the zone between the beach crest and the back-waters.

Run-up can be calculated using Equation 15 and Figure 6. However, the scientist or engineer needs to know the wave height at the base of the beach. This varies substantially with the offshore bathymetry and the slope of the beach face. Thus, we have simply included an allowance of 0.3 m for run-up in the calculations. Figure 6 can be used to estimate run-up on beaches. It shows that run-up can be much larger in extreme cases. Further site-by-site assessments will be needed to better specify this value. In addition, the run-up can be much larger on the front of a steep wall, such as a rock seawall.

Specifying MFL

MFL is determined by summing the above factors. It is anticipated that the permit granting authority will require a site-specific assessment of coastal hazards including subsidence, coastal erosion, tsunami and earthquake. Further, areas prone to flood and inundation risk due to adjacent rivers require specific assessment. Thus, our MFL values may be considered a minimum useful value. An example calculation is presented in Table 1. The chosen location is central in each State. Northern Maharashtra, for example, has a bigger tide range and so MFL would normally be a site-specific calculation. The reader should understand that the values in Table 1 are conservative, i.e. these are minimum possible floor levels and some agencies may like to add at least 0.5-1.0 m for a safety factor or in cases with other compounding factors such as seawalls and rivers.

Table 1. Example calculation of MFL (m) above MSL for specific locations of different States of India

	Gujarat	Maha-rashtra	Karna-taka	Kerala	Tamil Nadu	Andhra Pradesh	Odessa	West Bengal
Input data								
Latitude	21.439	17.471	13.869	10.211	11.007	16.337	19.888	21.809
Longitude	72.682	73.192	74.606	76.151	79.856	81.654	86.210	88.171
50-year significant wave height (m)	3.19	7.5	6.28	5.15	4.1	3.96	5.62	5.33
Calculating MFL								
Tide (m)	3.20	1.53	0.98	0.56	0.49	0.94	0.90	1.13
Storm surge (m)	2.99	0.95	0.62	0.49	2.30	3.14	3.49	6.20
Seasonal sea level variation (m)	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
SLR (m)	0.50	0.50	0.50	0.5	0.5	0.5	0.5	0.50
Set-up (m)	1.00	2.49	2.06	1.67	1.31	1.27	1.83	1.73
Run-up (m)	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Minimum Floor Level (m)	8.3	6.1	4.8	3.8	5.2	6.5	7.3	10.2

As can be seen from Table 1, storm surge heights are generally lower to the south and higher to the north of the Indian Peninsula, the range for the 50-year period being 0.49 m in Kerala to 6.20 m in West Bengal above mean sea level (MSL).

In some places, the building regulations have a requirement that certain building elements, including floors, function for not less than 50 years. In Table 1, a '50 year' allowance for sea level rise has been given, but if the life of a building is expected to extend beyond 50 years, then an additional allowance should be added to the MFL.

In locations close to river mouths, minimum floor level will be affected by a combination of flooding due to storm surge, tide and river discharge. For floor level assessments at these locations, the flood level should be determined either by using historical data or by calculation of catchment characteristics.

In some countries, structures are built on piles (legs) to achieve MFL, with the lower level being used for mobile storage only so that goods can be removed in the event of a flood.

Steps for Calculating the Minimum Floor Level

- **Step 1:** Find the tide height from Figure 1. For example, for Maharashtra the maximum tide height is 2.57 above MSL.
- **Step 2:** Find the maximum surge height from Figure 2. For example, for Maharashtra the surge is 3.15 m.
- **Step 3:** Find the predicted sea level rise from Figure 3. For example, for Maharashtra the predicted sea level rise is 1.17 m.
- **Step 4:** Find the offshore wave height from Figure 4. For example, for Maharashtra the offshore wave height is 8.46 m.
- **Step 5:** Transform the offshore wave height (Ho) to the breakpoint. In the absence of a computer model, the breaker height (Hb) can be estimated as Hb=1.2Ho. If the beach is sheltered the fraction 1.2 may be smaller.
- **Step 6:** Determine the set-up from Figure 5. For example, for a breaking wave height of 6 m, the set-up is 1.15 m. The set-up can be obtained using equations 6, 7 and 8.
- **Step 7:** Determine the run-up. As described above, this is very sensitive to surf zone bathymetry and beach slope. The height needed for this calculation is the residual wave height at the beach face. This will be normally much less than the breaking wave height. For a 1 m wave height at the beach face, wave period of 12 s and beach face gradient of 1:10, Figure 6 indicates that the run-up will be 1.52 m. The minimum value should be 0.5 m. The run-up can be obtained with equation 15. As a rule of thumb, the beach face wave height will be 10% of the breaking wave height. But it may be much bigger in front of a rock seawall subjected to scour at the toe.
- **Step 8:** Find the sum of the numbers which gives you the Minimum Floor Level (Figure 7). The seasonal sea level variation is taken as 0.3 m Examples are given in Table 1.

Figure 9. Coastal road with revetment at Port Blair

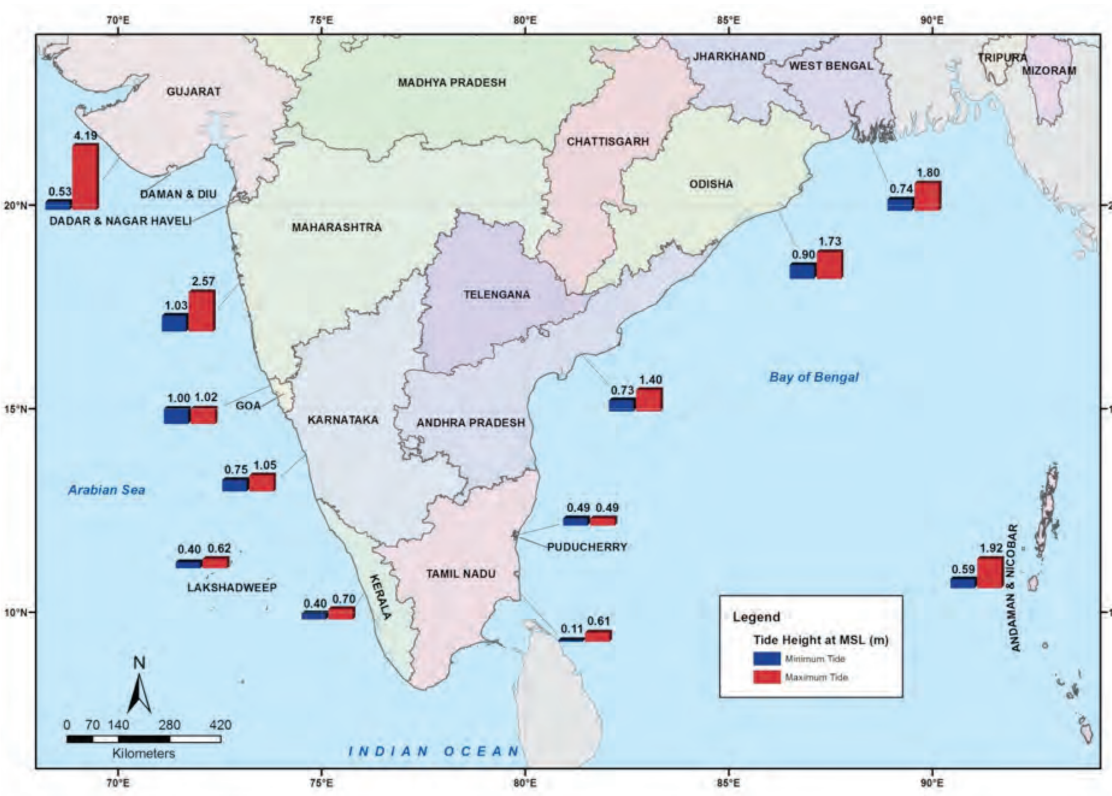


Figure 2. Surge height around India in the year 2100 under RCP 8.5

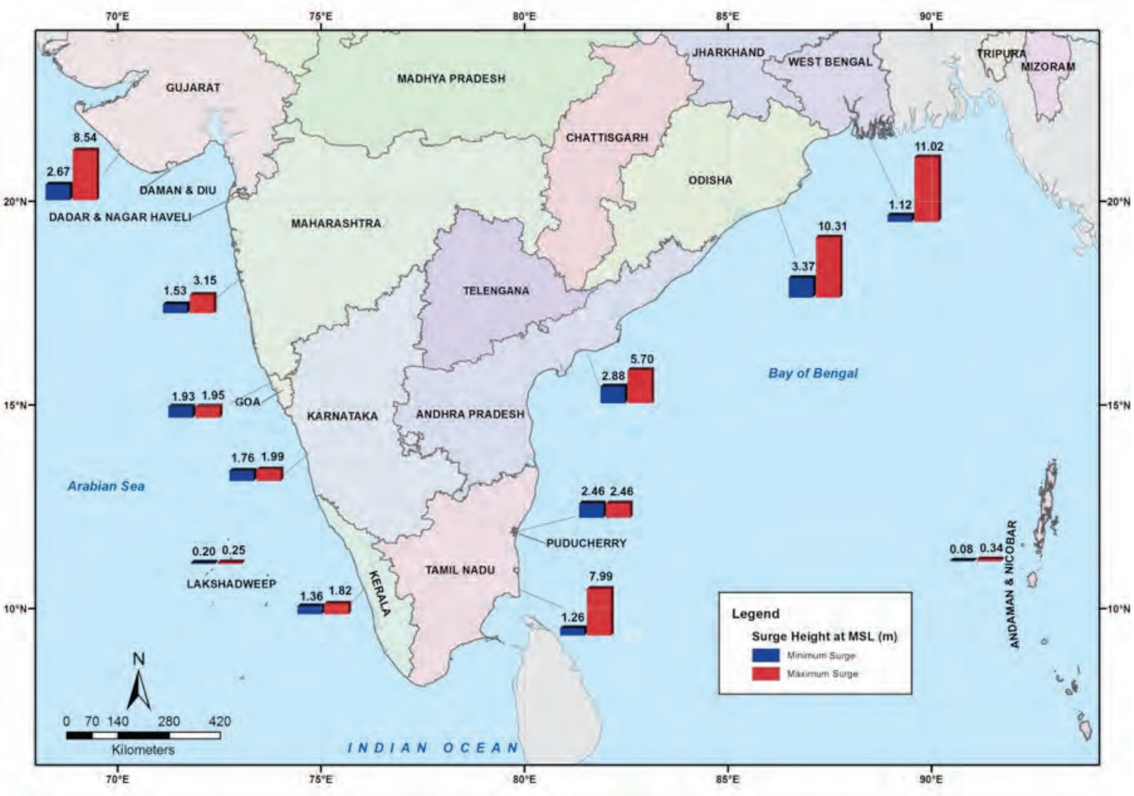


Figure 3. Predicted sea level rise for India in the year 2100 under RCP 8.5

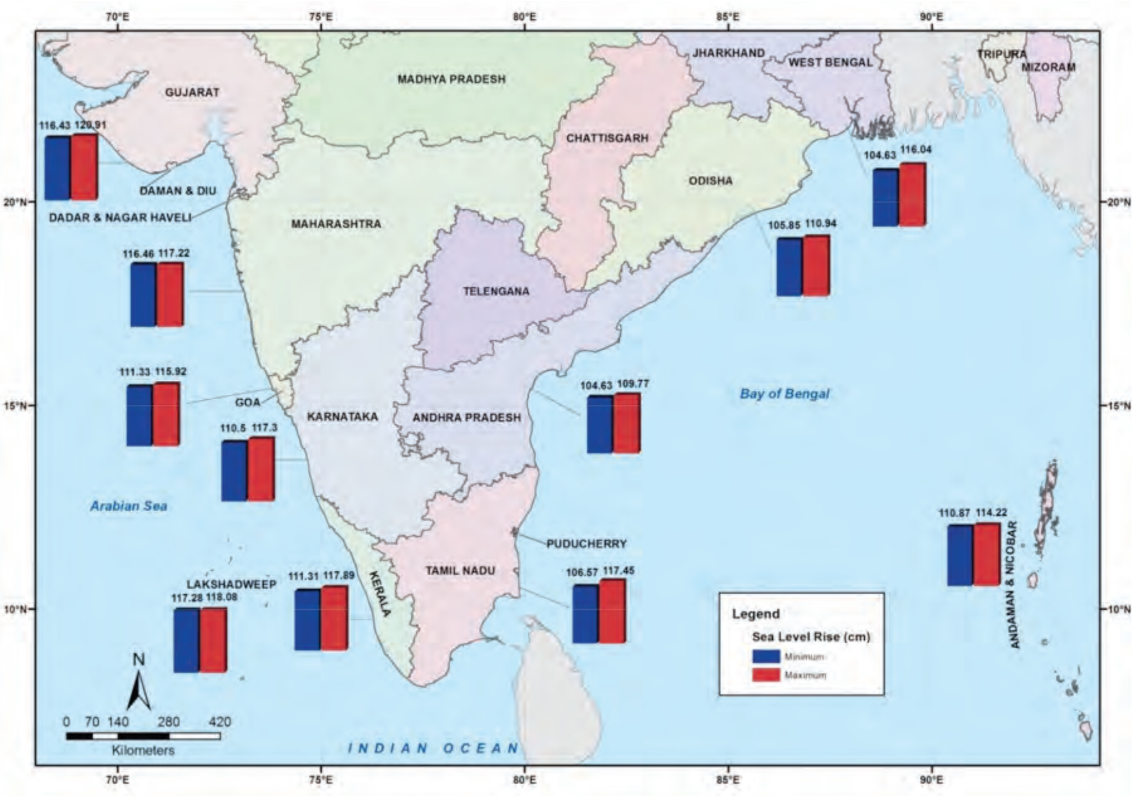


Figure 4. Offshore extreme wave heights for 1:50 year storm

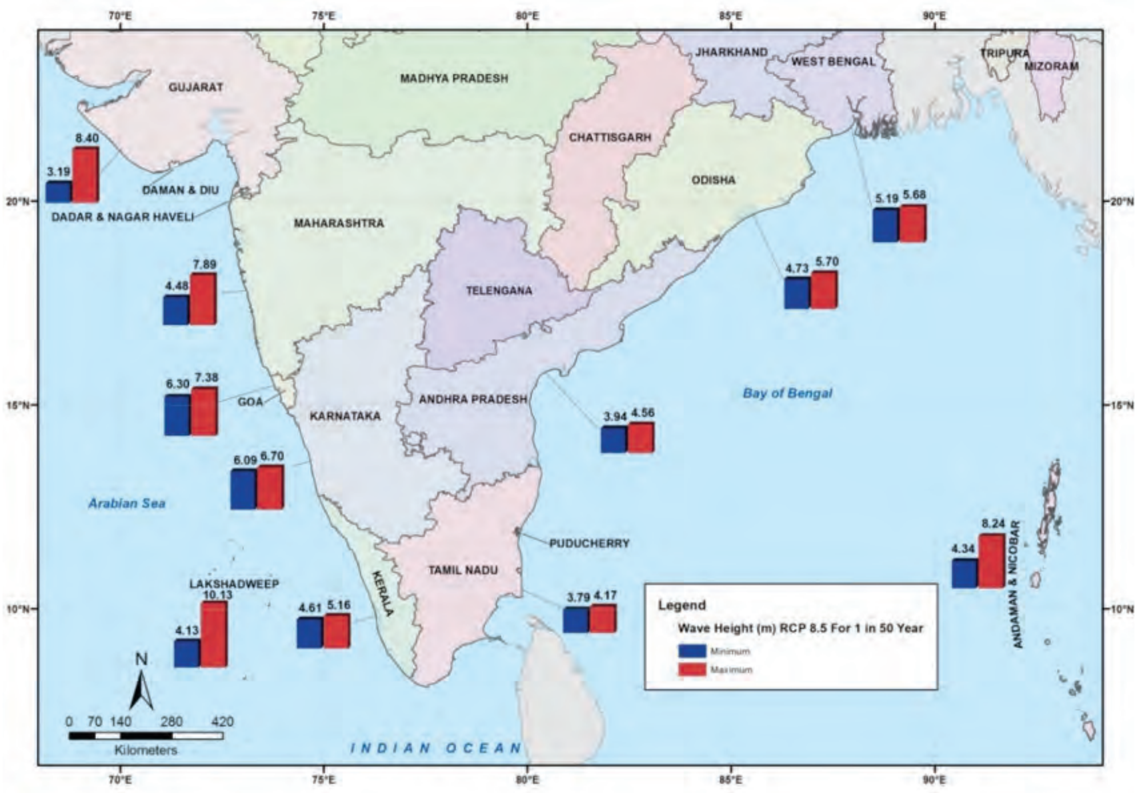


Figure 5. Set-up, set-down and shoreline water level as a function of breaking wave height

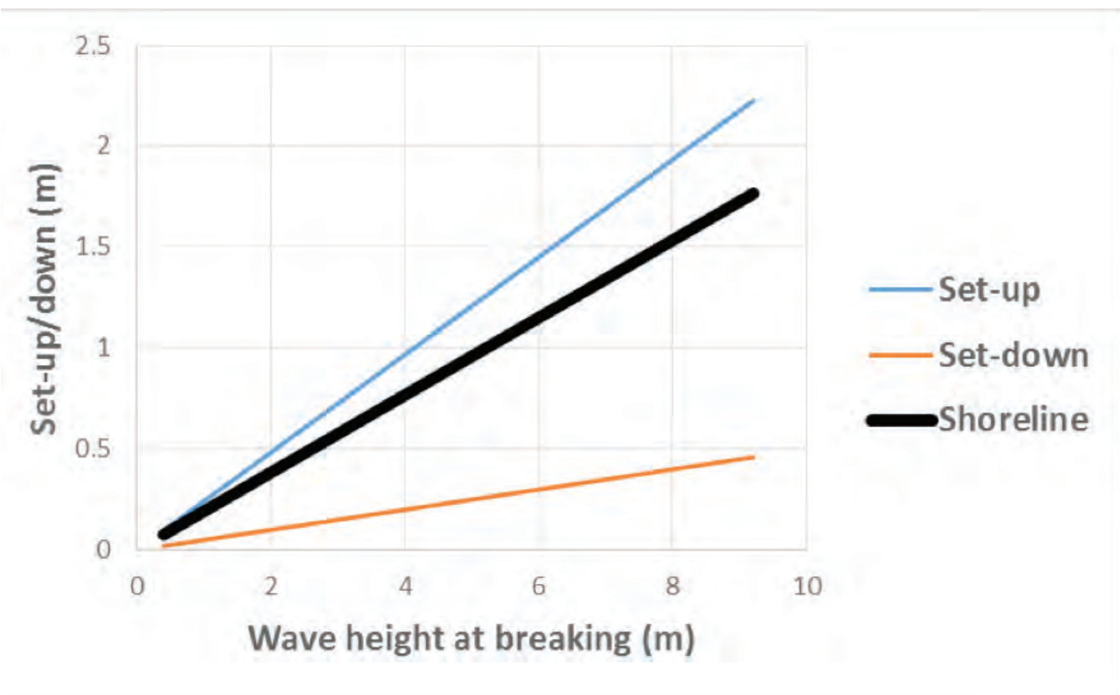


Figure 6. Wave run-up as a function of wave height reaching the beach face, for a beach with 1:10 slope and 12 second wave period.

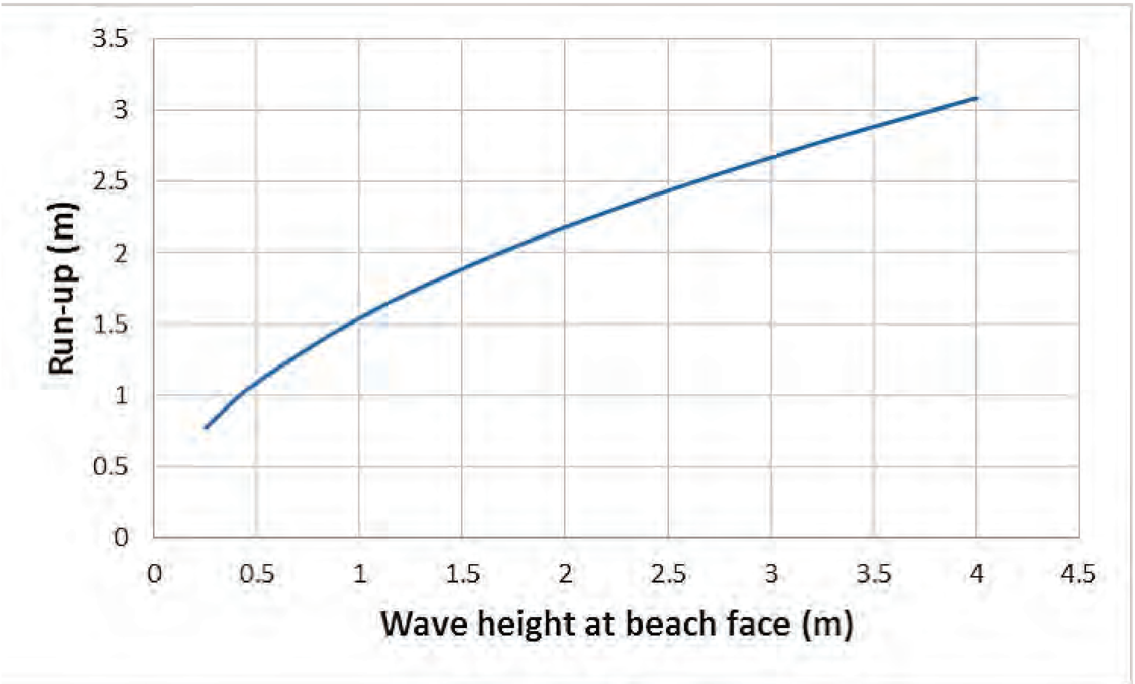
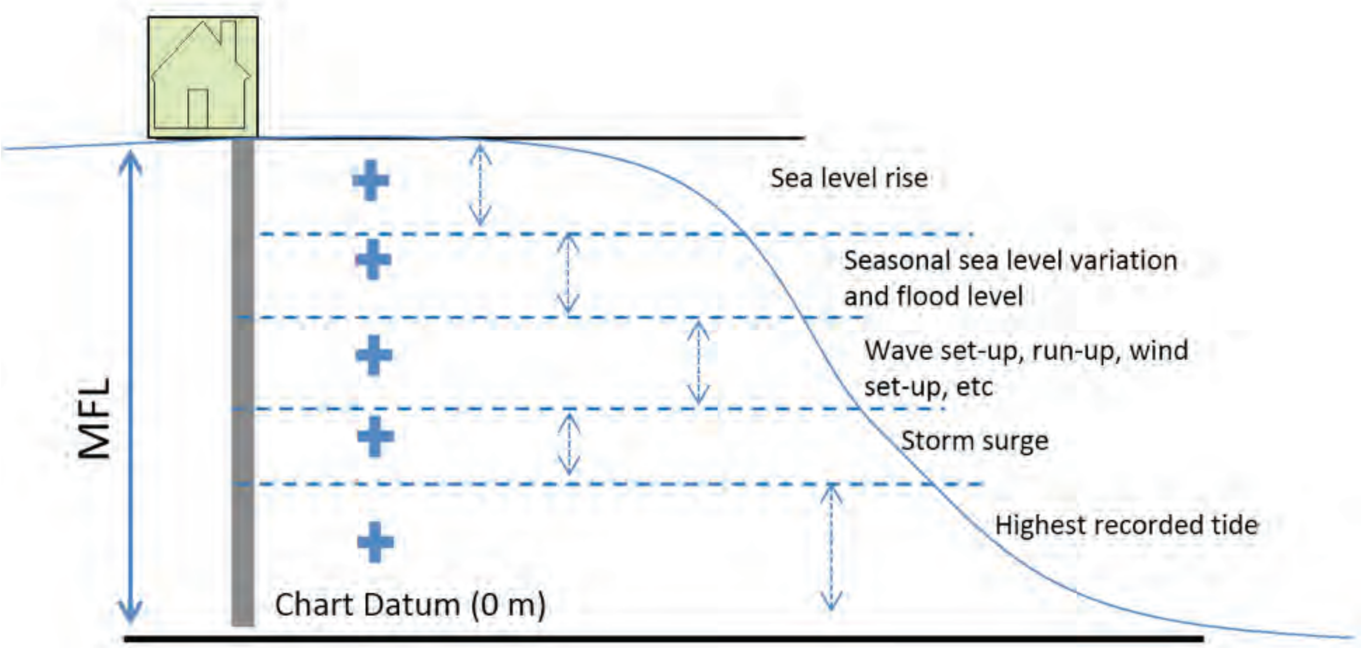
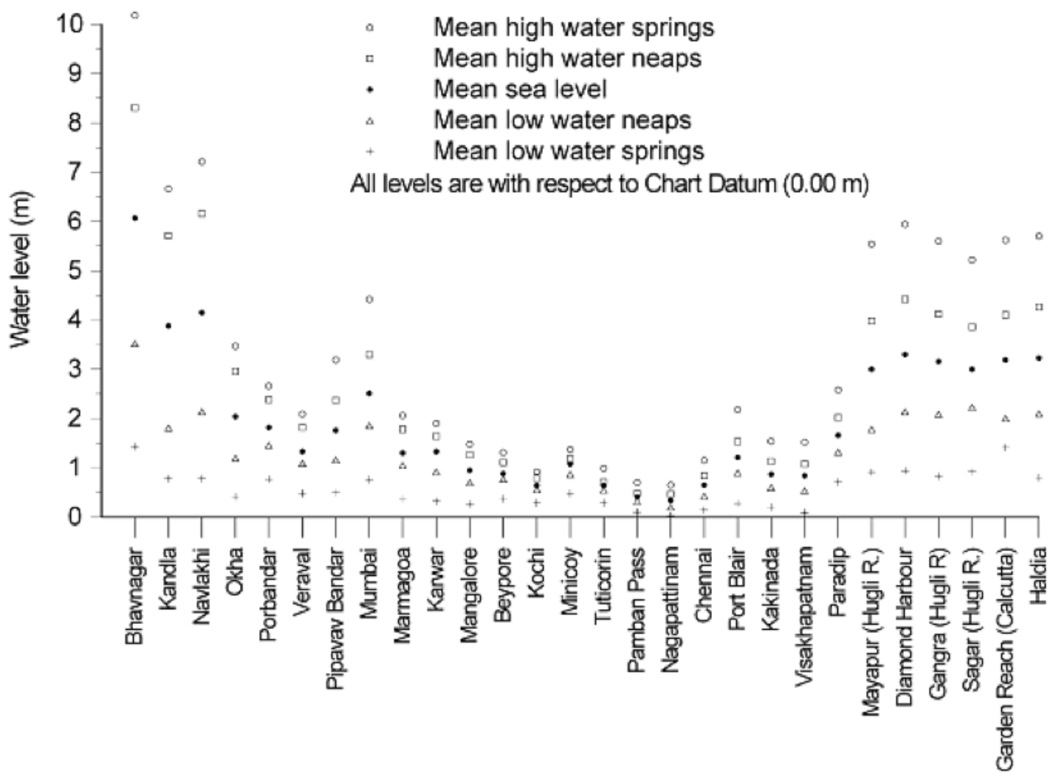


Figure 7. Determination of Minimum Floor Level



The tides around India vary from small ranges in the south (order 0.8 m) to large ranges in the north (order 4-5 m). The largest tides occur around Gujarat where ranges of 10 m occur (Figure 8).

Figure 8. Water levels along the Indian Coast

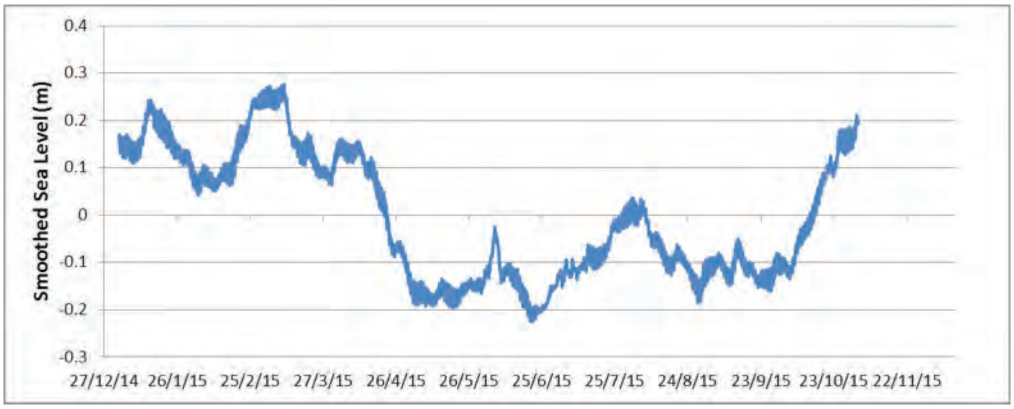


Source: Kumar et al. (2006)

Seasonal Variations in Sea Level

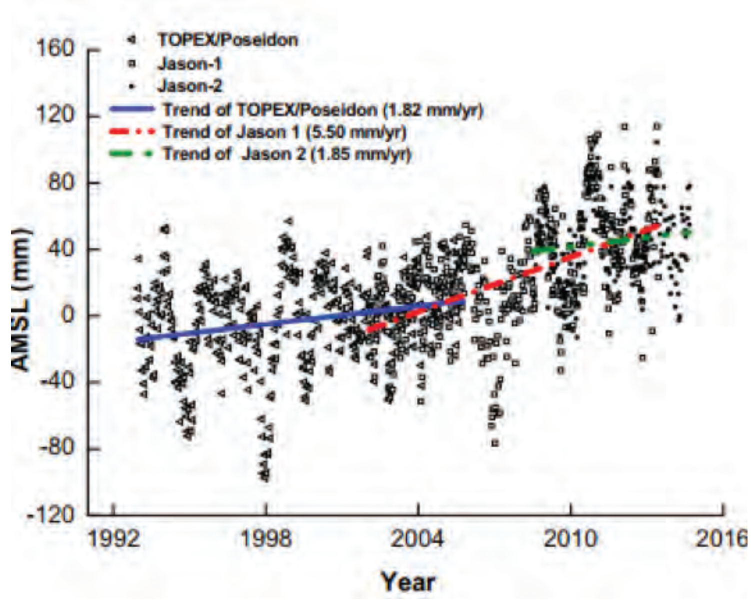
Throughout the entire Indian Ocean, the water levels vary above and below MSL between the summer and winter. An example for the southern Indian Ocean from Mauritius is shown in Figure 9 and from the Bay of Bengal in Figure 10. The sea level is more than 20 cm below MSL in winter and 15-20 cm above MSL in summer. The same patterns occur in the Arabian Sea (Unnikrishnan et al., 2007; Chowdery and Behera, 2015).

Figure 9. Annual cycles in sea levels at Port Louis, Mauritius



Source: Kumar et al. (2006)

Figure 10. Long-term sea levels showing strong seasonal variations in the Bay of Bengal



Source: Kumar et al. (2006)

Coriolis Deflection of Currents and Coastal-Trapped Waves

Because the Earth rotates on its axis, circulating water is deflected towards the right in the northern hemisphere and towards the left in the southern hemisphere (Figure 11). This deflection is called the Coriolis Effect. Thus, a current travelling south down India's west coast will deflect offshore. This has the effect of lowering water levels at the coast. The magnitude depends on current strength and latitude. A current travelling to the north on the west coast will raise water levels. An oscillating current can also occur, known as coastal-trapped waves (Middleton and Black, 1994)

The set-up at the shore is estimated most simply as,

$$\Delta Z = \frac{fV}{g}\Delta X \tag{1}$$

where ΔZ is the sea level change at the coast, f is the Coriolis parameter, V is the longshore velocity averaged over the continental shelf (positive to the north) and ΔX is the local width of the shelf.

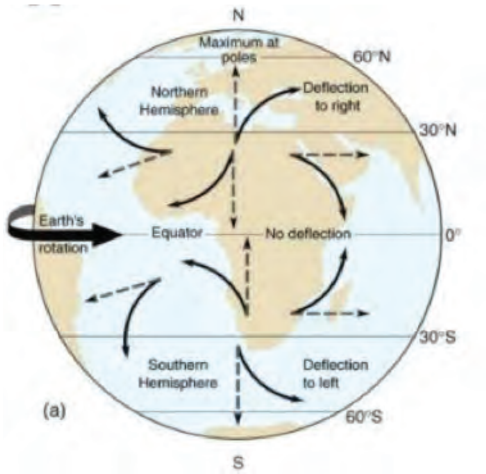
The Coriolis parameter is,

$$f = 4\pi \sin(N)/\ 86164 \tag{2}$$

where N is the latitude in radians (positive in the northern hemisphere). Currents averaged through the water column are typically less than 0.5% of the longshore wind speed when averaged across the shelf. A value of 0.5% is used in CoastTool so that the set-up is not under-estimated. Notably, the currents are highly dependent on bathymetric topography, seabed friction, depth of water and wind stress and so CoastTool only provides an estimate. A sounder approach would use computer models to simulate the full hydrodynamic equations over real bathymetry.

Studies of storm surge for Port Phillip Bay in southern Australia showed that the deflection of longshore currents by Coriolis force caused larger water level rises at the coast than the direct action of onshore winds pushing water against the coast (Black, 1992). The effect of Coriolis deflection grows bigger at higher latitudes, from south to north India.

Figure 11. Deflections of currents due to Coriolis Force



Source: Lyles (2014)

Cross-shore Wind Set-Up

'Wind setup' is the vertical rise in the still water level on the landward side of a body of water caused by wind stresses on the surface of the water (Figure 12). The wind blows onshore and causes sea level to push up against the coast. The setup, nw depends on the square of the wind speed, wind fetch and water depth,

$$\eta_W = \frac{\rho_a C_{DW} U^2 F}{\rho g \bar{h}} \tag{3}$$

ρ_a is Density of air. $\rho_a = 1.2041\, kg\, m^{-3}$ at 20 °C and 101.325 kPa

C_{DW} is Drag coefficient due to wind stress given by

$$C_{DW} = \frac{0.63 + 0.066V_s}{1000} \tag{4}$$

U: The surface wind speed at an elevation of 10 m above sea surface,

$$U = U_z \left(\frac{10}{z}\right)^{\frac{1}{7}} \tag{5}$$

Uz: Measured wind speed at an elevation z m

F: The fetch along the wind direction (m), often taken as the width of the Continental Shelf

ρ: Density of sea water ρ=1025 kg m^{-3}

g: acceleration due to gravity 9.81 ms^{-2}

d: Average water depth along the fetch.

Mostly the wind setup occurs on the continental shelf, which defines the wind fetch and average depth.

Wave Set-Up and Set-Down

Wave set-up is the change in the water level inside the breaker zone in the presence of waves (Figure 12),

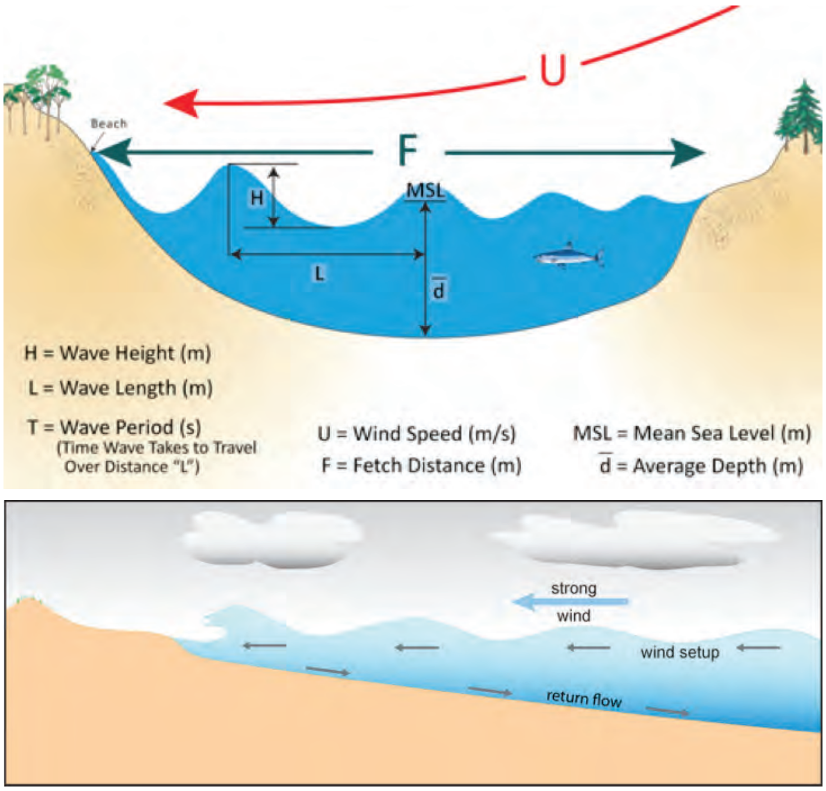
$$\eta_u = \left(\frac{1}{1+\frac{8}{3\gamma^2}}\right)(h_b - h) + \eta_d \tag{6}$$

where, h is water depth, which is equal to zero at the shoreline where maximum set-up occurs, hb is the breaker water depth. A wave of given height will break at this water depth.

$$h_b = \frac{Hb}{\gamma} \tag{7}$$

In shallow water, the equations can be simplified and assuming the breaking coefficient is γ=0.8, the set-up is equal to $0.242H_b$ (Figure 13).

Figure 12. Coastal water level set-up due to wind



Source: Natural Capital Project (2017)

The wave set-down ηd at the breakpoint given by,

$$\eta_d = -\frac{kH_b^2}{8sinh(2kh)} \tag{8}$$

where H_b is the wave breaker height. A wave of this height will break at the given water depth $H_b = \gamma h$

In shallow water at the breakpoint, the set-down can be approximated as

$$\eta_d = -\frac{H_b^2}{16h} \tag{9}$$

γ is the wave breaking index. The ratio of wave height to water depth at which the wave will break γ=0.8, k is the angular wave number. The number of wave units which are contained within unit horizontal distance.

$$k = \frac{2\pi}{L} \tag{10}$$

L is the shallow water wave length

$$L = L_0 \tanh\left(\frac{2\pi h}{L}\right) \text{ or } L = T_p\sqrt{\frac{gh}{F_a}} \tag{11}$$

L_0 is the deep water wavelength.

$$L_0 = \frac{gT_p^2}{2\pi} \tag{12}$$

g: acceleration due to gravity where g=9.81 ms^{-2}

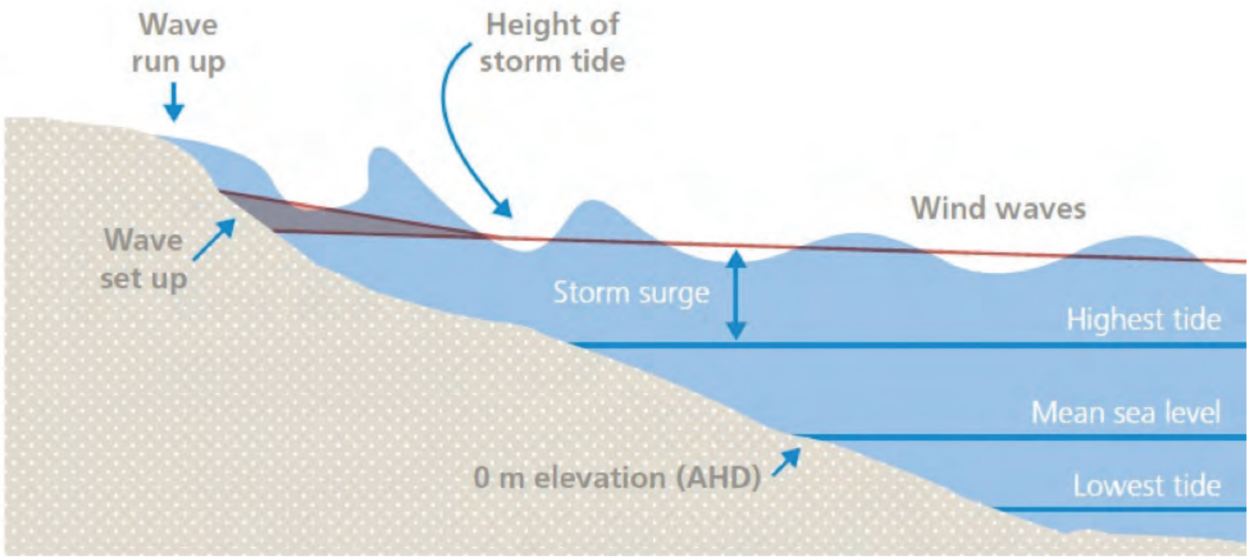
The wave group speed in shallow water is

$$C_g = (gh)^{1/2} \tag{13}$$

and shallow water wavelength can be calculated as,

$$L = T_p C_g \tag{14}$$

Figure 13. Beach parameters showing wave set-up and wave run-up



Source: DSE (2012)

Wave Run-Up

Wave run-up is the maximum vertical extent of wave uprush on a beach or structure above the still water level (SWL) (Sorensen, 1997).

$$R_w = \frac{2.3 H_s T_p s_{WB}}{8} \sqrt{\frac{2g}{H_s}} \tag{15}$$

where, S_{wb} is the beach face slope and Hs is the wave height at the beach face. The run-up is larger on steep beaches.

Figure 6 shows the case for a 1:10 beach face and 12 second wave period. For long period waves and steep slope of the beach face, the run-up can be very large. However, computer models are needed to accurately determine the height of the wave reaching the beach face, as much of the energy could be removed by wave breaking in the surf zone. The worst case is the rock sea wall which is often very steep and the scour at the toe allows bigger waves to reach the wall.

Transforming wave height and angle from offshore

Wave statistics can be approximately transformed from offshore to the surf zone for calculation of set-up and run-up using the following simple equations. Wave height transformation is given by,

$$H_b = K_R K_S K_f H_0 \tag{16}$$

where H_o = offshore wave height; H_b = inshore wave height at the breakpoint; K_R = refraction coefficient; K_S = shoaling coefficient; K_f = frictional coefficient.

The refraction coefficient is given by

$$K_R = (\cos\theta_0 / \cos\theta_2)^{1/2} \tag{17}$$

where $\theta 0$ = offshore wave angle; $\theta 2$ = inshore wave angle.

The shoaling coefficient is given by

$$K_s = (C_{g0} / C_{g2})^{1/2} \tag{18}$$

where C_{g0} = group speed offshore; C_{g2} = group speed inshore

The group speed is obtained using a Newton-Raphson iterative solution of the linear wave dispersion relation:

$$\sigma^2 = gk \tanh(kd) \tag{19}$$

Where σ = radian frequency; g = gravitational acceleration (9.81 m.s-2); k = wave number; d = water depth.

The equation for depth-limited breaking is given by

$$H_b = \gamma d_b \tag{20}$$

where γ= breaker index often taken as 0.78. Thus, the depth at breaking can be found knowing the inshore wave height.

The friction term is based on the non-dimensional orbital velocity, and is,

$$K_f = 1. - C_f(\omega U_B / g)^2 \Delta x \;/\; \cos(\vartheta) \quad (21)$$

where Cf is the friction coefficient (taken as 0.2), the radian frequency is ω = 2π / T, T is the wave period, UB is the bed orbital velocity, g is gravitational acceleration, Δx the size of the iterative steps from offshore to inshore and ϑ is the wave angle. Friction losses increase with bed orbital motion and as the wave period drops. However, for CoastTool, the friction multiplier Kf is treated as a constant = 0.97, i.e. the waves lose 3% of their height as they cross the inner shelf to the beach due to friction. This is a highly conservative value so that longshore transport rates are not under-estimated.

The wave angle transformation is calculated by Snell's Law

$$\frac{\sin\theta_0}{C_0} = \frac{\sin\theta_2}{C_2} \quad (22)$$

where C_o = phase speed offshore; C_2 = phase speed inshore at the breakpoint.

The dispersion relation for linear waves is,

$$\omega^2 = gk\, tanh(kh) \quad (23)$$

where ω is the radian frequency (2π / T), k is the wave number (2π / L). An iterative Newton-Raphson method is adopted to solve the equation, knowing the period T and the water depth h. The wave phase speed is given by,

$$C = L \;/\; T \quad (24)$$

Cyclones

Cyclones have a major impact on the coast. Our study is investigating cyclones with the assistance of the Indian research institutes. IIT Delhi is using computer models to simulate the storm surge, taking into account wind set-up, Coriolis Effects and barometric pressure with measured bathymetry.

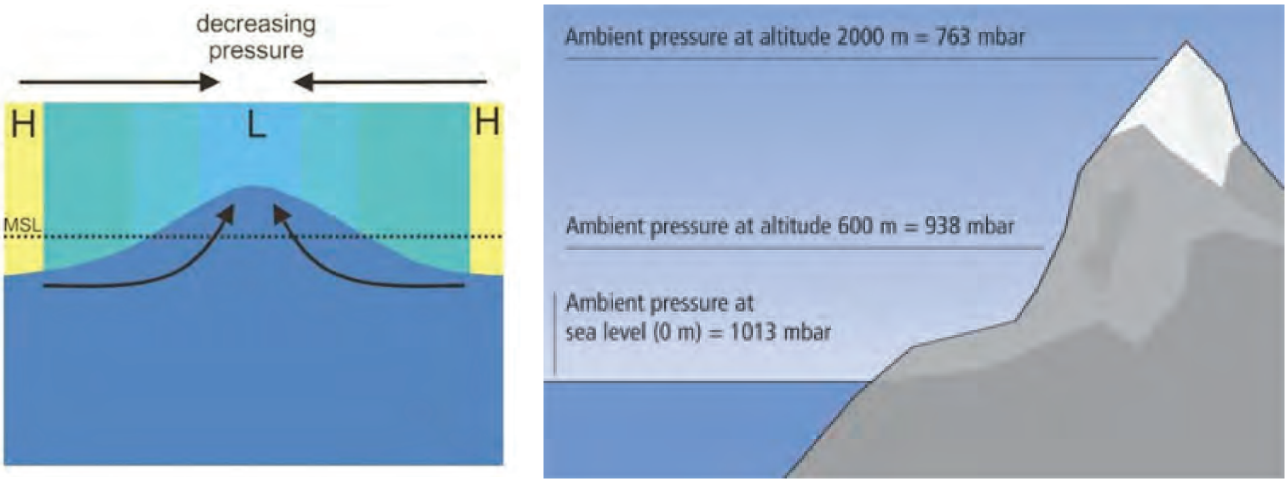
Barometric Pressure

The inverse barometer (IB) is the correction for variations in sea surface height due to atmospheric pressure variations. A 1 mbar atmospheric pressure change corresponds to a linear response of the sea level of about 1 cm, although there can be local variations due to land effects. The inverse barometer correction B (cm) can be computed from the air pressure P (mbars):

$$B = 1013 - P \quad (25)$$

Notably, the inverse barometer effect is modulated by large-scale bathymetry and coastal morphology which can only be accurately treated by computer models. The value 1013 mbar is the long-term average of local air pressure at the site and may vary along the Indian coast (Figure 14).

Figure 14. Barometric pressure varies with elevation and location. Low atmospheric pressure causes the sea level to rise and augment the storm surge felt at the shoreline



Source: Right: NIWA (2005); Left: Palma (2015)

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CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 2

APPENDIX 18

TRAINING FOR USING THE CLIMATE CHANGE ADAPTATION GUIDELINES

ADB TA-8652 IND:

CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

APPENDIX 18
Training for Using the Climate Change Adaptation Guidelines

Introduction

The "Climate Change Adaptation Guidelines for Coastal Protection and Management include: (i) preparing planning and design criteria and guidelines for climate change adaptation; (ii) analysis and interpretation of climate change trends and projections for the entire Indian coast; (iii) incorporation of climate change parameters into information systems being developed under India Water Resources Information System (WRIS). The latter part has been developed with support from four Indian institutions providing analysis of climate change trends and projections. The development of the Guidelines is a consultative process and has been developed after discussion with the stakeholders and technical review committees.

The intention is that future development of coastal protection work in India will follow these Guidelines and information sources on likely climate change impacts. Thus, both those developing coastal protection and management schemes and those reviewing and approving the schemes will need to be aware of the Guidelines and requirements. This will require a large number of people trained in the use of the Guidelines. Therefore, there is a need for this training program to be repeated many times at different locations so that the capacities of all staff members are built and then sustained. The appropriate centers of expertise for provision of the training in the use of the Guidelines are the Central Water and Power Research Station (CWPRS) and Central Water Commission (CWC). The key technical experts in the relevant fields are already part of the CWPRS faculty and the institute is keen to take on the training role with the support of National Water Academy (NWA). The approach has been to build capacity mainly within CWPRS to deliver training in the use of the Guidelines, through collaborative development of training material and through targeting capacity building within CWPRS to develop their ability to provide the training. This is to be done by:

- An initial training session conducted by the Technical Assistance (TA) team and guest trainers in July 2016 targeted at the identified future training providers ("master trainers", nominated from CWC, two baseline states, and other coastal states, in addition to CWPRS);
- A second training session to be delivered by the TA team, external trainers (who received training) and the "master trainers" for the stakeholders in February 2017; and
- A third training session again delivered by the "master trainers" supported by the TA team for the stakeholders.

Afterwards, the modules developed can be used by States and other institutes for providing training at the local level. It is anticipated that external faculty might be needed in some subject areas. Some training institutes of national standing that can be considered for this purpose are: i) Centre for Environment Education; ii) NWA, Pune; iii) Institute of Ocean Management, Anna University, Chennai; iv) National Centre for Earth Science Studies, Trivandrum, and; v) National Center for Sustainable Coastal Management, Chennai. The concerned agencies also can identify some local agencies and independent resource persons. They are cost-effective and can provide post-training follow up support.

Schedule and Outline of Instruction Material

DAY 1: 'Coastal Processes', 'Climate Change', 'Climate Change Impacts on the Coast' and 'Shoreline Management Plans and Existing Guidelines'.

DAY 2: 'Climate Change Adaptation Guidelines', 'Utilizing the Guidelines', 'Sand-Based Solutions and Climate Resilience' and 'Structural Solutions and Climate Resilience'.

DAY 3: 'Environment Impact Assessment', 'Economic Analysis', 'Monitoring and Analysis', Hands-on Training' and 'Training Skills'.

DAY 4 and 5: Field visit to the coast / climate resilient coastal protection demonstration sites.

The objective of field visit is to demonstrate how communities around the coast can be motivated to implement and sustain climate resilient coastal protection measures. For this, besides technical orientation, on-site community interactions need to be organized. The technical orientation can be completed during the class room training and the participants prepared prior to the site visit. The on-site discussions can cover the following issues:

The Guidelines are approached in two parts:

i. What was the physical status of the coast before the project was initiated?

ii. What were the major issues / problems communities faced? How were they resolved?

iii. Who in the community took a lead role? Why and how? Was there a coastal community organization? How was it formed? Is it being sustained now?

iv. What was the duration of the project and how was it implemented?

v. What are the typical site maintenance issues? How does the community handle them? (e.g. plants dying, replanting of saplings, soil degradation)

vi. What were the benefits from the project to the communities? (e.g. enhanced livelihood, reduced erosion, improved fish catch, improved greenery)

vii. Any gender specific or pro-poor benefits? What are they?

Brief Outline of Instruction Material

Coastal Processes

Coast: definition; evolution of the coast in relation to sea level changes in geological times; depositional and erosional coasts

Coastal hydrodynamics: waves and wave generation mechanisms; shallow water wave transformation; wave set-up and wave run-up; wave induced nearshore circulation; wind set-up; tides and tide generating forces; tidal currents and coastal currents; monsoon and non-monsoon hydrodynamics, cyclones, storm surges, tsunami.

Coastal sediments and coastal morphodynamics: origin and general description of sediments; sediment transport and coastal morphological changes; beach erosion- short-term and long-term

Coastal processes in the climate change scenario: sea level rise; implications of climate change in wave height, period and direction and extreme weather events; storm surge influenced coastal processes.

Climate Change

Review of the latest CMIP5 climate data; global patterns; Indian patterns; The basis for understanding risk through the application of Coupled Model Intercomparison Project (CMIP5) data and representative concentration pathways and climate sensitivity.

Simple physics of the relationship between various greenhouse gases and their longevity in the atmosphere; warming potential; intended national determined contributions (INDCs) globally and the Indian position. Possibilities of reaching goals (cumulative INDCs) described at the recent United Nations Climate Change Conference in Paris and limitations and ramifications.

Implications from a response perspective: slow onset versus extreme events, combined adaptation/mitigation/disaster prevention approaches and challenges across the key variables of temperature, rainfall, wind, storm surge and sea level rise. Interrelationships between discrete climate variables such as humidity, temperature; sub-daily modelling for heat stress as one good example of use of global climate model data for good effect in risk profiling.

Climate Change Impacts

Geographic set-up of Indian coast: Urban, rural and ESAs: distribution of population.

Geomorphology of Indian coast: Land and water features and their distribution; migrating river mouths and spits; deltas of the east coast of India; mangroves.

Climate and climate change in India: Present climatic conditions in India; changes expected in the frequency, intensity, and duration of extreme events, heat waves, heavy precipitation and cold days.

Impacts of climate change: Coastal erosion by promoting offshore transport of sediment; inundation, flood and storm damage; long-term wetland loss; ecosystem modifications, mangrove migration and coral bleaching; altered patterns of erosion and accretion; saltwater intrusion; rising water tables / impeded drainage; life, livelihood and property loss to community.

Adaptation: Vulnerability of natural and human systems to climate change; adaptation both autonomous and reactive; approaches for preserving and protecting coastal habitats; importance of timely and accurate scientific information and guidelines / tools.

Climate Change Adaptation Guidelines

Regulations and Guidelines: Challenges; effectiveness of the existing regulations and their enforcement.

Climate Change Guidelines: Two parts - regulatory guidelines; intervention guidelines.

Regulatory Guidelines: Six sub-categories; administrative guidelines to strengthen approval processes; economic guidelines for financial assessments and cost-benefit of climate resilient coastal protection measures; land use guidelines; mining and dredging guidelines mainly to address sand resources and uses; environmental impact assessment guidelines; ecological guidelines to protect the natural ecosystem flows and function.

Intervention Guidelines: Strategies to address climate change impacts at the coast; selection of the best solution resilient to climate change; soft and hard solutions; ranking various coastal protection methods; softness-index ladder.

Utilizing the Guidelines

C-Guide for coastal protection projects, environmental softness ladder, resources and CRZ, WRIS, defining a project.

Sand-Based Solutions and Climate Resilience

Sand-based soft solutions: beach nourishment, dune management, sand bypassing/ back-passing, beach scraping.

Beach nourishment: Factors controlling beach equilibrium, importance of beaches for wave attenuation; benefits of beach nourishment; important considerations for successful beach nourishment; sand sources and sinks; beneficial use of dredged sand; sediment grain size compatibility and borrow site considerations; maintenance requirements, beach nourishment and sea level rise.

Coastal dunes: Structure, formation, types, vegetation and dune erosion; importance of dunes in coastal erosion management; sand dunes and sea level rise; methods of artificial dune creation and management, sand bypassing and beach restoration: determining the amount of sand actually in transport along shorelines; how sand bypassing works.

Beach scraping: Beach recovery rate compared with natural processes; beach scraping in combination with dune management schemes; coastal processes which need to be considered in the design of a beach scraping project; physical and ecological impacts.

Beach monitoring: Aims and objectives for monitoring, frequency, timing and location of measurements, maintenance of equilibrium beach profile and dune management.

Case studies: Beach nourishment, dune management, sand bypassing.

Structural Solutions and Climate Resilience

Coastal protection structures: Types; those used in India; rock seawalls / revetments.

Case studies: Seawalls, groins; stable beaches.

Sustainable structural solutions: Notion of sustainability.

Designing for climate change effects: Predicting climate change effects; adaptation of existing structures; design of new structures.

Summary of key factors: Conflicting aspects of sustainability and safety need to be weighed against uncertainty of future climate change effects and higher cost; possible ways of optimizing in designing new schemes.

Environment Impact

Environmental impact assessment (EIA): Aim; projects subject to EIA; role of different actors in EIA process; EIA procedure.

EIA report: Generic structure; rapid and comprehensive; secondary and primary data; data assimilation and analysis; environment impact statement; environmental management plan; loopholes and deficiencies.

EIA notification – 2006: procedures and time lines; implementation in India.

Environment Impact

Principles of cost-benefit analysis (CBA) for resource allocation and least-cost analysis; time preference and opportunity cost of capital; application for coastal protection and climate change mitigation measures decision making.

Issues relating to coastal protection: long time horizon for manifestation of costs and benefits and intergenerational equity issues; uncertainty of the magnitude of climate change impacts and costs of protection; choice of discount rate representing the opportunity cost of capital affects present value of future costs and benefits; valuation of non-monetized costs and benefits and externalities; accommodating future anticipated climate change impacts in planning coastal protection measures.

Development of a CBA model:

- Simple, relevant to coastal protection and capable of being applied by non-economists;
- Used to determine least-cost solutions to provide the same outcomes to help plan the most cost-effective and economically viable solution;
- Applied to capture all cost and benefits and to allow for the inclusion non-monetary values and externalities;
- Based on current best international practice for evaluating climate change impact protection measures;
- Apply concept of total economic value including the value of subsistence and non-market values, ecological functions and non-use benefits;
- Allowing for full life cycle costs – full capital, operating, maintenance, and renewal costs over the economic life of the project;
- Inclusion of full environmental costs and allowing for uncertainty;
- The total economic value of an ecosystem can be categorized into four components: direct values, indirect values, option values and non-use values;
- Use of alternative valuation techniques to value externalities and non-market values – market prices, price of alternative or substitutes, collection and production labor, contingent valuation/willingness to pay, travel cost approach, participatory valuation, and;
- Use of Monte Carlo simulation to allow for risk and uncertainly of climate change variables and impacts.

Monitoring and Analysis

Need for data collection at the pre-implementation, implementation and post-implementation stages of project.

Locational parameters: geomorphology of the area; land use; land cover; topography; bathymetry; beach profiles; soil investigations; behavior of existing structures; availability of materials for intervention / construction.

Coastal environmental parameters: wind- speed, direction; pressure; temperature; waves - height, period and direction; tides - water level; currents - speed and direction; bed material- grain size and distribution, composition; climate change projections.

Analysis: Fourier analysis, harmonic analysis, spectral analysis.

Hands-on Training Skills

Aim: To build the skills and abilities of trainers; interactive training with emphasis on effective 'training delivery" for better learning by participants; hands-on training on the use of 'C-Guide'.

Focus: Adult learning principles, tools and techniques; qualities of a good trainer; areas of self-development required; knowledge and skills required; appreciate learning preferences of adults - principles and practices of adult learning; acquire skills and attitudes.

Methods: Concepts, group exercises, and presentations; training versus learning; techniques and tools of training, including group facilitation techniques and use of training aids; organizing and managing training programs; Post-training follow up; training feedback and effectiveness assessment.

The training feedback forms once received, the data needs to be compiled, analysis to be made, improvement areas need to be identified for future. The analysis must focus on the specific achievements that can be attributed to the training program and changes needed in the design and delivery (knowledge gain, objectives achieved, learning that can be applied to the job, how can the contents of the programs be improved, trainers' ability etc.).

To cover this aspect of hands-on training skills, external support may be sought.

Feedback and Evaluation

There are many methods of obtaining feedback. It is a skilled exercise. The format provided in this document is one example of seeking written feedback from the participants. The trainers can also obtain oral feedback using open ended discussions with the participants. The trainers can choose to combine the two methods, i.e. validate oral feedback with written feedback methods.

Evaluation of a training program is normally done after a gap of three months to one year, depending on the need to assess retention of knowledge and perceived benefits. There are many ways of achieving this task. Since the evaluation is a more detailed exercise and the need varies from agency to agency, we have kept it outside the scope of this manual.

Questionnaire to Assess Learning of Participants

Program-specific and target group- specific questionnaires need to be developed to assess learning (knowledge track) of the participants. It can be administered as a "paper and pencil" test or in the form of a quiz.

Use of Climate Change Adaptation Guidelines for Coastal Protection and Management Feedback by Participants

1. General
1.1. Title of the Training Program: *Use of Climate Change Adaptation Guidelines for Coastal Protection and Management in India*
1.2. Training Dates:
1.3. Venue:
1.4. Trainers:

Please provide comments as detailed as possible on all relevant items. Place a tick mark ✔ on the score that most closely represents your views as described below.

Excellent	Good	Average	Poor
4	3	2	1

2. Feedback on Training
2.1. To what extent were the objectives of the training program achieved? ☐ Excellent 4 ☐ Good 3 ☐ Average 2 ☐ Poor 1
2.2. To what extent has your understanding of climate change guidelines improved, as a result of the training program? ☐ Excellent 4 ☐ Good 3 ☐ Average 2 ☐ Poor 1
2.3. What is your overall rating of this training program? ☐ Excellent 4 ☐ Good 3 ☐ Average 2 ☐ Poor 1
2.4. What was the level of communication shared with you before the training program? *(a) To attend the program* ☐ Excellent 4 ☐ Good 3 ☐ Average 2 ☐ Poor 1
2.4. What was the level of communication shared with you before the training program? *(b) Quality of reference material received and training tool kit* ☐ Excellent 4 ☐ Good 3 ☐ Average 2 ☐ Poor 1
2.5. Please rate the training program from (a) to (d) and provide suggestions under (e) *(a) Knowledge of trainers on the subject (overall)* ☐ Excellent 4 ☐ Good 3 ☐ Average 2 ☐ Poor 1
(b) Organization of sessions ☐ Excellent 4 ☐ Good 3 ☐ Average 2 ☐ Poor 1
(c) Style and delivery ☐ Excellent 4 ☐ Good 3 ☐ Average 2 ☐ Poor 1
(d) Facilitation skills of trainers (responsiveness to group needs and queries) ☐ Excellent 4 ☐ Good 3 ☐ Average 2 ☐ Poor 1
(e) General suggestions for trainers:

Use of Climate Change Adaptation Guidelines for Coastal Protection and Management Feedback by Participants

3. Program Content
3.1. List some of the key takeaways from the training program (what you have learned)
3.2. List any missing items / subjects and what you would like to be included in the program
3.3. Describe specific recommendations for improvements in the future

Name and designation	Department	Signature