CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 1

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

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CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

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

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EDITORS:
Black K.P., Baba M., and Parsons S.B.

AUTHORS:
Black K.P., Baba M., Mathew J., Kurian N.P., Urich P., Narayan B. and Stanley D.O.

INDIAN RESEARCH INSTITUTES ENGAGED IN THE CLIMATE CHANGE STUDIES:
Indian Institute of Technology, Delhi
Indian Institute of Tropical Meteorology, Pune
Indian Institute of Technology, Mumbai
National Institute of Oceanography, Goa

NATIONAL TECHNICAL COMMITTEE MEMBERS:
Member, River Management, Central Water Commission (Chairman)
Senior Joint Commissioner (FM wing), Ministry of Water Resources, River Development and Ganga Rejuvenation
Ministry of Environment, Forests and Climate Change (representative)
Ministry of Earth Sciences (representative)
Ministry of Shipping (representative)
Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture (representative)
Bureau of Indian Standards (representative)
National Hydrographic Office, Dehra Dun (representative)
Director, Central Water and Power Research Station
Project Director, World Bank Integrated Coastal Zone Management Project
Project Director, Project Management Unit, Sustainable Coastal Protection and Management Investment Programme, Karnataka
Project Director, Project Management Unit, Sustainable Coastal Protection and Management Investment Programme, Maharashtra
Chief Engineer (FM), Central Water Commission (Member Secretary)

PANEL OF EXPERTS:
Dr. J.S. Mani, Professor (Retd.), Indian Institute of Technology Madras (Chairman)
Shri. K.A. Keshvani, Chief Engineer and Director, Gujarat Engineering Research Institute, representative of Government of Gujarat
Shri. N. Vasudevan, Chief Conservator of Forest, representative of Government of Maharashtra
Chief Engineer (WR), representative of Government of Goa
Project Director, Project Management Unit, Sustainable Coastal Protection and Management Investment Programme, Karnataka, representative of Government of Karnataka
Dr. K.V. Thomas, Scientist-G (Retd.), National Centre for Earth Science Studies, representative of Government of Kerala
Chief Engineer, Water Resource Department, representative of Government of Tamil Nadu
Shri P. Swaminathan, Chief Engineer (PWD), representative of Union Territory of Puducherry
Prof. N. Subba Rao, Andhra University, representative of Government of Andhra Pradesh
Shri. Jugal Kishor Tripathy, Superintending Engineer, representative of Government of Odisha
Director, River Research Institute, representative of Government of West Bengal
Superintending Engineer, LPWD, representative of Union Territory of Lakshadweep
Dr. S.M. Yadav, Dean (AI & RG), National Institute of Technology, Surat, representative of Union Territory of Daman and Diu
Prof. J.K. Mishra, Pondicherry University, representative of Union Territory of Andaman and Nicobar Islands
Dr. M.V. Ramana Murthy, National Institute of Ocean Technology, Ministry of Earth Sciences
Prof. Prasad Kumar Bhaskaran, Indian Institute of Technology, Kharagpur
Prof. G.S. Dwarakish, National Institute of Technology Karnataka, Surathkal

FOCAL POINT

Central Water Commission, Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India

EXECUTING AGENCY

Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India

IMPLEMENTING AGENCIES

Central Water and Power Research Station (responsible for climate change data and training)
Maharashtra Maritime Board (responsible for subprojects in Maharashtra)
Department of Public Works, Ports, and Inland Water Transport (responsible for subprojects in Karnataka)

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Abbreviations

ADB	Asian Development Bank
CD	Chart Datum
CRZ	Coastal Regulation Zone
EIA	Environmental Impact Assessment
ESL	Environmental Softness Ladder
FIDIC	International Federation of Consulting Engineers
IPCC	Intergovernmental Panel on Climate Change
MFL	Minimum Floor Level
MoEF&CC	Ministry of Environment, Forests and Climate Change
MSL	Mean Sea Level
NIO	National Institute of Oceanography
RCP	Representative Concentration Pathways
SLR	Sea Level Rise

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CHAPTER 1
MEETING THE CHALLENGE

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

The Need for Climate Change Adaptation for Coastal Protection

The climate change projections of the Intergovernmental Panel on Climate Change (IPCC) from 2014 indicate a range of climate change impacts that will alter the prevailing local weather conditions. Based on the projections, there is high likelihood that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. Surface temperature is predicted to increase under all assessed scenarios. The ocean will continue to warm and acidify, and mean global sea level is predicted to rise. The primary impacts in coastal areas are likely to result from Sea Level Rise (SLR) which, coupled with waves during storms, may lead to increased coastal erosion, tidal inundation, and storm surges, creating local flooding.

India has an extensive and diverse coastline of more than 7,500 km with varied geologic and geomorphic evolutionary phases.

A beach in Karnataka, India

Over 100 rivers flow into the sea, sculpting the shape, orientation, and character of the beaches. Sand from the rivers feed the beaches and builds complex sedimentary systems, contextualized and sculpted by the wave, wind, and physical coastal dynamics. Indian coast supports the country's major economic sectors, such as fisheries, agriculture, tourism, as well as transport and communication. However, it is under threat from climate change impacts, which are over and above the wave, wind, and physical coastal dynamics. Among the numerous direct and indirect pressures, coastal protection and management has evolved as a challenge to the development. Substantial anthropogenic and environmental pressures have caused sediment deficit, erosion, sedimentation, and decreased water quality. Case studies in India demonstrate that most coastal problems are induced by people.

Coastal protection is a global issue and remediation is expensive globally and in India. This includes the costs for reparation arising from industrialization and urbanization of the coast. These factors can directly cause erosion (e.g., a port or building on the dune / beach) and are exacerbated through the impacts of climate change. Further pressures arise from changes to the flow regime and reductions in sediment brought to the beaches by the rivers (e.g., damming and sand mining).

Current coastal protection measures in India sometimes result from emergency responses to a hazard event, which may lead to unplanned coastal protection of varying quality. These ad-hoc approaches may not demonstrate the required strategic management of the coastline, particularly when confronting climate change impacts. Moreover, piecemeal solutions focused at single sites without considering the full sediment cell may lead to the problems downstream.

There is a need to bring the scientific overview of coastal dynamics into coastal protection which would deal with full sediment cells.

Innovative methods to protect coasts continue to evolve, but the best technical solutions may not be seen as cost-effective or most acceptable. Furthermore, coastal protection measures deal with many competing factors around resource sharing.

The review and audit of the Indian coast conducted during this study led to a broad conclusion that the beach is the best form of coastal protection. However, harder solutions such as groynes may be required in some locations where the public and government agencies demand them. Hybrids using a hard structure with nourishment are viable under climate change scenario, but structures designed to capture natural sand from the beach are no longer feasible.

Climate Change Adaptation Guidelines for Coastal Protection and Management in India deal with coastal protection under climate change

1. "If it's not broken, don't fix or break it"

Comparison of stable and eroding beaches

The goal is to show the differences between stable and eroding beaches in the absence of any infrastructure and structural activities. The aim is to highlight morphological aspects that need to be sustained to stabilize beaches under changed climatic conditions.

2. "The beach is the best form of coastal protection"

Sand-based solutions

The goal is to consider the softest possible solutions (as compared to hard solutions based on structural interventions). Examples are mechanical re-introduction or re-alignment of beach sand, nourishment, construction or protection of sand dunes, management of public use, and engagement of communities.

3. "When the going gets tough, build something"

Construction-based solutions

The goal is to examine the hard solutions like seawalls, groynes, or detached breakwaters and the softer construction-based solutions like offshore reefs. Hybrid methods are also considered.

Sand-based (soft) solutions are gaining acceptance in India, although conventionally the overwhelming preference has been seawalls and groynes. Asian Development Bank (ADB) funded projects have shown greater diversity. Ullal in Karnataka (offshore reef, geotubes, and sand nourishment), Mirya Bay in Maharashtra (offshore reef and sand nourishment), and government funded Kovalam beach protection project in Kerala (offshore reef using sand filled geotubes) demonstrated the adoption of softer solutions. Conventional construction technology, availability of materials, and engineering know-how have been the key determining factors for the historical preference for seawalls and groynes. International best practice has favored a wider variety of soft and hard solutions.

Definitions
of "soft" and "hard" coastal protection solutions

While the terms "soft" and "hard" are used in coastal engineering to describe the coastal protection "solution", the definition is sometimes confused by the construction materials being used. To avoid any confusion, the terms are defined here.

Soft coastal solutions are those that do not damage or grossly interfere with the beach, and which allow natural flow of sand along the beaches. They normally include nourishment or offshore reefs.

Hard coastal solutions are those that disrupt the beach, natural sediment movement 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.

Soft construction materials are usually sand-based. Notably, a geotube inflated with sand is very solid, but it is considered to be a soft construction material because of its lower durability.

Hard construction materials are substances like natural rock, concrete, wood or steel.

Under these definitions, a soft solution can be constructed from hard materials, e.g. an offshore reef which is made of rocks. Conversely, a hard solution using soft materials might be a seawall or groyne made of geotubes.

Hybrids are defined here as solutions which adopt beach nourishment with structure(s).

To eliminate confusion about reefs, breakwaters, and islands, a **reef** is defined as being underwater at some stage of the tide, i.e. crest level is at or below high tide.

A **breakwater or island** is defined as being out of the water at all times, i.e. crest level above high tide. The term "submerged breakwater" is not used.

Another structure adopted in India is known as an **"offshore seawall"**. These are very long but narrow structures which are nearshore and shore parallel. They often consist of just two or three small geotubes laid underwater and parallel to the coast between the high tide line and breakpoint. The narrow base and energetic surrounds make them prone to subsidence. Their narrow width leads to minimal influence on the waves and so they are considered to be a separate genre and not part of the "reef" category.

The concept of the **sediment cell** is an important part of the Guidelines. A sediment cell is defined as a stretch of coastline where the inputs of sand from outside and losses to adjacent beaches are small. Common examples of morphological features which bound sediment cells are large headlands and/or major shifts in coastal orientation. The volume of sand in a sediment cell is essentially fixed, notwithstanding new deliveries from rivers or losses due to dredging/mining. Works within a sediment cell have only a small influence on adjacent cells. Thus, the sediment cell is a convenient method to sub-divide the coast into zones which are essentially independent. Some cells are very long, such as Kerala beaches where one cell stretches over 300 km from Kollam to Koyilandy. Some cells are small, such as Mirya Bay (Maharashtra) which is just 3 km long. Proponents will need to define the cell around each site before embarking on a protection solution.

Structure of the Document

The key document is Volume 1: "Climate Change Adaptation Guidelines for Coastal Protection and Management in India". 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.

The appendices are designed for specialized training, selection of coastal protection measures, and as a tool to help practitioners use the information from this study. Teachers may find that the appendices could form the basis for academic lessons. Some users may be unable to comprehend the equations and physics of coasts and waves, while others may show strong interest in economics or beach dynamics, and thus the various topics are dealt with in separate appendices.

The topics covered in the Guidelines are enclosed in detail in 18 appendices, as follows:

1. Acronyms
2. Glossary of Coastal Terms

Regulatory framework

3. Existing Regulations for the Indian Coastal Zone
4. Strategic Planning of Coastal Zone and Shoreline in India

Coastal systems

5. Indian Coastal Scientific Literature and Institutions
6. Coastal Processes

Interventions for coastal practitioners

7. Design of Sand-based Climate Resilient Solutions for Coastal Protection
8. Seawalls – their Limitations in Climate Change Scenario
9. Groyne Design under Climate Change
10. Offshore Reefs, Breakwaters and Islands – Design Considerations for Climate Resilient Coastal Protection

Project planning

11. Data Collection and Modeling for Coastal Protection
12. Environmental Impact Assessment of Coastal Protection
13. Climate Change Projections for the Indian Coast
14. Using the WRIS Database for Climate Resilient Coastal Protection and Management
15. Economics and Life-cycle Costing for Coastal Protection Schemes
16. Island Case Studies
17. Calculating the Minimum Floor Level
18. Training Module for Climate Resilient Coastal Protection and Management.

Background to the Guidelines

Climate Change Adaptation Guidelines for Coastal Protection and Management in India (Guidelines) are part of ADB TA-8652 IND: Climate Resilient Coastal Protection and Management Project, which also contains other components, such as case studies, pilot subprojects, and capacity building. The case studies are selected to help formulate the Guidelines. The pilot subprojects provide real examples of a recommended solution for the future management of the shoreline. Capacity building program is designed from the Guidelines with compatible information. The outputs have been passed on to the Central Water and Power Research Station and other relevant departments for ownership. The Guidelines are vetted by a panel of experts from all coastal states, coastal zone management authorities, specialists from Indian research institutes, implementing agencies of the project, and the National Technical Committee (created for this purpose) represented by the concerned ministries.

The Guidelines are intended for application throughout India, including the islands and union territories.

> *Primary goal of the Guidelines is development and fostering of sustainable methods to protect coasts in India, which can be adapted to climate change impacts through the engagement of engineers, scientists, and coastal communities.*

While many regulations exist in the Coastal Regulation Zone (CRZ), 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.

> *The Guidelines are approached in two parts. The first part considers* **"regulatory Guidelines"** *and the second part focuses on* **"intervention Guidelines".** *Neither element can be successful without the other, as regulations have no substance without practical solutions and solutions may not work without a regulatory framework.*

Regulatory Guidelines bridge the gap between the existing CRZ regulations and the need to manage events of the future. Each regulation under the CRZ aims to embody an anticipated outcome, and by examining the effectiveness of the existing regulations and their enforcement, informed decision making for the future is contextualized. The CRZ regulations made no allowance for SLR or other factors causing elevated water levels. The CRZ focusses on horizontal (rather than vertical) distances, including a provision to demarcate the "hazard line", which has not yet been put into practice. Accordingly, the concept of the "Minimum Floor Level" (MFL) is introduced, which is the highest sea level that may occur at a coastal site, defined relative to the Mean Sea Level (MSL) or Chart Datum (CD). MFL varies around the Indian coast, and values for each state are defined in Appendix 17. The essential re-adjustments required to accommodate these in the existing CRZ are given as a table in Appendix 3.

Intervention Guidelines incorporate an understanding of a range of soft and hard intervention strategies that can be considered to address climate change impacts at the coast. Soft and hard solutions with best global and Indian practice are considered and an "Environmental Softness Ladder" is presented to help the user rank the softness of existing / proposed coastal protection methods. In Chapter 4, the "C-Guide" system is developed to administer the Guidelines. A checklist of choices to protect the coast under climate change gives guidance for practitioners.

The Guidelines aim to provide engineers, designers, planners and decision makers with a simplified framework to guide decisions about coastal protection intervention options, both under present day conditions and with projected climate change. This includes identifying the key issues and understanding the relevance of coastal processes and how the coast may respond during extreme events. These Guidelines are not intended to be an engineering design manual; rather, the tools needed to do these designs are specified and clarified. For detailed design criteria, the recommended manuals are given in the Bibliography and Appendix 4.

An unscientific design cannot be made climate resilient. Hence the Guidelines are more holistic; blending scientific knowledge to guide practical engineering solutions while adopting coastal planning and management measures which complements India's efforts on integrated coastal zone management spearheaded by the Ministry of Environment, Forests and Climate Change (MoEF&CC). Options for protection are based on case studies of existing methodologies which provide the necessary well-founded knowledge to plan for the future.

An extensive reference list of coastal science and engineering publications from Indian researchers is given in Appendix 5 and an up-to-date bibliography containing relevant global information on designing shore protection measures is given at the end of this document. The essential considerations for the designing of the shore protection measures are provided in appendices 4, 7, 8, 9, and 10. Terminologies that may not be readily understood are included in the glossary in Appendix 2 which gives an insight into the commonly-used terms. It aims to increase communication and analytical skills of the coastal managers.

To support the Guidelines, much work has been done to quantify possible changes to key parameters with climate change (Appendix 13). Databases have been established through commissioned research with four Indian research institutes (Indian Institute of Tropical Meteorology, Indian Institute of Technology Bombay, Indian Institute of Technology Delhi, and National Institute of Oceanography) and CLIMsystems from New Zealand, to create weather patterns, wave climate, storm surge and sea level all along the Indian coast up to the year 2100 in a climate change scenario at a 50-km coastal grid. These are presented in detail in Appendix 13 and being uploaded on the public India-WRIS website (http://india-wris.nrsc.gov.in), which needs to be periodically updated when better projections are available. This database shall be used only as a preliminary assessment of the location and all designs shall be based on site-specific detailed measurements, studies, and projections.

The Users

The intended users include engineers, planners, administrators responsible for decisions about coastal protection, and people involved in natural resource sharing, including scheme planning, design, approvals / clearances and construction. A holistic approach is adopted also to engage economists, ecologists and resource managers so that coastal protection strategies can be more strategic, rather than local. The importance of the social and environmental aspects of future climate change cannot be overstated.

Some readers may have training in coastal disciplines, but many users will have no formal training and limited experience. Users faced with decisions regarding adaptation options should be prepared to seek expert technical advice from appropriately qualified physical coastal scientists / engineers and other relevant professionals, but the document aims to inform such discussions.

Status of the Guidelines

The Guidelines were developed during three phases over 24 months in 2015-2017. This has enabled stakeholders to voice opinions, make contributions, and consider the implications of the Guidelines in day-to-day practice. The well-founded suggestions for the Guidelines were examined and endorsed by the agencies responsible for implementation through reviews and workshops.

This document presents the final Guidelines which were examined by the panel of experts and needs approval by the National Technical Committee for the release. It is hoped that practitioners will continue to voice their questions and concerns, add more valuable inputs, or find ways to beneficially modify the Guidelines as more knowledge becomes available in the future. A document is never completed; it is just a milestone along the journey. It is hoped that this milestone will help to save India's beaches and coasts from the impacts of climate change and benefit future generations confronting an uncertain future.

CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 1

CHAPTER 2
CLIMATE CHANGE

ADB TA-8652 IND:

CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

Global Patterns

The climate change projections from the IPCC (2013) indicate surface temperature increases under all assessed scenarios. There is a high likelihood that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions causing flash floods. The ocean will continue to warm and acidify, and global MSL will continue to rise. The primary impacts in coastal areas arise from sea level rise and storms, which will lead to increased coastal erosion, tidal inundation and flooding. Tidal inundation will cause salt intrusion and reduce vegetation and crop growth. Increased storm surges and waves will accelerate erosion and damage settlements, infrastructure, water resources and agriculture, as well as create unexpected economic burden on populations and local authorities.

Simple Physics of Climate Change

Over millions of years, the planet has gone through cycles of extreme heat and extreme cold. Geologists know that sea levels have been more than 60 m higher. But never have we witnessed such a rapid shift. Heat storage in the Earth's oceans is feeding the rapid climatic change observed since the Industrial Revolution. The physics of climate change can be simply explained as a series of linked steps:

- Carbon is being released from fossil fuels, deforestation, changed land use etc.
- The carbon forms CO^2 in the atmosphere
- The increased concentrations cause a rise in atmospheric temperature
- At the same time, the oceans start to store heat - oceans are the powerhouse of global weather
- With increased energy levels in the sea, well beyond the power of any nuclear bomb, the energy in storms rises dramatically
- Evaporation is higher over the warmer oceans and storms and cyclones are stronger and more common
- The heat also melts the ice on land
- Extra heat causes the oceans to expand
- The sea rises and the whole process feeds back on itself as more ice melts, the atmosphere becomes more polluted and the seas grow in heat
- Once started, it is hard to reverse
- The scientists are conservatively predicting just a one meter rise in sea level by 2100, but the final level depends on us.

Measured Responses

The National Oceanic and Atmospheric Administration (2015) reported that the level of CO_2 has now exceeded 400 ppm globally, which is an extreme level; already well above the safe level of 250 ppm. Emissions have been exponentially increasing. Thus, we not only have to slow the rate of gas emissions, the climate scientists are saying that the high CO_2 levels need to be reduced.

While this summary is relatively simple, the nonlinear relationship between greenhouse gases and global warming is complex. The world's best atmospheric and ocean scientists have developed numerical models to project the world's climate (e.g. temperature, wind, and precipitation) and ocean responses (e.g. temperature, sea level, wave height). While they vary within a range, they all agree that the sea level will rise, storms will worsen and rainfall patterns will change. Oceans will continue to warm and acidify. In worst case is more than 70 m of SLR.

In confirmation of the models, global average sea surface temperatures have increased since both the 1900s (inferred) and the 1950s (observed) (IPCC, 2013). And the level of the sea is rising due to: (i) melting of snow and ice on land (e.g. potentially Greenland, Antarctica, glaciers and mountain ranges), and (ii) thermal expansion of the warmer seawater through heat-transfer from the atmosphere.

There is some uncertainty about the future projections of climate change as they depend on the application of complex models to a range of CO_2 emission scenarios that may not prove to be plausible in the future. Different assumptions in the Global Climate Models lead to different projections. Combined with the uncertainty about future greenhouse gas emissions there will always be some doubt surrounding the magnitude of global heating. However, there is no doubt that our planet is getting hotter and the climate is changing at a rate which has not been witnessed before (Appendix 13).

Changes to surface wind and waves, sea level, intense rainfall and storm intensity will increase the vulnerability of coastal communities and industries such as shipping, energy, and mineral extraction (IPCC, 2013). Climate change risks can be mitigated through better awareness, policies, coastal planning, and management, but risks and uncertainties will increase with further climate change (IPCC, 2013).

Regional Climate Change Impacts: South Asia

Warming trends and increasing temperature extremes have been observed across most of the Asian region over the past century (IPCC, 2013). A number of recent studies confirm the trends from the IPCC AR4 (2007) indicate that India is highly vulnerable to the consequences of sea level rise (SLR) and extreme events. A 10% increase of the current 1 in 100-year storm surge level combined with an assumed 1m SLR could affect around 7.6 million people in India (Wheeler, 2011). The same study shows that India has the second highest population (out of 84 developing countries studied) affected by the potential effects of climate change. The affected population depends upon climate-sensitive sectors like agriculture and forestry for its livelihood.

Water scarcity is expected to be a major challenge for most of the region as a result of increased water demand and lack of good management (IPCC, 2013). Any adverse impact on water availability due to recession of glaciers and decrease in rainfall (even increased flooding in certain areas) would potentially threaten food security, cause dieback of natural ecosystems including species that sustain the livelihood of rural households and adversely impact the coastal system.

Impacts on land are compounded by coastal changes in sea level, increased frequency and magnitude of extreme events, as well as the resulting coastal erosion. Coastal and marine systems in Asia are under increasing stress from both climatic and non-climatic drivers (IPCC, 2013). Mangroves, salt marshes, and sea grass beds may decline unless growth and migration rates exceed SLR with the shift in the coastline, while coastal freshwater swamps and marshes will be vulnerable to the saltwater intrusion resulting from SLR. Coral bleaching caused by increasing water temperatures, as well as ocean acidification are expected to cause widespread damage to reef structures. Although marine biodiversity is expected to increase at temperate latitudes with warm water species expanding their ranges northward, it will decrease in the tropics as the thermal tolerance limits of certain species is exceeded (IPCC, 2013).

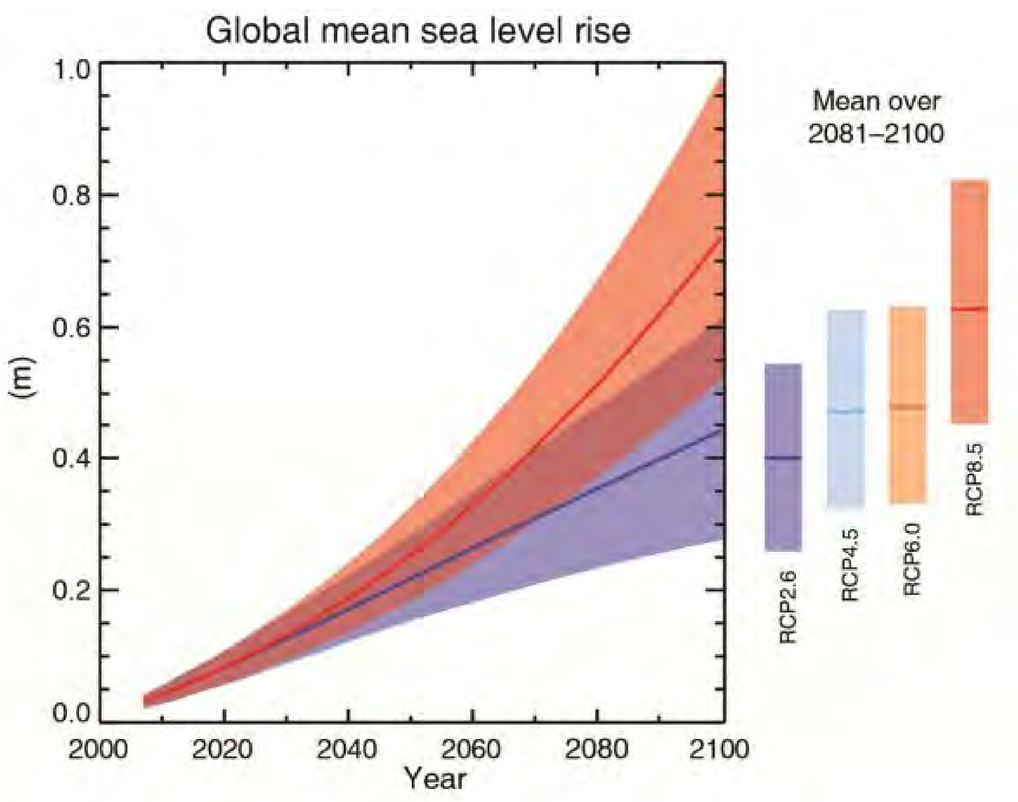
Projected change in global mean surface temperature and global mean SLR for the mid and late 21st century, relative to the 1986-2005 period for the four Representative Concentration Pathways (RCPs)* that IPCC uses in their analyses (IPCC, 2013) is presented in Table 1.

Table 1. Projected global mean surface temperature and sea level rise under four RCP scenarios

		2046 - 2065		2081 - 2100	
	Scenario	**Mean**	**Likely range**	**Mean**	**Likely range**
Global Mean Surface Temperature Change (°C)	RCP 2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP 4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP 6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP 8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
	Scenario	**Mean**	**Likely range**	**Mean**	**Likely range**
Global Mean Sea Level Rise (m)	RCP 2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP 4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP 6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP 8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

Source: IPCC (2013)

Figure 1. General circulation (climate) model projections for global mean sea level rise relative to 1986-2005 for the four RCP scenarios



Source: IPCC (2013)

* RCPs are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its fifth Assessment Report (IPCC, 2013), used for climate change modeling and research. They describe four climate change scenarios which are considered possible depending on how much greenhouse gases are emitted. The four RCPs, RCP2.6, RCP4.5, RCP6.0, 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).

In Figure 1, the solid lines show the median projections, the dashed lines show the likely ranges for RCP4.5 and RCP6.0, and the shading shows the likely ranges for RCP2.6 and RCP8.5. RCPs usually refer to the portion of the concentration pathway extending up to 2100, for which Integrated Assessment Models produced corresponding emission scenarios. RCP2.6: One pathway, where radiative forcing peaks at approximately 3 W m−2 before 2100, and then declines. RCP4.5 and RCP6.0: Two intermediate stabilization pathways in which radiative forcing is stabilized at approximately 4.5 W m−2 and 6.0 W m−2 after 2100. RCP8.5: One high pathway for which radiative forcing reaches greater than 8.5 W m−2 by 2100 and continues to rise for some amount of time (IPCC, 2013).

Local Climate Change Impacts: Indian Coast

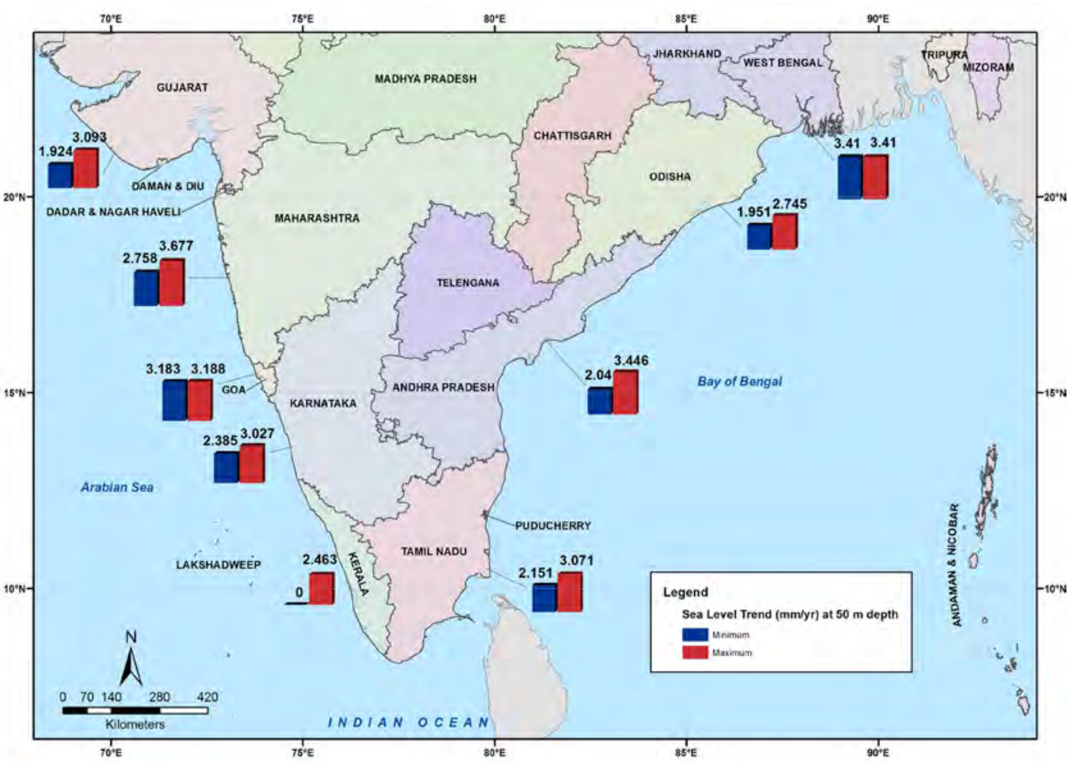
According to the climate change projections (SNC, 2012), the daily extremes in surface air temperature in India can intensify in the future. The spatial pattern of the change in the highest maximum temperature suggests warming of 1–4°C towards 2050s, which may exceed even 4.5°C in most places towards 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. 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, simulations of Second National Communication (2012) indicate an increase in the rainfall.

As SLR occurs, inundation episodes from storm surges and flash floods will intensify (both in frequency and magnitude), while being compounded by the overtopping of waves during storms. This will also increase coastal erosion and in some cases, lead to salinity intrusion rendering unproductive soils. SLR is a relatively fast process, with the observed global mean rate between 1993 and 2012 estimated as 3.2 mm / year (Unnikrishnan et al, 2014). Over a person's 50-year lifetime, the levels have risen by 17 cm and the rate is accelerating. Moreover, the frequency of a given extreme event is more pronounced: a small shift in the magnitudes on the extreme event distribution curve causes a large increase in frequency.

National Institute of Oceanography (NIO) has analyzed the historic sea level data, trends during historical periods (tide gauge data) and recent periods (satellite altimetry). The sea level trends with maximum and minimum for each coastal state and islands are shown in the map (Appendix 13). Maximum sea level trend of 3.677 mm / year is seen off Maharashtra.

Figure 2. Minimum and maximum sea level trends (mm / yr) based on historical tide gauge and altimetry data along the Indian coast.

Source: ADB TA-8652 IND: Climate Resilient Coastal Protection and Management Project



A second analysis of sea level projections under a climate change scenario was undertaken by CLIMsystems (2016). The analysis incorporated vertical land movement along the Indian coast as well. The SLR values around the coast of India are relatively consistent as vertical land movement of the sub-continent is relatively slow (Appendix 13).

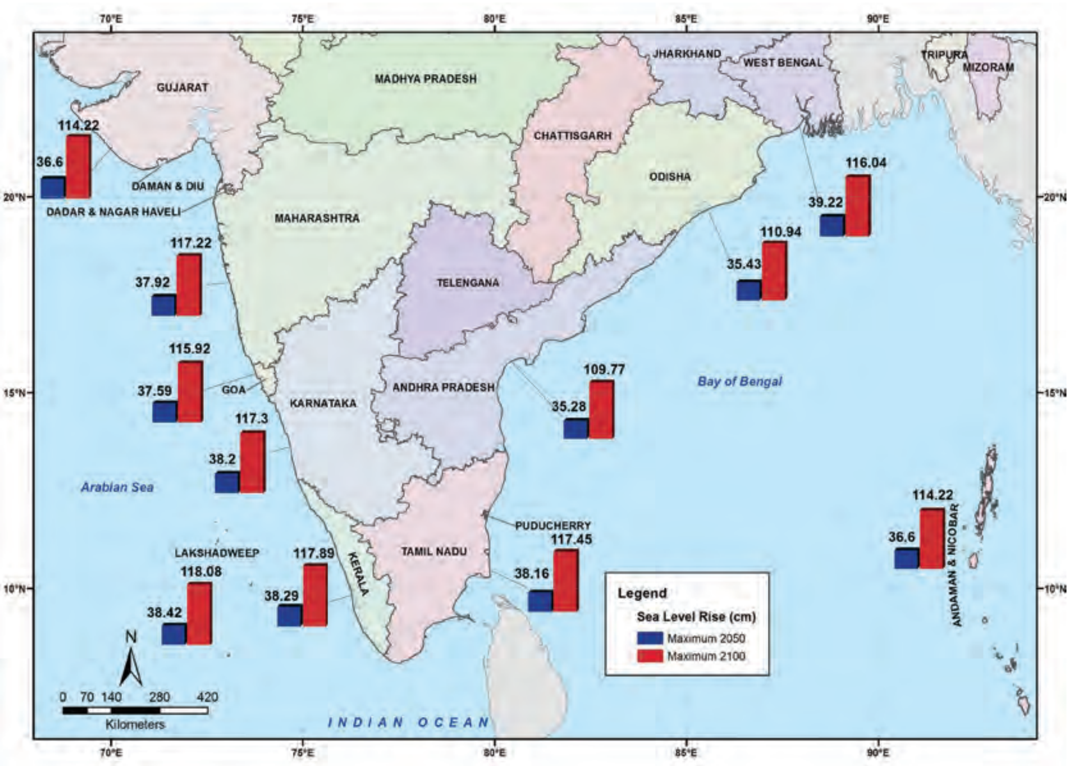
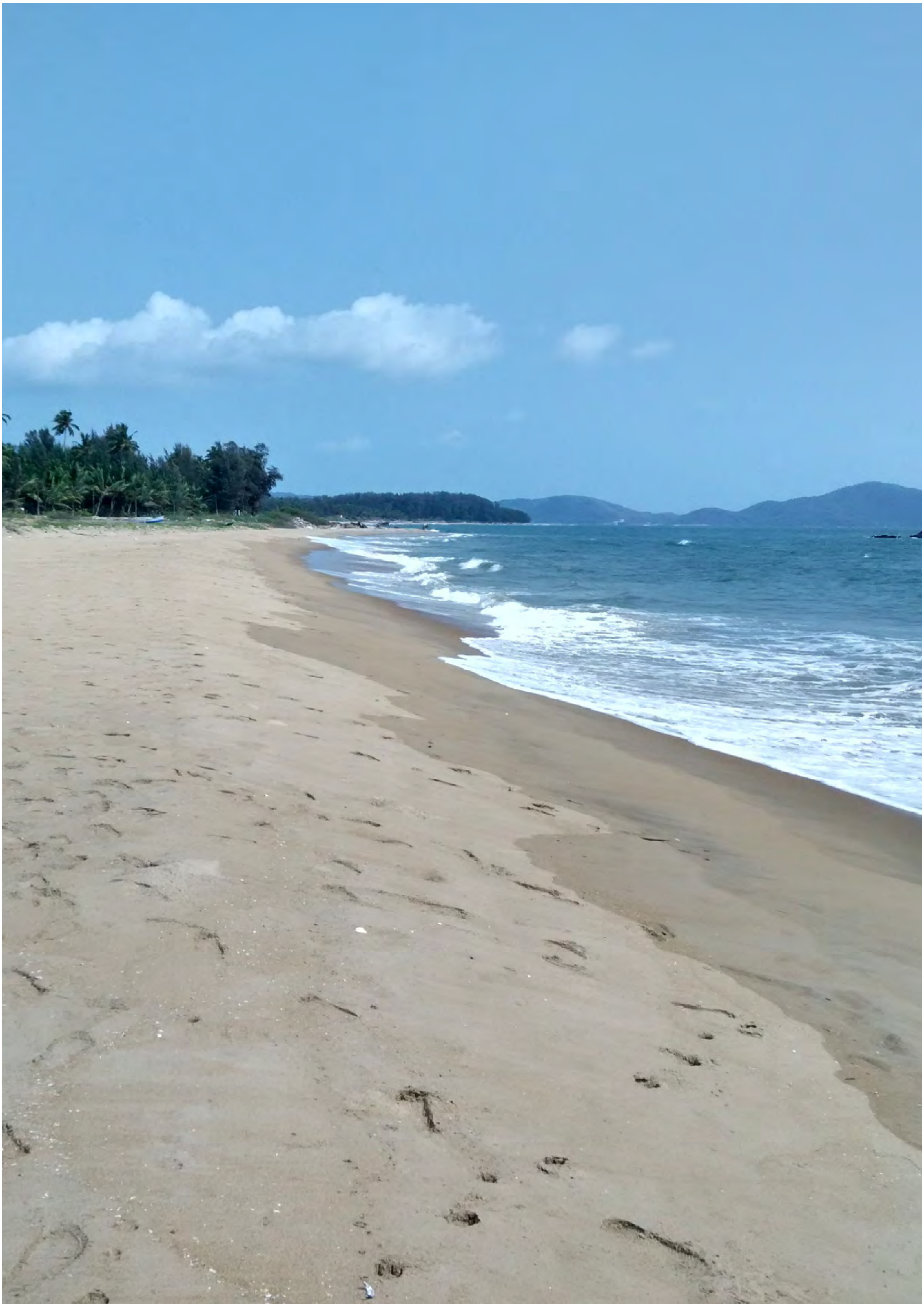


Figure 3. Sea level rise projections (in centimeters) due to climate change for 2050 and 2100 along the Indian coast.

Source: ADB TA-8652 IND: Climate Resilient Coastal Protection and Management Project

In general, the coast of India is experiencing a slightly greater than global average SLR. Under an RCP 8.5 (medium sensitivity) assessment including vertical land movement, the rises are between 1.10 m and 1.20 m by 2100. As SLR is a nonlinear phenomenon the values around the coast under the same RCP conditions and sensitivity could be between 0.35 and 0.38 m by 2050.

Computation of probable maximum water level elevations generated by any tropical cyclones crossing coastal states of India and Andaman and Nicobar, and Lakshadweep islands is carried out by the Centre for Atmospheric Studies of the Indian institute of Technology Delhi. In the northern Indian Ocean, about 16 cyclonic disturbances occur each year, of which about six develop into cyclonic storms (INC, 2004). 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.



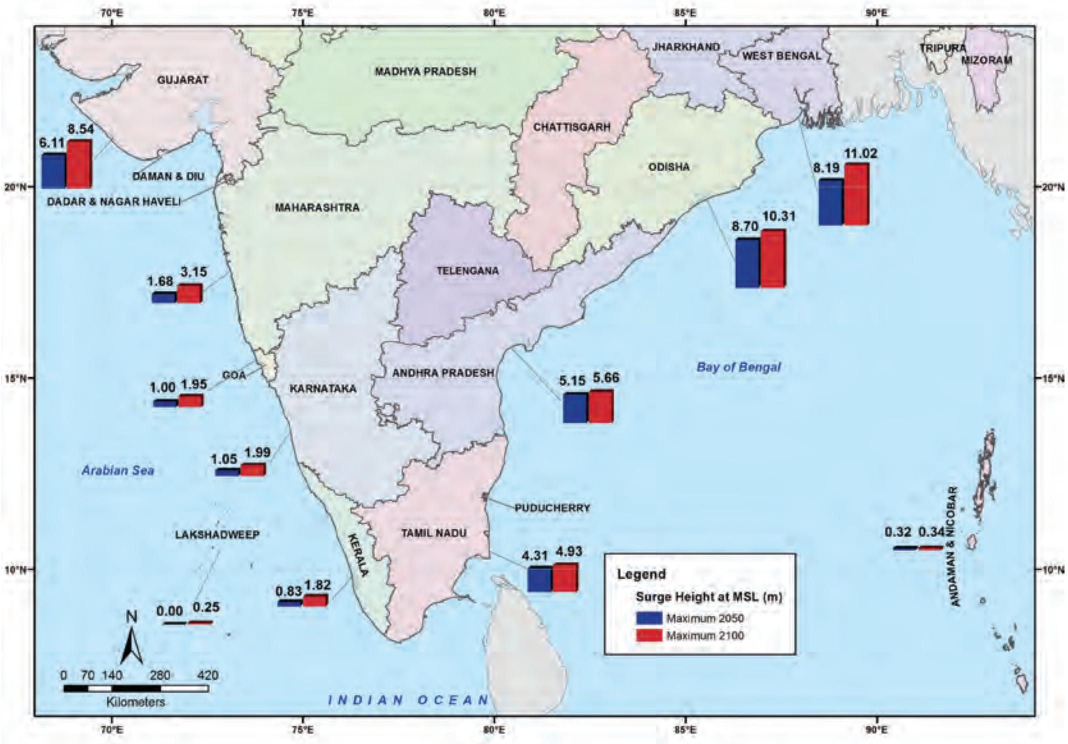


Figure 4. Maximum storm surge projections (in meters) due to climate change for 2050 and 2100 along the Indian coast.

Source: ADB TA-8652 IND: Climate Resilient Coastal Protection and Management Project

National Institute of Oceanography has carried out studies on wave climate changes in the near coastal region. The wave study analyses modelled wind waves for: (i) a historical period using hindcast re-analyzed winds, (ii) climate change scenario for medium greenhouse gas emission (7% increase in wind speeds), and (iii) climate change scenario for high greenhouse gas emission (11% increase in wind speeds). Modelling is carried out to provide waves at 20 m depth and at 50 km spatial resolution around the coastline. The variation of Hs along the mainland locations showed that the Hs for a 100-year return period varies between 2.98 m and 7.44 m while for the extreme case of 11% increase in wind speeds the 100-year Hs varied between 3.46 m and 9.41 m. All the maximum wave heights occurred in Gujarat State (Appendix 13).

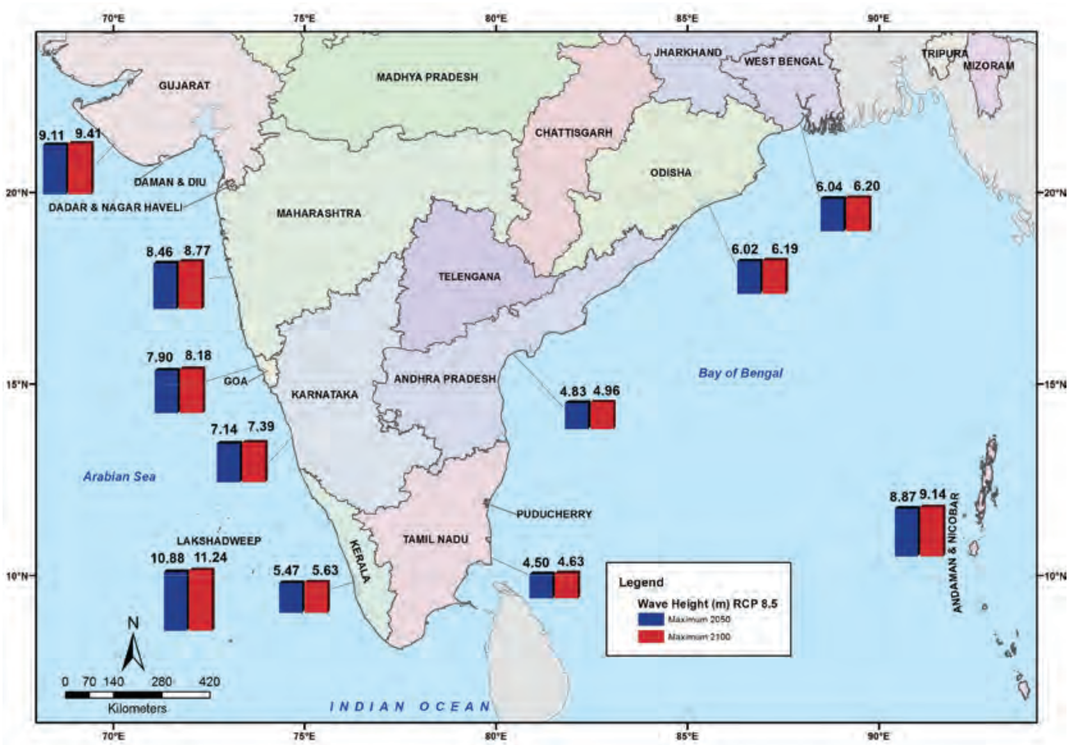
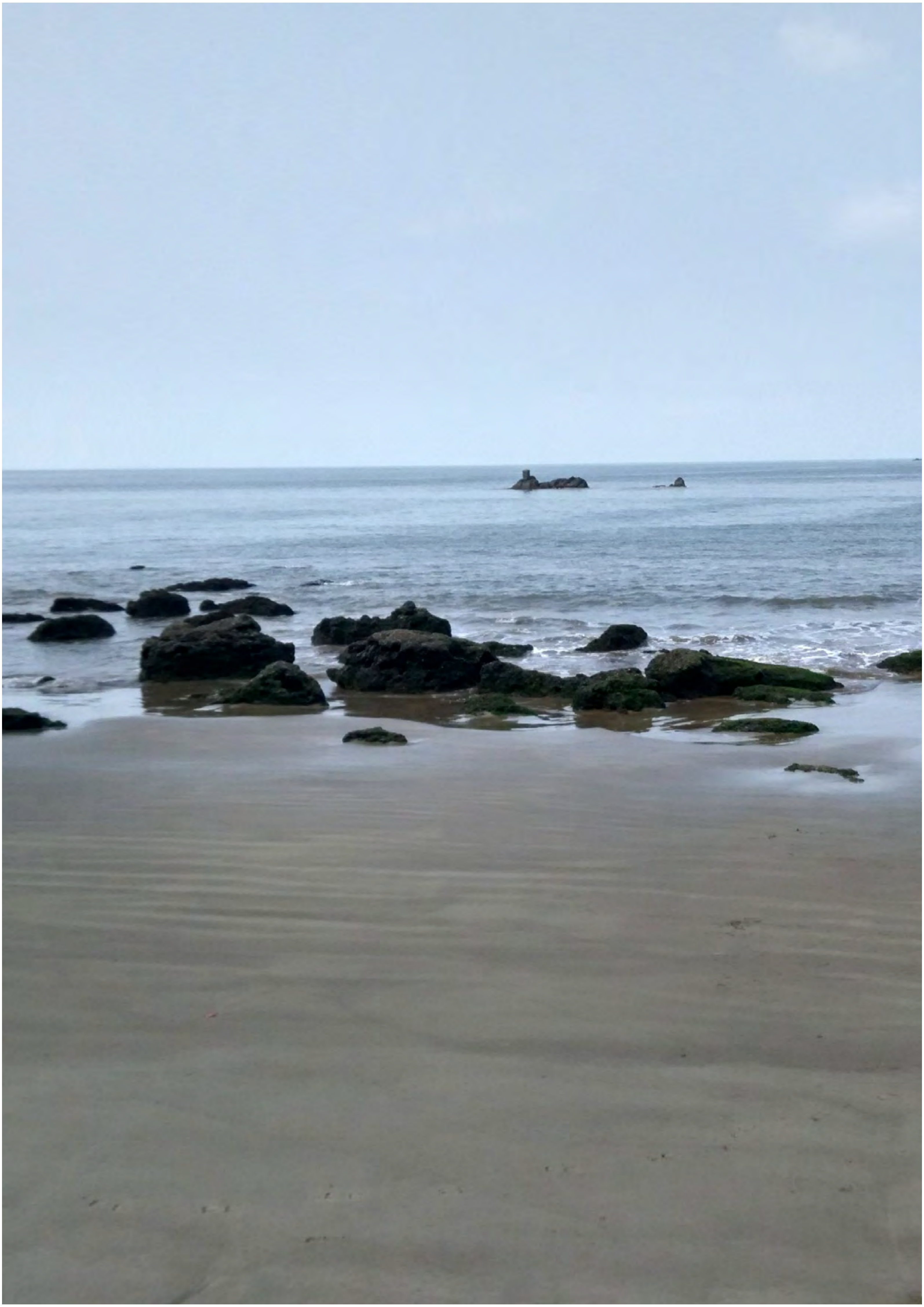


Figure 5. Maximum wave height (m) projections for 2050 and 2100.

Source: ADB TA-8652 IND: Climate Resilient Coastal Protection and Management Project

CHAPTER 3
THE GUIDELINES



Introduction

The Climate Change Adaptation Guidelines for Coastal Protection and Management provide scientifically well-founded suggestions to deal with a changed climate at the Indian coast. Scientific understanding has come from scientific literature and international shoreline management practices. In addition, coastal protection projects in India have been examined to provide insight into the methodologies and practicalities of the country's coastal protection schemes.

> *The driving need and purpose of the Guidelines is based on the concept of 'no regrets'. This means that decisions taken today will not be regretted in the future. A 'no regrets' approach fosters better planning to deal with climate change impacts.*

The Guidelines are approached in two parts:

1. The first part considers **"regulatory Guidelines"**. Several Guidelines are procedural and may be put in place by local government agencies, while others may require legislative / legal endorsement and creation of systems by the governments to be enforceable.

2. The second part focuses on **"intervention Guidelines"**, which are based on recommendations for best practice methods to protect the coast, particularly in the context of climate change. The intervention Guidelines include supplementary Guidelines:

    - **"Advisory Guidelines"**, giving advice on coastal processes and structure design. These are distinguished from the main Guidelines by their advisory nature, rather than directions that need to be followed.

    - **"Island Guidelines"**, focusing specifically on India's tropical island territories.

The Guidelines are presented in this chapter and explained in the following chapter. Methods to apply them are presented in Chapter 5.

Regulatory Guidelines

Many regulations and policies exist in the CRZ of India and coastal protection is a permitted activity after demonstrating a full understanding of the coastal processes and conducting risks assessment. However, most coastal states are recommending shore protection based on present climatic conditions, without considering adaptation measures in the context of climate change. The higher risks of climate change, sea levels, storms (more intense and more frequent), and simultaneous increases in population along the coast are not being accounted for.

This challenges the practical value of the regulations. Each regulation should aim to embody an anticipated outcome and, by examining the effectiveness of the existing regulations and their enforcement, informed decision-making for the future is contextualized. Some modifications required in the CRZ / Environmental Impact Assessment (EIA) regulations to adapt to the impacts of climate change are explained in Appendix 3.

National and state governments under appropriate policies can enforce many of the following regulatory Guidelines as they are mostly procedural. For example, changes to reporting standards or monitoring requirements in an EIA, or changes to the way a project is assessed, can be achieved within the responsible departments without legislation. However, a mutual policy is needed that sets the boundaries, as well as promotes implementation strategies to improve risk assessment methodologies and enhance understanding of the risks to critical infrastructure and services. Other Guidelines, such as building regulations along the shoreline, require legislative approval for enforcement. However, many of these are already in existence within the current CRZ (Appendix 3). While there are some provisions in the existing coastal regulations, the repetition here brings all relevant recommendations to one place for convenience and cross-sectorial understanding. In current legislation, the CRZ is defined as the zone 500 m landward of the high tide line out to the 12-nautical mile limit. Inland waterways have a different definition (Appendix 3). The CRZ regulations have numerous exemptions, mostly for the government (Appendix 3), which are not duplicated in this document. Such exemptions may be better dealt with when a guideline is ready to become a regulation.

Table 2. Regulatory Climate Change Adaptation Guidelines for Coastal Protection and Management in India

A. ADMINISTRATIVE GUIDELINES **Purpose:** To strengthen elements of the coastal protection approval processes. While the administration in India is systematic and comprehensive, some elements need to be changed and / or strengthened.	
Guideline A1	Develop a structure for compulsory cooperation / consultation between departments, ministries and agencies which have control over specific aspects of the coast prior to initiation of the project.
Guideline A2	Government administrators controlling projects will have to be multidisciplinary including experts from these categories: a physical coastal scientist, coastal engineer, coastal ecologist and socio-economist.
Guideline A3	Standard contractual agreements to define roles and liabilities are needed for all projects.
Guideline A4	National and state funding for coastal protection should be in three stages: (i) budget for design studies and EIA preparation, (ii) budget for project implementation after project approval and (iii) performance monitoring and corrective measures, if any, required.
Guideline A5	Develop a central web-based repository with linkage to the states and territories for designs and plans to be made accessible to the public.
Guideline A6	Necessary capacity building measures be ensured by the center, states, and territories.
B. ECONOMIC GUIDELINES **Purpose:** To deal with financial assessments and cost-benefit of climate resilient coastal protection measures. Economics underpins coastal protection funding. The practices need to consider modern and globally accepted cost-benefit and life-cycle costing.	
Guideline B1	Account for both the costs and benefits of coastal management strategies.
Guideline B2	Adopt “full life-cycle” cost analysis for projects.
Guideline B3	Achieve a minimum benefit-cost ratio of 1:1 over the full life-cycle of a project.
C. LAND USE GUIDELINES **Purpose:** To enforce land use regulations controlling public departments focusing on coastal protection, building offsets and elevations, public use of the land. The CRZ is framed around horizontal distances from the shorelines to control coastal development. Since its inception, climate change and SLR has become a global issue and now there is a need to consider the vertical dimension, i.e. elevations of land, as well as the horizontal position.	
Guideline C1	New construction in the CRZ should only be above the MFL which allows for tides, storm surge, wave effects and climate change on sea levels.
Guideline C2	All the provisions contained in CRZ be strictly enforced.

D. MINING AND DREDGING GUIDELINES (EXTRACTIVE ACTIVITIES) **Purpose:** To utilize sand resources sustainably. Growth of Indian cities and infrastructure rely on sand for concrete and construction. The resultant mining of sand has led to both large-scale and cottage level mining. However, the impact is now being felt through coastal erosion. These Guidelines reflect the need to act now in preparation for the upcoming decades of climate change and SLR.	
Guideline D1	Sand taken from within the CRZ may be used for beach nourishment only.
Guideline D2	Sediments taken from the CRZ with greater than 70% mud (sediment size <0.063mm) content can be used for port reclamation and other activities allowed under the CRZ.
Guideline D3	Sediments taken from the CRZ with less than 70% mud content shall be deposited on downstream beaches in depths no greater than 5 m.
Guideline D4	Sand temporarily stored on land for convenience should be returned to the beaches before the next monsoon.
Guideline D5	Offshore sand extracted from beyond 10 m depth shall be considered as a main source for beach nourishment. The extraction must be based on scientific study and EIA.

E. EIA GUIDELINES **Purpose:** To intensify studies, consideration of the environment, monitoring and environmental risks. A comprehensive EIA will be provided before approvals are given for projects within the CRZ. Rapid EIAs need to be made more intensive, given the potential for damage to the coast. Monitoring of the approval conditions shall be streamlined effectively.	
Guideline E1	The EIA shall satisfactorily address the Guidelines specifically.
Guideline E2	The EIA Guidelines shall be applicable to government departments and private agencies uniformly, without any bias or preference for one over the other.
Guideline E3	The EIA shall be site specific and based on a clear understanding of the coastal ecosystems and the physical coastal processes, including longshore transport rates, and the sediment cell concept, using best practice data collection and computer modeling.
Guideline E4	A multidisciplinary team of experts shall prepare the EIA, including, but not limited to, a physical coastal scientist, coastal engineer, coastal ecologist and socio-economist.
Guideline E5	The EIA shall be considered by a technical committee consisting of at least one expert recognized by the Centre or State from each of these categories, but not limited to: a physical coastal scientist, coastal engineer, coastal ecologist, and socio-economist.

Intervention Guidelines

"Intervention Guidelines" consider strategies to address climate change impacts at the coast, including the selection of the best engineering solution to be put into practice. Today's methods provide an essential initial basis for such decisions.

If the current methods do not solve the existing problems, then they will fail when confronting larger storms, higher water levels, increases in population, shortage of sand supply to the beaches and a myriad of other factors. Other more successful methods may need enhancement to be effective in the future. This means that great care has to be taken (i) to find the best shoreline protection methods being adopted now and (ii) to thoroughly crosscheck that these will succeed in the face of climate change projections.

Table 3. Intervention Climate Change Adaptation Guidelines for Coastal Protection and Management in India

F. COASTAL PROTECTION GUIDELINES **Purpose:** To encourage soft coastal protection measures, and to ensure that sufficient coastal buffer zones are provided for predicted climate change adaptation, and the solutions are adaptable to climate change.	
Guideline F1	The procedure defined by the "Environmental Softness Ladder" shall be followed. Softer projects lower on the ladder are climate resilient and will find it easier to gain approvals. All rungs on the ladder represent a stage, and all options lower on the ladder must be fully considered and eliminated before proceeding to higher (harder) rungs.
Guideline F2	Coastal protection measures should have the least possible visual, social and environmental impact.
Guideline F3	Climate resilient coastal protection measures must ensure survival of the beach during all seasons and should not inhibit public access to the beach.
Guideline F4	Structures should not be used for natural capture of sand on eroding coasts.
Guideline F5	Beach nourishment should be used to bring the beach system to equilibrium, rather than relying on the capture of natural sand around new structures.
Guideline F6	Nourishment volumes should consider the full sediment cell, cross-shore beach slumping and net longshore transport rates.
Guideline F7	Coastal protection measures causing negative impacts on adjacent beaches must be mitigated using beach nourishment or sand bypassing.
Guideline F8	Coastal structures across the beach (e.g. ports, inlet breakwaters, groynes) should not be constructed on exposed, long beaches (>8 km long), unless sand bypassing is occurring either naturally or mechanically or accompanied by nourishment.
Guideline F9	To prevent beach scour during floods, urban drainage should be discharged at depths below low tide.
G. MONITORING GUIDELINES **Purpose:** To (i) define impacts on biological communities and physical, environmental and social systems; (ii) gather scientific information about the behavior and efficacy of the developed solution so that future works can be improved; (iii) identify effects on adjacent locations; (iv) ensure that the parties responsible for adverse impacts are identified and (v) confirm that baseline data and EIA studies were sufficient.	
Guideline G1	Detailed monitoring of coastal projects (physical, biological, environmental and social) will be required pre-construction, during construction and for at least 3 years after construction.
Guideline G2	Quarterly and Annual Reports on environmental, physical, biological and social changes based on the monitoring shall be put in the public domain through web-sites.

H. ADVISORY GUIDELINES Purpose: To provide helpful information, rather than rules which must be followed to adopt the Guidelines	
Guideline H1	Primary sand dunes should be restored and elevated to the MFL.
Guideline H2	For nourishment or hybrid projects, both the nourishment volumes and the expected durability of the beach should be determined during the design studies.
Guideline H3	Allowance should be made for seasonal variations in beach width.
Guideline H4	For beach nourishment, sand with grain sizes less than the natural beach will slump and the sediment will be more easily washed away, and so studies shall accurately determine the life-cycle of the nourishment for analysis.
Guideline H5	Plastics / rubbish must be separated from the sands as they are not suitable due to environmental impacts.
Guideline H6	Scientifically -designed beach re-profiling for sand (by moving sediment from the surf zone to the upper beach) may be used to efficiently stabilize beaches and prevent slumping.
Guideline H7	Offshore sand sources deeper than 10 m depth could provide sufficient beach nourishment to protect against climate change.
Guideline H8	A critical design consideration is the net longshore transport, and solutions should be different on 'Happy' (low net longshore sediment flux) versus 'Hungry' (high net longshore sediment flux) beaches. In the latter case, proposed structures shall be designed to neutralize the net longshore transport and conserve sediment within the full sediment cell.
Guideline H9	Structures should be designed so that crest heights can be increased as SLR occurs following the standard design criteria given in coastal protection manuals.
Guideline H10	Offshore reefs and islands allow natural movement of sand along the beach, including the underwater part of the nearshore.
Guideline H11	The most appropriate minimum crest height for offshore reefs is high tide level to ensure that the structure provides protection now and will remain viable with SLR. Low-crested groynes would normally have the crest around 1 m above high tide. However, all designs must consider the local sea level elevations due to wind, waves, river flow and other physical factors.
Guideline H12	Reefs should be typically designed with the offshore distance from low tide being approximately equal to the alongshore length of the reef.
Guideline H13	On coasts with strong net sediment transport, if groynes are recommended they must be placed in a field along the full sediment cell to prevent end effects and downstream erosion and must be accompanied by nourishment. They may be designed with a large length and spacing which breaks the cell into sub-cells that are filled with nourishment. Isolated shorter groynes must allow for natural bypassing, but be sufficiently long to cope with the seasonal beach width variations due to cross-shore transport.
Guideline H14	As groynes provide limited benefit on beaches with neutral net sediment, offshore reefs are preferred in such cases if localized widening of the beach is required in front of critical infrastructure.
Guideline H15	Along with containing land erosion using seawalls, underwater erosion in front of seawalls must be considered as a sand deficit due to the downstream effects and this can result in the larger waves in a climate change scenario reaching the wall, unless fronted by an all-weather beach.
Guideline H16	On open coasts, navigational entrances (e.g. for ports, harbors or inlet entrance breakwaters) should be designed using modern bypassing shapes. These are curved with the two breakwaters overlapping and oriented with the entrance towards the direction of net longshore transport.
Guideline H17	Ports should be designed to provide additional public amenity and social benefits, notwithstanding operational areas. Any harbor engineering scheme must have a strong and multidisciplinary design team.
Guideline H18	Coastal development should be avoided in low-lying areas due to risk of flooding and inundation and retreat should have top priority in development planning.
Guideline H19	A national program for collection of coastal and nearshore data including coastal and nearshore bathymetry and sediment dynamics on a long-term basis has to be taken up for design and implementation of coastal protection measures.
Guideline H20	A national program for technological updating and skill development in implementation techniques for softer solutions within the country may be initiated.
Guideline H21	Each coastal State shall establish a coastal engineering wing with only people specialized in this topic being posted there for well-qualified review and guidance of coastal protection projects.

I. ISLAND GUIDELINES Purpose: To provide additional Guidelines which are specific to the islands (all the above Guidelines are applicable to the islands as well).	
Guideline I1	Existing sand on the island beaches must be preserved as it's a very scarce resource in the islands.
Guideline I2	Coral reef preservation / enhancement should be adopted on the islands.
Guideline I3	Sand for nourishment can be extracted from the lagoon or reef passes in depths greater than 5 m.
Guideline I4	In Andaman and Nicobar Islands, land emergence / subsidence due to frequent tectonic activity must be considered while designing coastal protection measures

CHAPTER 4

EXPLAINING THE GUIDELINES

Introduction

Case studies and explanations are provided here to fully understand the Guidelines, their purpose and their origin. More background information can be found in the appendices.

A. ADMINISTRATIVE GUIDELINES

> ***Guideline A1**. Develop a structure for compulsory cooperation and consultation between departments, ministries and agencies which have control over specific aspects of the coast prior to initiation of the project.*

Currently in India, coastal projects in the same sediment cell can be designed and implemented by independent agencies. Central committees have been established (e.g. National Coastal Zone Management Authority and Committees for EIA / CRZ clearance) which aim for compulsory recognition of multiple projects from different departments. However, for more efficient approval and monitoring, better communication is needed across agencies, with more balanced assignment of responsibilities and cost allocations.

Case study: Mirya Bay, Ratnagiri, Maharashtra

Erosion at north Mirya Bay was treated by constructing a very high seawall. However, fishermen complained about the loss of access to the sea and boat landing sites. Detailed studies (FCG ANZDEC and ASR Ltd, 2009) later found that the extended port in the south of the Bay had caused the erosion by trapping large volumes of beach sand in the lee of the breakwaters. The sand was being stock-piled and used for reclamation and berth construction. While the port is using the sand at the south end of the Bay, the beach Agency has now constructed a reef with sand nourishment at the north end. Thus, one government department is creating the problem while another is paying for the mitigation.

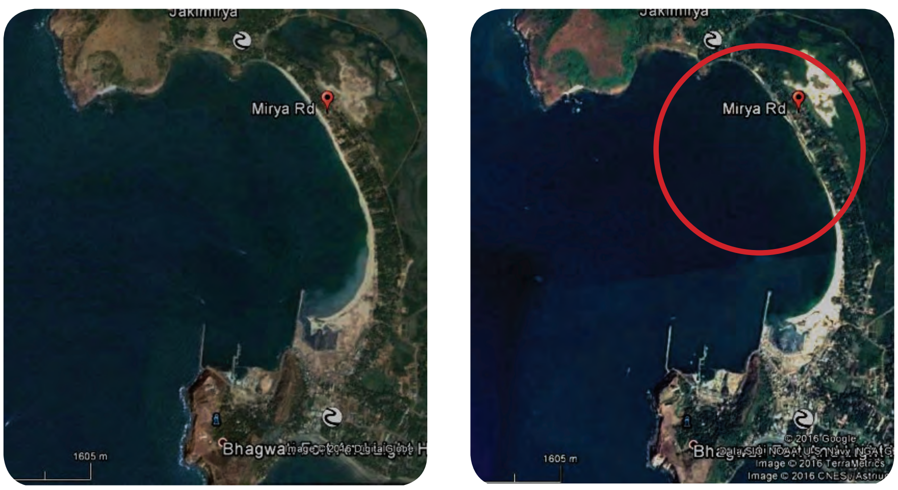


Figure 6. Mirya Beach in 2005 (left) and 2015 (right) showing the large volume of sand trapped by the port.

Source: Google Earth

Guideline A2. *Government administrators controlling projects will have to be multidisciplinary including experts from these categories: a physical coastal scientist, coastal engineer, coastal ecologist and socio-economist.*

An overview of the physical system and broader inputs are needed to assess the full cost of projects. The physical coastal scientist would be concerned about the system and how the structures might impact on the physical environment, while the coastal engineer may be heavily engaged in construction design. Other disciplines like coastal ecology and socio-economics give more balance and breadth to the decision making.

Guideline A3. *Standard contractual agreements to define roles and liabilities are needed for all projects.*

A designer is required to find the "best possible" solution within the budget. In some instances, the designer may identify negative impacts but the implementing agency may still go forward. In other cases, poor design studies by consultants may lead to unforeseen problems. Furthermore, the design approval process is multi-layered; the design is passed from the original designer to a reviewer or Expert Committee who may alter the design, sometimes without the requirement for right of reply or approval from the original designer. The same occurs when a design is completed and passed onto the contractor. Ultimately, the roles and liabilities become blurred unless they are clearly defined in contracts.

Contractual arrangements vary case by case in India. While there are many forms available, the methodology of the International Federation of Consulting Engineers (FIDIC) (www.fidic.org) has become widely accepted. FIDIC prescribes standard forms of contracts for works and for clients, consultants, sub-consultants, joint ventures, and representatives, together with related materials such as standard pre-qualification forms to formalize procedures, responsibilities, and liabilities. Complying with FIDIC norms will mitigate these problems to a large extent.

Guideline A4*. National and State funding for coastal protection should be in three stages: (i) budget for design studies and EIA preparation, (ii) budget for project implementation after project approval and (iii) performance monitoring and corrective measures, if any, required.*

Currently, national and state funding is tied to specific projects and the solutions for coastal protection and are determined prior to the funding application so that budgets can be estimated. However, this pre-empts the full process needed to make sound decisions. The direct tying of funding to specific pre-empted solutions needs to be changed to allow adjustments, better outcomes etc. to occur as the project evolves and the EIA is developed. This will be achieved if projects are funded in two or three stages.

Guideline A5. *Develop a central web-based repository with linkage to the States and Territories for designs and plans to be made accessible to the public.*

In the past, projects have been essentially a department driven process with restricted public transparency, even though the Right to Information Act allows access to documents. Nowadays, freely-available Google Earth satellite imageries allow people to show the effects of projects, but this is after the project has been built. Consulting reports and other documents may be difficult to procure. Moreover, the project may have identified negative impacts without the public having access to this information. In addition, the design studies may not have used the essential and relevant data for the design.

Though the public hearing is mandatory for certain categories of projects under the EIA Notification, the process needs strengthening. The concept of "informed choice" needs to be put in place, making it compulsory to put selected consulting documents to a central website. If copyright issues arise, then the minimum requirement may be proposed plans and an executive summary focusing on the studies undertaken, anticipated benefits and impacts of the works and the cost-benefit analysis.

Notably, the design of coastal structures is complex and requires years of training and so a balance must be struck between community engagement and the need for professionals to be responsible for the design of coastal structures. This guideline also provides good quality assurance control over the scope and magnitude of the studies.

Guideline A6. *Necessary capacity building measures be ensured by the center, states, and territories.*

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 being 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 sustained.

B. ECONOMIC GUIDELINES

Guideline B1. *Account for both the costs and benefits of coastal management strategies.*

Accounting for both costs and benefits (project, social, and environmental) leads to a more balanced decision and the most beneficial use of the shared resources of the coastal zone. Costs may include construction, maintenance and implementation delays. Benefits may be accrued to offset costs, e.g. environment, beach restoration, infrastructure, livelihood security, public amenity etc. An example cost-benefit calculation is given in Appendix 15.

The environmental costs may be substantial. Losses of beach amenity, fishing access, tourism, degradation of the coastal ecosystem and public distaste for poor coastal protection measures all play a role in project value. Even simple factors like public health are influenced when residents are unable to take a stroll on the beach in the morning and evening, when public space in settlement areas is diminishing.

Guideline B2. *Adopt "full life-cycle" cost analysis for projects*

The full life-cycle method incorporates the costs and benefits over the life of the project, not just the construction cost. It may include climate resilience, maintenance, environmental flows, downstream impacts and other costs (social to be included) that may arise due to the protection measure over its full life-cycle.

For example, a rock seawall may be built because it is considered to be the cheapest form of coastal protection. However, the long-term costs may be substantial with maintenance of the wall, need for bigger rocks in the future as the beach disappears, and need for repairs to the beaches through nourishment. Currently, seawalls are popular for their low initial cost but they may be more expensive than other forms of coastal protection over the full life-cycle if the economic, environmental, climate change related, and social costs were included with the maintenance.

Case study: Pondicherry City Beach

After construction of a port to the south Pondicherry beach began to erode. Rock seawalls were constructed, slowly lengthened and made higher as the erosion persisted and migrated along the shore. While the wall stopped the erosion of the land, the sub-tidal underwater sand bars in front of the wall continued to erode which led to downstream impacts and the need for substantial nourishment to recover the beach. Groynes were added but provided no improvement to the City beach. Domestic and international tourism dropped. More recently, a detailed study (Black and Mathew, 2015; Black et al., 2016) identified offshore structures with nourishment as the solution.

Thus, the full life-cycle costs of the rock seawall have been substantial. The wall was placed as an emergency measure (without studies) and now further expenditure is required to recover the beach. The “full life-cycle” costs are therefore multiplied and much more than the cost of the initial structures. Given the wide experience in India with rock seawalls, the loss of the beach in front of the wall could have been predicted.

Figure 7. Pondicherry Beach before erosion (top left) and the current rock seawall and ineffective groynes along the shoreline with the degraded seawall

Source: PondyCAN and Mathew (2017)

Case study: Muthalapozhi harbor in Perumathura of Thiruvananthapuram District, Kerala

Muthalapozhi harbor lies north of Thiruvananthapuram on the west coast of India, near the center of a long (40 km) sandy beach with nearly uniform orientation. The sequence of change after construction is shown below. In 2003, the first river breakwater was built. Sediment transport from the south immediately built up against the wall blocking the river outlet. In 2011, the structure was repaired and supplemented by lengthening and then adding a long breakwater and a barrier to waves at the entrance. As before, sand built up quickly on the south beach and immediately started to overflow around the new wall into the harbor entrance, blocking the channels.

By January 2013, the entrance was blocked, although maintenance dredging was on-going. By December 2013, the harbor had been re-designed for the third time. The southern breakwater was lengthened to 450 m from the base of the beach. The sand arriving as longshore drift from the south rapidly created a wider fillet which extended nearly to the end of the wall. In November 2015, sand is once again passing around the tip of the greatly lengthened breakwater to infill the channels. The failed inner breakwater at right angles to the channel had been removed by this time.

Erosion was underway on the north side by 2011, and a seawall was constructed. The beach in front of the rock seawall has been totally lost. Beyond the rock seawall, the beaches to the north became degraded and very narrow. If the same practices are continued, the rock seawall will need to be extended, spreading the full life cycle financial and environmental costs further to the north. The sand available in the south should have been utilized for bypassing to the downstream beaches instead of using it for other purposes. A cost-benefit analysis would have identified that. This case study justifies and explains several aspects of the Guidelines: (i) the need to build by-passing shapes for ports; (ii) the need to bypass all sand coming to the port; (iii) beach sand should have been put back to the beaches; (iv) the need for coordination between beach, port and other departments; (v) the importance of detailed scientific studies, and; (vi) the need for coast-benefit analysis, life-cycle costing, and comprehensive EIA.

Figure 8. Muthalapozhi Harbor (Jan 2012, Mar 2003, Mar 2011)

Source: Google Earth

Figure 9. Perumathura (Muthalapozhi) Harbor in South Kerala (Jan 2013, Dec 2013, July 2014, Nov 2015)

Source: Google Earth

Figure 10. The beach north of Perumathura. Left Panel: the beach is lost in front of the seawall. Middle and Right panels: Beach further north in 2003 and 2015 respectively

Source: Google Earth

Guideline B3. *Achieve a minimum benefit-cost ratio of 1:1 over the full life-cycle of a project.*

The Guidelines have set a low benefit-cost target of >1:1, i.e. the financial value of benefits should be greater than the costs of the project over its lifetime. An example spreadsheet is given in Appendix 15.

C. LAND USE GUIDELINES

Guideline C1. New construction in the CRZ should only be above the MFL which allows for tides, storm surge, wave effects, and climate change on sea levels.

The CRZ regulates construction over horizontal zones at the coast up to the "hazard line". The hazard line has to be demarcated by the MoEF&CC (through the Survey of India), taking into account the tides, waves, SLR, and shoreline change. However, it has not yet been put into practice. With impending SLR, the vertical dimension needs to be more formally incorporated into the regulations, and the MFL is recommended for that purpose.

> **Definition:** MFL is the highest vertical level that may occur due to floods, waves and sea SLR. MFL is defined relative to the present day MSL or CD at the site.

MFL can be calculated knowing the MSL, river flood levels, storm surge, wave climate, wave set-up, swash levels, beach gradients, sand grain sizes and factors like continental shelf waves, coastal-trapped waves and local barometric pressure effects. The methodology is presented in Appendix 17. MFL varies around the Indian coast and the values for the States from Appendix 17 are shown in the Table below.

To more easily achieve MFL while allowing buildings to be constructed in low-lying areas, structures on piles have been adopted in many parts of the world including the United States and Australia. The lower level of the building forms a temporary room or provides storage, but walls must be constructed from fragile materials that will allow the floods and wave action to pass unhindered below the main building. Insurance or government compensation for damage cannot be obtained however. To incorporate this in the current regulatory process, certain amendments are suggested in the CRZ (Appendix 3).

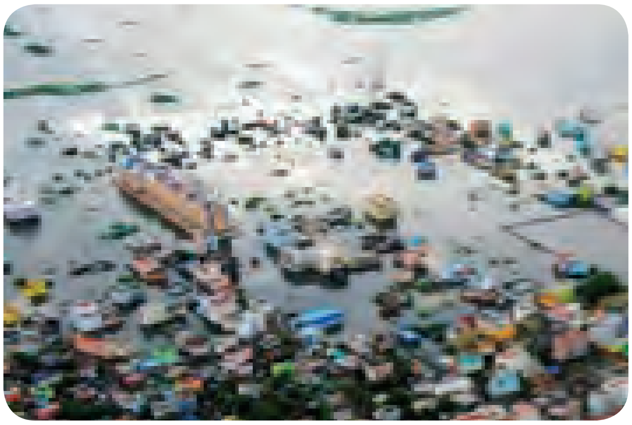
Table 4. Example calculation of MFL (m) above MSL for specific locations of different states of India

	Gujarat	Maha rashtra	Karnataka	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)	8.4	7.9	6.7	5.2	4.2	4.6	5.7	5.7
Calculating MFL								
Tide (m)	4.2	2.6	1.1	0.7	0.6	1.3	1.6	1.8
Storm Surge (m) (2050)	6.1	1.7	1.0	0.8	4.3	5.2	8.7	8.2
Seasonal Sea Level Variation (m)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
SLR (m) (2050)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Set-up (m)	1.7	1.6	1.4	1.1	0.9	1.0	1.2	1.2
Run-up (m)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MFL(m above MFL for 2050)	**13.2**	**7.1**	**4.7**	**3.8**	**7.0**	**8.7**	**12.7**	**12.4**

Figure 11. Existing seawalls in the Visakhapatnam District are already much higher than 3 m above high tide and they are still being overtopped during cyclones. The MFL is well above MSL.

Source: Narendra (2013)

Figure 12. Flooding in Chennai, Tamil Nadu



Source: Reuters (2015) (left) and DNA Research (2015) (right)

Figure 13. Mumbai in severe weather

Source: Noronha (2014)

Guideline C2. *All the provisions contained in CRZ be strictly enforced.*

The CRZ is a strong and highly respected governmental control mechanism with provisions that greatly help to protect the coastal environment. The current Guidelines do not supersede the CRZ or recommend any reduction in its applicability. As noted earlier, the main weaknesses of the CRZ relates to three key factors: (i) inadequate enforcement; (ii) numerous exemptions, and; (iii) non-consideration of the SLR and storminess under climate change.

D. MINING AND DREDGING GUIDELINES (EXTRACTIVE INDUSTRIES)

Guideline D1. *Sand taken from within the CRZ may be used for beach nourishment only.*

Stopping the removal of sand from the CRZ needs to be strictly enforced. This includes opportunistic accumulation in the lee of structures which is ultimately reclaimed or used for reclamation in ports. While many communities and regulators are aware of the need to maintain the sand on the beaches, the price of sand and the pressure to find sand for building construction has increased. However, as the beach is the main natural protector of the coast, the overall cost of coastal protection will be extremely high if the beaches are lost. The works along the coast with maintenance are already costing more than the price of the sand and these works will become more expensive when they need to be stronger and bigger to defend against SLR and stronger storms in the future. The costs for putting rocks or other structures along the foreshore are exponential. This means as the beaches erode and larger waves attack the seawalls, the rock size must increase. But the cost of large rocks is rapidly increasing while the sources are becoming scarcer with the closure of quarries and restrictions on rock transport. The present Guidelines embody the principle that the “beach is the best form of coastal protection”.

Guideline D2. *Sediments taken from the CRZ with greater than 70% mud (sediment size <0.063mm) content can be used for port reclamation and other activities allowed under the CRZ.*

Separation of muds from sand is not economically viable when the mud content is too large. Hence, such sediments only are recommended for reclamation purposes permitted in the CRZ.

Guideline D3. Sediments taken from the CRZ with less than 70% mud content shall be deposited on downstream beaches in depths no greater than 5 m.

In India, sand for nourishment is scarce and many sites (particularly in the northern Indian coasts) are muddy. Globally, the regulations about dredging relate to turbidity levels which cannot be exceeded. For example, muds can easily kill corals and may smother some beach species. However, in India the rivers are delivering large volumes of mud with altered upstream land use. This leads to colonization by mangroves and eventual reclamation of coastal land combined with high turbidity along the coast.

The 70% value is high and such sediments would not be considered suitable for beach nourishment in many countries. In India, a site-by-site assessment is recommended to decide if the mud need to be mechanically separated from the sands (e.g. using a centrifuge dredging system) or whether the sediments may be dropped nearshore to allow natural wave processes to sort the mud from the sand. If mud content is small (e.g. less than 20%) then the material may be placed directly on the beach.

A benefit of shallow water disposal is that the waves act to separate unwanted fine material from the beach sand in the spoil. Most beaches receive waves of sufficient size to bring sand shoreward from the five-meter depth. The waves and tides will do the sorting over time and the mud will be dispersed. This depth is also convenient for dredge and disposal operators as it is normally well beyond the surf zone. If the wave climate is very weak at the site, the five-meter depth may need to be reduced.

Guideline D4. *Sand temporarily stored on land for convenience should be returned to the beaches before the next monsoon.*

Dredging of navigation channels sometimes requires temporary storage. However, the requirement to return this sand to the littoral system needs to be enforced before the next monsoon. Longer storage times may be too late as erosion could occur during the first monsoon.

Guideline D5. *Offshore sand extracted from beyond 10 m depth shall be considered as a main source for beach nourishment (the extraction must be based on scientific study and EIA).*

Sand is in high demand in the construction industry and may not be available for beach and dune nourishment. Offshore reserves beyond 10 m depth need to be considered as a potential source, based on scientific study and EIA.

E. ENVIRONMENTAL IMPACT ASSESSMENT GUIDELINES

Guideline E1. *EIA shall satisfactorily address the Guidelines specifically.*

In the following chapters, methods to adopt the Guidelines are explained with examples. Although focused on future impacts, the Guidelines are relevant to current-day projects.

Guideline E2. *EIA Guidelines shall be applicable to government departments and private agencies uniformly, without any bias or preference for one over the other.*

Many case studies indicate that projects have inadvertently caused damage to beaches in multiple ways. Coastal protection is a permitted activity under the CRZ. However, EIA study exemptions are provided to the government projects, as against private projects. Therefore, this guideline aims to bring government projects as well as private projects on a uniform platform, without any preference or bias for one over the other.

Guideline E3. *EIA shall be site specific and based on a clear understanding of the coastal ecosystems and the physical coastal processes, including longshore transport rates, and the sediment cell concept, using best practice data and computer modeling.*

Every site has different elements. It may be on the east or west coast or islands, or in the far north where tides are larger, waves are smaller and the seabed is muddier. Some sites have variations like the presence of headlands versus a long straight beach. It is not possible to transfer all coastal protection solutions from one site to the next. For example, a groyne field or offshore reef may be successful in one location but the same solution may be unsuitable at a site with different longshore transport, wave heights, net sediment flux or wind climate regime.

Each study needs to reconcile the site-specific conditions for the entire length of the local 'sediment cell' even though experience from other sites might remain relevant. One of the key factors is the longshore transport rate. In locations where the net flux is close to zero, an offshore solution or beach nourishment is likely to be the best solution. In locations with strong longshore transport in one direction, a field of groynes along the full sediment cell might be successful. It is imperative that every site be defined by the longshore transport fluxes which can be calculated using computer models or empirical equations.

The wave data provided in the India - WRIS' CCIS can give a qualitative picture for the site. For quantitative estimates, long-term time series of waves are now available for most of the world's coasts, including India. These come from the combination of satellite observations, wave buoys and computer models which can accurately hindcast wave conditions over decades.

Computer modelling of coasts has reached a very sophisticated level. These models allow forecasts of outcomes to be determined prior to construction. However, if they are casually used without calibration data then they may not be reproducing the conditions at the local site.

Some models have become readily available off the shelf, but the background and training of the modeler is not uniform. The modeler and the field data collection and analysis will need peer review to prevent cursory model studies being undertaken.

Guideline E4. *A multidisciplinary team of experts shall prepare the EIA, including, but not limited to, a physical coastal scientist, coastal engineer, coastal ecologist and socio-economist.*

This inclusion of different relevant specialties in the team of experts preparing the EIA is required to cover all the aspects mentioned in the explanation of the Guidelines E3 and E5.

Guideline E5. *EIA shall be considered by a technical committee consisting of at least one expert recognized by the center or state from each of these categories, but not limited to: a physical coastal scientist, coastal engineer, coastal ecologist, and socio-economist.*

Both Guidelines aim to broaden the level of expertise brought into coastal erosion management decision making. The training provided to professionals will vary with the discipline. For example, the engineer will take a strong interest in the structural aspects, while the scientist will be more determined to find the underlying causes of erosion and to match the solution with the environment. Climate change needs to be specifically addressed. This might include optimum beach levels, structure heights, construction materials, rock sizes or likely erosion impacts under a changed climate or bed levels.

The ecologist will deal with marine ecosystems and could proactively enhance the marine ecosystem. For example, well placed rocks create habitat. Sheltered zones behind reefs can provide a more stable substrate for some species. Beach nourishment can be beneficially used to enhance shoreline species of plants and animals. Such potential benefits are currently not being utilized. As another example, mangroves are suitable for low energy coasts and the banks of the inland tidal water bodies. They assist marine organisms and entrap sediments which can provide storm surge and SLR benefits over long periods. However, the same mud can eventually lead to the loss of the water body due to infilling and eventual reclamation. Great care needs to be taken with the management of mangroves and all other aspects of the coast, which requires a multidisciplinary approach.

Traditionally, coastal protection has remained with engineers, many of whom have been transferred from sectors like irrigation / public work / dams / road / harbors. Coastal engineering is a specialized subject within the larger domain of civil engineering. The coastal dynamics and its unique challenges need to be managed by skilled and trained coastal engineers and scientists. Many universities and specialized institutes do recognize this and offer specialized coastal engineering courses, thereby addressing the skill gap.

F. COASTAL PROTECTION GUIDELINES

Guideline F1. *The procedure defined by the **Environmental Softness Ladder** shall be followed. Softer projects lower on the ladder are climate resilient and will find it easier to gain approvals. All rungs on the ladder represent a stage, and all options lower on the ladder must be fully considered and eliminated before proceeding to higher (harder) rungs.*

Unless the beaches are restored, the only alternative for India will be to build barricades against the sea around the country. For millions of years, the beaches and dunes have been protecting our coasts, with waves breaking offshore, rather than on the seawalls or other barricades ("the beach is the best form of coastal protection"). Once other hard structures are placed along the shore, the dune and beach are nearly always lost. In these cases, restoration of the dune is very difficult to achieve and can only be done with large-scale beach nourishment programs. In the United States of America in the 1990s, virtually all important coastal projects were changed to nourishment only.

Environmental Softness Ladder (ESL) is designed to encourage the use of sand-based solutions on the remaining beaches without seawalls. The beaches with seawalls will need a larger program, as the many dunes have been buried or mined out already. The beaches with groynes may be able to sustain a dune system if the groyne compartments have adequate sand within them. The beach will widen if offshore reefs / breakwaters are used in conjunction with nourishment, and a dune re-establishment program should be initiated in those cases. Ultimately, sand reserves on the beaches prepare them for climate change. Well-nourished beaches are not expected to erode under climate change if the sediment supply is maintained either artificially or naturally.

Each solution is ranked on the ladder according to its likely environmental impact. The higher you go up the ladder, the harder it gets! Softer projects lower on the ladder will find it easier to gain approvals. All rungs on the ladder represent a stage and all options lower on the ladder must be fully considered and eliminated with proper justification before proceeding to higher (harder) rungs. If an option lower on the ladder is considered unsuitable then arguments with proper studies to support that decision will need to be presented. The goal is to encourage the use of softer solutions, while retaining the rights of the designer to appeal for a harder solution in certain exceptional cases. The utilization of the ESL including issues of hybrid or composite schemes is elucidated in the next chapter.

Case studies in this document indicate that hard structures can be locally successful but downstream effects are often severe and costly. Seawalls are hardest, being unsuitable for changed climate conditions when water levels and waves are larger during cyclones. Groynes have a lower impact than seawalls, but low-crested groynes are ranked softer than the traditional groynes with a high crest. The latter acts to block longshore transport and can have a stronger environmental impact downstream than the low-crested groynes which fill to a level and then allow the residual sediment to pass over the top unhindered.

Offshore solutions are in the middle of the ladder. These allow the beach to grow seawards as a "salient" in their lee. They act on the waves which cause erosion, rather than trying to deal with the effects at the shoreline. They also allow free passage of sediment along the shore, unlike a groyne. At the soft base of the ladder, are the soft sand-based methods.

Several research projects are needed to fully understand the Indian coastal systems, but there is sufficient knowledge to make this ranking. An environmental audit of seawalls, groynes and offshore structures can be found in Appendices 8, 9 and 10. Detailed information to adopt the ESL is presented in the next chapter.

Guideline F2. *Coastal protection measures should have the least possible visual, social and environmental impact.*

In the past, no consideration had been given to visual impacts, human use of the beach or landscape, instead of just land protection. This has led to the "industrialization" of India's coasts with numerous seawalls and groynes. Several attractive beaches were lost which decimated the coastal tourism potential, a high priority economic activity of the coastal states and islands. The fishermen lost their natural fish landing and net drying environment and so they ultimately clamored for more fishing harbors and artificial fish landing centers, leading again to loss of more beaches downstream of the port's entrance training walls.

Natural landscape protection is a legacy for future generations. An example is Navabag beach, Vengurla, Maharashtra where seawall, vegetation and wide beach facilitates fishing operations, recreation and tourism. The seawall at Navabag is known as "last line of defense". It was built a long way inland and will only play a role if a succession of very large and unusual storms erodes the beach. Under such conditions, the wall does not interfere with natural processes. Walls placed further seaward have been shown to cause loss of the beach.

Figure 14. Seawall, vegetation and wide beach at Navabag, Maharashtra facilitating fishing operations, recreation and tourism

Source: ADB TA-8652 IND: Climate Resilient Coastal Protection and Management Project

Guideline F3. *Climate resilient coastal protection measures must ensure survival of the beach during all seasons and should not inhibit public access to the beach.*

Any structure that causes the beach to be lost is not providing coastal protection. To ensure that the beaches can resist climate change, projects need to ensure that the beach remains intact after the structure is built. Seawalls are unlikely to meet this requirement unless an all-season beach is maintained.

Guideline F4. *Structures should not be used for natural capture of sand on eroding coasts.*

Beach structures which capture sand deplete the total sand budget of the 'sediment cell'. In some cases, with large net sediment transport, the amount captured by the structure may be small by comparison and nourishment may not be required. The project proponent will need to provide sufficient evidence to allow the project to proceed without nourishment.

__Guideline F5.__ Beach nourishment should be used to bring the beach system to equilibrium, rather than relying on the capture of natural sand around new structures.

Many structures in the past have been designed to trap sand but the downstream effects have been severe. Nourishment is needed to prevent impacts in these cases.

Figure 15. A successful case of offshore breakwaters combined with beach nourishment and beach planting

Source: http://www.dcr.virginia.gov/soil-and-water/document/shoreline-management-in-chesapeake-bay.pdf

__Guideline F6.__ Nourishment volumes should consider the full sediment cell, cross-shore beach slumping and net longshore transport rates.

Nourishment will spread naturally throughout the “sediment cell” due to the action of waves and tides. The rate of movement is determined by many factors, especially the longshore transport rates. On eroded coasts, sand may also travel offshore to refill the eroded underwater profile, causing the beach to slump. While this sand is not lost from the system, many projects appear to fail because the nourishment volumes were too small in relation to the sediment cell size. A quality scientific analysis is needed to ensure that these factors are fully considered and an optimum sustained profile is achieved.

__Guideline F7.__ Coastal protection measures causing negative impacts on adjacent beaches must be mitigated using beach nourishment or sand bypassing.

Projects creating impacts need to mitigate them. There are many examples where proponents have captured sand for their beaches, leaving their neighbors within the ‘sediment cell’ exposed. Other examples are ports, harbors and inlet breakwaters who rarely care about the neighboring beaches.

__Guideline F8.__ Coastal structures across the beach (e.g. ports, inlet breakwaters, groynes) should not be constructed on exposed, long beaches (>8 km long), unless sand bypassing is occurring either naturally or mechanically or accompanied by nourishment.

Long straight beaches are a unique environment in themselves. The whole beach is one single cell and any disruption along this beach can have widespread impacts.

The most appropriate locations for ports are on beaches bounded by headlands, where the sediment cell is no longer than 8 km. While 8 km remains large and mitigation along such a length would be expensive, this length sets a limit whereby further studies and greater care will be required on longer beaches. If sand builds up on one side of the port and erosion occurs downstream, then sand bypassing will alleviate the problem. While ports could be located in eroding areas to protect the eroding shoreline, no sand could be used for reclamation and studies would be essential to determine the scale and magnitude of erosion along adjacent shoreline.

Figure 16. Mormugao Port, Goa located at the Mormugao Bay. Located between two headlands, this port has no measurable impact on adjacent beaches

Source: Google Earth

Guideline F9. *To prevent beach scour during floods, urban drainage should be discharged at depths below low tide.*

Urban drainage causes beach pollution and can sweep sand off the beaches during the monsoons. This sand loss disrupts the beach and numerous drains will cause erosion. The quality of the beach is also affected by such discharges. The CRZ Notification insists on discharge of treated drainage, but does not specify a depth.

Figure 17. Polluted effluent from Travancore Titanium Products Limited is discharged directly onto the beach at Veli, Thiruvananthapuram instead of further offshore (Guideline F9)

Source: Google Earth

G. MONITORING GUIDELINES

Guideline G1. *Detailed monitoring of coastal projects (physical, biological, environmental and social) will be required pre-construction, during construction and for at least three years after construction.*

Scientific information about the behavior and efficacy of the developed solution is needed so that future works can be improved and adverse impacts can be mitigated. Project performance / function monitoring consists of observations and measurements aimed at evaluating the project's performance relative to the design objectives. An essential component is a provision for gathering sufficient baseline data prior to construction, as it will provide the basis for meaningful interpretation of measurements and observations after completion of the project. Structural condition monitoring provides the information necessary to make an updated assessment of the status of the structure on a periodic basis or after extreme events. Environmental and social monitoring provide feedback for planning future projects. The monitoring scheme shall cover social impact, biological impact, beach profiling / shoreline change, longshore currents and littoral drift among other environmental parameters as given in Appendix 11.

Guideline G2. *Quarterly and Annual Reports on environmental, physical, biological and social changes based on the monitoring shall be put in the public domain through websites.*

Monitoring information must always be in the public domain as the monitoring should demonstrate the success of the project. The amount of monitoring will be evident to the public as well as the quality.

H. ADVISORY GUIDELINES

Guideline H1. *Primary sand dunes should be restored and elevated to the MFL.*

Sand dunes provide an essential storage volume utilized by nature during storms. Dunes also elevate the top of the beach to protect against SLR. Beaches will function better under climate change when the dune is healthy and erosion is not expected to occur if the full sediment cell has been repaired with a healthy dune and wider beach.

Nature cuts into the beach during storms to transport beach sand offshore onto the breakpoint bar. The shallower depth on the bar then reduces the storm wave height and thereby the beach is protected. The sand is returned to the berm of the beach during swell conditions and the system repairs itself. Wind can then blow the sand back to the upper beach and restore the dune. The wind effect is stronger along the east coast and the existing high sand dunes need to be protected and maintained in a healthy condition.

The wind effect is relatively minor along the west coast and the dunes are normally low and do not provide sufficient protection under climate change. This guideline aims to increase the dune crest height by mechanical means with nourishment.

Dunes on their own, without vegetation, are not stable. Thus, the addition of planting and fencing allows the dune plants to become established. Walking and trampling on the dune breaks the plant root and prevents the dune from properly establishing and growing.

Figure 18. Navabag, Maharashtra and Candolim, Goa dune-berm system

Source: Mathew (2017)

Figure 19. Dunes in New Zealand are being planted, protected and nurtured with public access routes

Source: Environment Bay of Plenty (top left), Mathew (2017) (top right), O'Connell (2008) (bottom left) and Texas General land Office (2005) (bottom right)

Guideline H2. *For nourishment or hybrid projects, both the nourishment volumes and the expected durability of the beach should be determined during the design studies.*

Many nourishment projects without or with protective structures (hybrid) will not have sufficient sand to fill the full sediment cell in the first project. Several projects may be needed to spread the budget over a manageable period. In the meantime, natural wave and current action will spread the sand throughout the sediment cell, both longshore and cross-shore to repair the eroded beach profile. Thus, projects need to determine the expected durability of the nourishment to plan for future re-nourishment and to determine the total volume of sand needed to repair the full sediment cell.

Definition: A “Hybrid” project uses nourishment with structure(s).

Guideline H3. *Allowance should be made for seasonal variations in beach width.*

Beaches change their width over the year, being narrower during the monsoon storm events. Thus, structure and nourishment designs need to allow for this natural movement. For example, if the beach width changes by more than the groyne length, then the groyne will provide limited benefits. Similarly, if nourishment is placed seaward of a seawall, the width of the repaired beach needs to exceed the reduction in width during storms to be effective. Baseline data collection is required to determine the annual variations in beach width.

Guideline H4. *For beach nourishment, sand with grain sizes less than the natural beach will slump and the sediment will be more easily washed away, and so studies shall accurately determine the life-cycle of the nourishment for cost-benefit analysis.*

Sand with grain sizes less than the natural beach sands are normally not suitable for nourishment of exposed beaches. First, the fine sand will be quickly washed away and may be deposited in zones with less intense wave action, such as offshore, leaving the beach unprotected. Second, the gradient of the beach is known scientifically to be proportional to the sand grain size. The fine grain beaches will have a very low gradient (e.g. northern Maharashtra or Gujarat), while the coarser beaches will be steep. Low gradient beaches are easily overtopped by waves and it is difficult to keep the required beach elevations intact, especially under elevated sea levels. If only finer sand is available, the beach nourishment may need suitably designed offshore structures to moderate the wave energy level at the beach or much more frequent re-nourishment.

Guideline H5. Plastics / rubbish must be separated from the sands as they are not suitable due to environmental impacts.

Plastics and rubbish are not suitable for beach protection.

Guideline H6. Scientifically designed beach re-profiling for sand (by moving sediment from the surf zone to the upper beach) may be used to efficiently stabilize beaches and prevent slumping.

Beach re-profiling is an effective way of dealing with coastal erosion in India. Very large volumes of sand move between the beach and breakpoint bar every year due to natural wave and current action. Thus, the zone from the berm to the breakpoint is highly energetic and the sea bed elevations are never static. However, the wind regime in India makes it difficult for nature to return this sand to the crest of the sand dune. Thus, mechanical means support the natural mechanisms that are not strong enough to do this work themselves.

Sand would normally be removed from below the low tide line with an excavator and put to the top of the beach or dune. Normally, no more than 1 m depth is removed and the beach is given time to re-stabilize before the next action. Works are normally undertaken systematically from one end of the beach to the other (over the full sediment cell) which gives time for stabilization and prevents disruption of a single region. The best time for re-profiling is during the first one to two months after the monsoon when sand is returning to the beaches from the offshore bar. This inexpensive method can be easily adopted in communities.

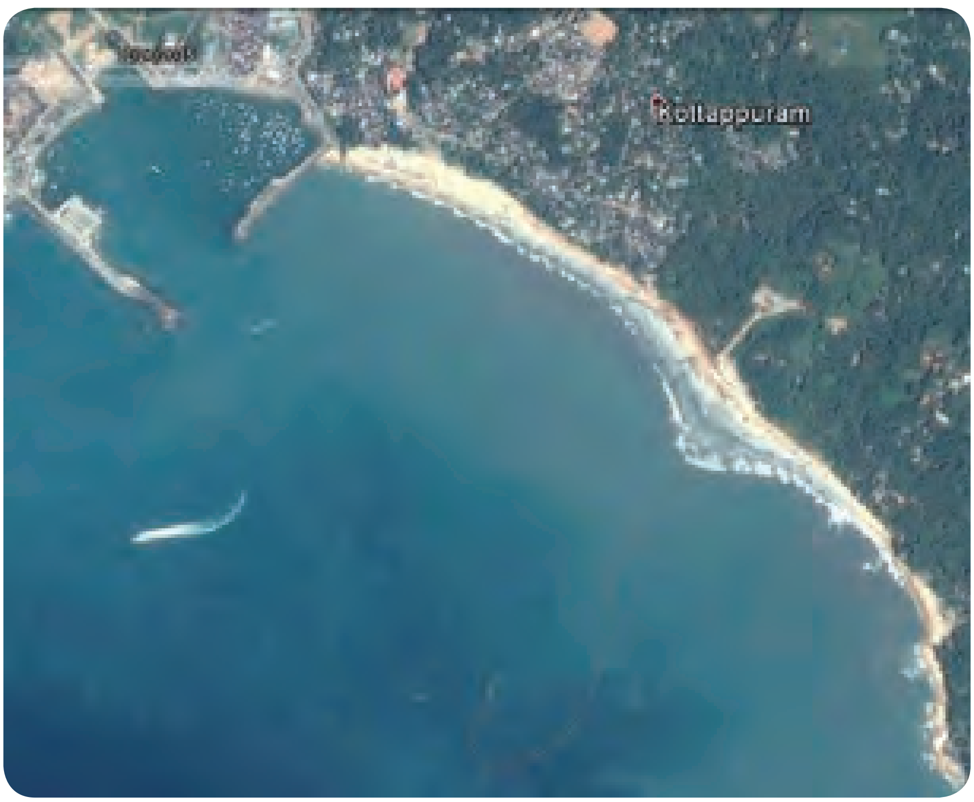
> ***Guideline H7.*** *Offshore sand sources deeper than 10 m depth could provide sufficient beach nourishment to protect against climate change.*

India is struggling to find sufficient sand for building which puts further pressure on the remaining sand resources along the coast. River deliveries have been disrupted by dams and illegal mining by villagers and larger companies. There are large reserves offshore which could be tapped, if environmental studies show limited impacts. The zone from 10-40 m depth is not strongly connected to the beaches by physical processes and so removal of sands for nourishment would overcome this natural deficiency. The mining costs may be covered by extracting the heavy minerals for sale and the residual sand could be put to the beaches.

Currently, offshore extraction is not allowed under the CRZ, except there are precedents where offshore sands are being brought shoreward for port reclamation. For Port activities, dredging navigation channels is a permitted activity and sand may be used for reclamation (see Figure 20 below).

The port works can deplete the coastal sediment cell when sand is removed from a shallow depth, and this must ultimately lead to downstream erosion of beaches. Thus, the use of this sand for beach restoration may be a better public use.

Figure 20. Sand (as seen on the beach) is being dredged from offshore and put to the beaches in preparation for the reclamation for Vizhinjam International Port at Trivandrum, Kerala



Source: Google Earth

Guideline H8. *A critical design consideration is the net longshore transport, and solutions should be different on 'Happy' (low net longshore sediment flux) versus 'Hungry' (high net longshore sediment flux) beaches. In the latter case, proposed structures shall be designed to neutralize the net longshore transport and conserve sediment within the full sediment cell.*

A "happy" beach has close to neutral net sediment transport, while on a "hungry" beach the net sand movement is from one end to the other. The latter requires a source at the downstream end to feed the Hungry beach. In India now, these sources are greatly depleted due to sand mining, river damming and changed beach conditions. Thus, hungry beaches are very difficult to manage and they require substantial quantities of sediment nourishment to keep them healthy. However, the nourishment is not expected to be lost as quickly on a happy beach. Thus, when designing structures, one goal is to minimize the net longshore transport in the full sediment cell by rotating the beach onto a more stable alignment. This may be achieved with offshore reefs / islands, long groynes or multiple structures, combined with nourishment. Notably, the hungry beach is far more susceptible to downstream impacts. Many erosion problems in India have been caused by sediment disruption on a Hungry beach with works being done over a short section of the beach only, rather than treating the full sediment cell.

Two ports, at Perumathura in south Kerala and Koilandy in north Kerala are compared and shown below. In the first case, the longshore drift has accumulated on the south side and the port has starved the beaches to the north requiring major seawall protection. However, at Koilandy, the impacts are relatively minor at the beach, even though the Koilandy port is very large. The difference is caused by the different longshore transport conditions. One has strong net transport to the north (hungry) while the other experiences relatively neutral longshore drift (happy).

Figure 21. Comparison of two ports at Perumathura (left) and Koilandy (right), Kerala

Source: Google Earth

Guideline H9. *Structures should be designed so that crest heights can be increased as SLR occurs following the standard design criteria given in coastal protection manuals.*

With rising sea level and larger waves, the crest levels of structures may need to be elevated. This may be incorporated into the design of the structure now, or suitable allowance for future increases can be made in the design. Most structures can accommodate a higher crest in future. While the crest level of seawalls also can be raised, they are less able to meet the demands of climate change due to the presence of erosion at the toe causing larger wave attack, and the required rock sizes to stabilize this erosion are becoming unavailable.

Guideline H10. *Offshore reefs and islands allow natural movement of sand along the beach (including the underwater part of the nearshore).*

Offshore reefs are a good solution for coastal erosion because the storm waves break offshore, rather than on the eroded beach. They provide sheltered coast in their lee, lower water levels at the coast by reducing surf zone set-up and sand accumulation in the form of a salient at the beach. They also allow free movement of sand along the shore and provide many potential amenity benefits like safe swimming, fish habitat and tourism potential.

Guideline H11. *The most appropriate minimum crest height for offshore reefs is high tide level to ensure that the structure provides protection now and will remain viable with SLR. Low-crested groynes would normally have the crest around 1 m above high tide. However, all designs must consider the local sea level elevations due to wind, waves, river flow and other physical factors.*

Reefs provide a very important solution, but they are best when the crest is higher. Many computer model simulations have shown that having the crest at high tide allows the reef to have low visual impact, while providing substantial protection to the coast (Black & Mathew, 2016). Lower levels are satisfactory but if the reef was to subside, lose its crest in storms or lower in any way, the efficacy of the reef can be lost. Moreover, reefs with a lower crest induce strong currents around the structure and so they need to be built further offshore in deeper water, which raises the construction cost. Thus, to allow for these factors and for climate change, the level of the crest may be best placed at the high tide level, so that the reef still forces the waves to break offshore. Crest height can be augmented in the future.

Guideline H12. *Reefs should be typically designed with the offshore distance from Low Tide being approximately equal to the alongshore length of the reef.*

Scientific studies have shown that the most cost-effective reefs will have a length which is approximately equal to the distance offshore (i.e. from the beach low tide level to the reef crest) (Black & Andrews, 2001). Other ratios still provide strong protection to the coast. If the reef is longer, then a tombolo may form at the beach, rather than a salient.

Guideline H13. *On coasts with strong net sediment transport, if groynes are recommended they must be placed in a field along the full sediment cell to prevent end effects and downstream erosion and must be accompanied by nourishment. They may be designed with a large length and spacing which breaks the cell into sub-cells that are filled with nourishment. Isolated shorter groynes must allow for natural bypassing, but be sufficiently long to cope with the seasonal beach width variations due to cross-shore transport.*

Structures which block transport at the beach will have downstream impacts, especially on Hungry beaches, e.g. a groyne field over a short section of beach. Groynes have been shown to be viable, but only if they are built in a field which occupies the full sediment cell and nourishment is placed in each compartment. A long groyne field which remains unnourished will have major impacts throughout the field due to the sediment disruption it causes.

However, on a grander scale, very long groynes or large reefs / islands can be used like a natural headland to break the sediment cell into compartments which are then acting independently with little sediment exchange. Beach re-alignment will occur in the compartments which can beneficially change the beach from Hungry to Happy. There are very long beaches in Kerala and on the east coast of India which may benefit from such a grand scheme.

Groyne fields with shorter groynes allow some sediment bypassing between the compartments, but studies have shown that the groyne length must be longer than the natural fluctuations in seasonal beach width to be effective.

> ***Guideline H14.*** *As groynes provide limited benefit on beaches with neutral net sediment, offshore reefs are preferred in such cases if localized widening of the beach is required in front of critical infrastructure.*

Groynes are designed to block transport, which has limited benefit when the net transport is close to zero. However, reefs block the waves which are causing the erosion. Thus, a reef is more appropriate for these cases.

> ***Guideline H15.*** *Along with containing land erosion using seawalls, underwater erosion in front of seawalls must be considered as a sand deficit due to the downstream effects and this can result in the larger waves in a climate change scenario reaching the wall, unless fronted by an all-weather beach.*

Studies around Pondicherry (Black & Mathew, 2016) showed severe scouring continuing underwater in front of the City seawall, even though land erosion had ceased. This allowed larger waves to reach the coast and attack the wall which collapsed in sections and had to be widened.

> ***Guideline H16.*** *On open coasts, navigational entrances (e.g. for ports, harbors or inlet entrance breakwaters) should be designed using modern bypassing shapes. These are curved with the two breakwaters overlapping and oriented with the entrance towards the direction of net longshore transport.*

Bypassing shapes have greatly reduced the downstream impacts on downstream beaches. Moreover, such ports are easier to manage because sedimentation is focused over a smaller area near the entrance. Channels can be sustained with a more cost-effective bypassing system, either using fixed land based plant or a vessel. The agency responsible should arrange and fund remedial measures, such as sand bypassing.

> ***Guideline H17.*** *Ports should be designed to provide additional public amenity and social benefits, notwithstanding operational areas. Any harbor engineering scheme must have a strong and multidisciplinary design team.*

Ports can provide a beneficial public facility. For example, jetties that are useful for the broader community, safe moorings, safe swimming beaches etc. The public may not be allowed into dangerous operational areas.

Guideline H18. *Coastal development should be avoided in low-lying areas due to risk of flooding and inundation and retreat should have top priority in development planning.*

Zoning of low-lying areas will reduce the number of problems in the future. Once people build close to the shore, either legally or not, the responsibility to protect them normally comes back to the government. It may be very difficult to deal with millions of climate change coastal refugees in the future and so planning now may reduce that problem. We acknowledge that strict implementation of the CRZ of MoEF&CC and the Coastal Hazard Vulnerability Zone Atlas of the Ministry of Earth Sciences, Government of India, are convenient tools in the site selection for development.

Guideline H19. A national program for collection of coastal and nearshore data including coastal and nearshore bathymetry and sediment dynamics on a long-term basis has to be taken up for design and implementation of coastal protection measures.

Data is the foundation of a modern society and the coast is no exception. However, in India most funding relates to project development rather than data collection and monitoring. Little can be learned and the same mistakes may be repeated, if constructed solutions are not monitored. However, the coast of India is long and varied. Studies are needed in many different locations and this will require a strategic national program.

Guideline H20. *A national program for technological updating and skill development in implementation techniques for softer solutions within the country may be initiated.*

Beach protection in India has concentrated on seawalls and groynes. To uptake the softer solutions will require more training and case studies. A scheme for training in climate resilient coastal protection and management is given in Appendix 17.

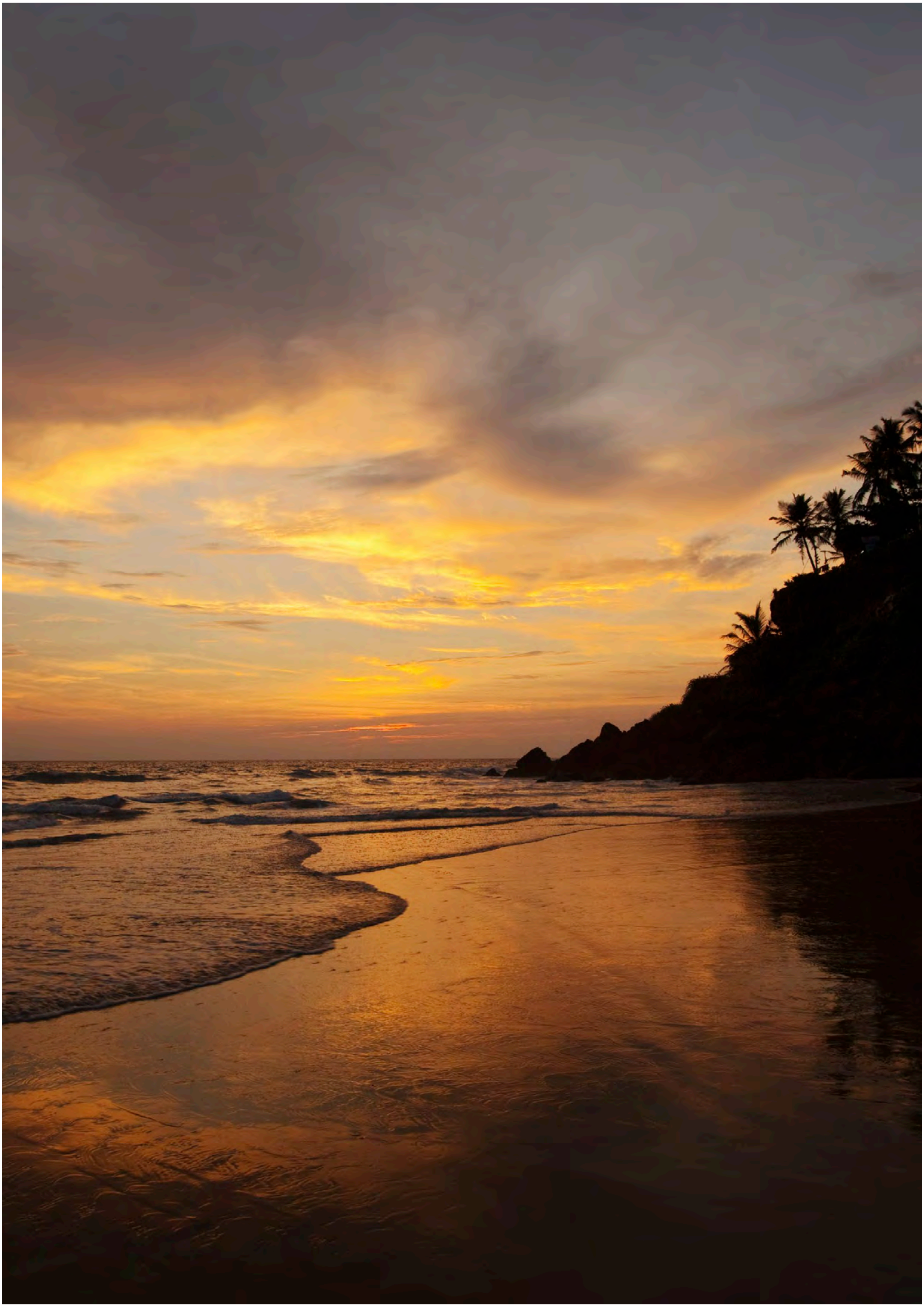
Guideline H21. *Each coastal state shall establish a coastal engineering wing with only people specialized in this topic being posted there for well-qualified review and guidance of coastal protection projects.*

India has successfully allowed engineers to take up most of the scientific research. While very practical, the engineers dealing with the coast have not had sufficient exposure to the complex coastal scientific research and the unusual environment where the land meets the sea. In addition, engineers may be moved from land based works to the coast with no introduction to coastal processes. The fault is systemic, rather than with individuals. One way to overcome this major deficiency is to develop coastal engineering wings with a focus on the coast and beaches.

I. ISLAND GUIDELINES

Guideline I1. *Existing sand on the island beaches must be preserved, as it's a very scarce resource in the islands.*

The Guidelines proposed for the mainland are generally applicable to the islands. However, the coral islands are very different to the mainland, with fringing coral reefs already protecting the coast. The reefs produce a coarse coral sand which is protecting the beaches, however coral growth is slow and the corals are threatened by global warming. If the reefs are damaged, then the beaches will start to erode. Thus, it is essential to nurture the existing sands (with no removal) in preparation for global warming and climate change.



Guideline I2. *Coral reef preservation / enhancement should be adopted on the islands.*

The offshore reefs on tropical coral islands already provide substantial protection to the beaches. It is expected that the reefs will grow naturally to catch up with the SLR. However, due to coral bleaching and manmade damages the coral growth is stunted. In such areas, the SLR will allow larger waves to reach the shore. In any circumstance, the best approach is to copy nature's systems. Thus, offshore reefs should be reinforced biologically by introducing modern biotechnology. In critical areas, the reef could be reinforced shoreward of the reef crest which allows the natural reef to break the waves while the smaller manmade reef can compensate for SLR.

Guideline I3. *Sand for nourishment can be extracted from the lagoon or reef passes in depths greater than 5 m.*

On tropical coral islands, the waves induce strong flows over the reef crest and into the lagoon. This builds up the lagoon level which then drives currents alongshore. These currents exit in the deeper water of the reef passes. These flows carry coral debris and sand with them, so that large deposits of sand are normally found in the passes beyond 5 m depths. Removal of this sand can be used for nourishment and is not expected to harm the beaches. However, investigations are needed on a site-by-site basis before desilting the passes and nourishment of the beaches.

Guideline I4. *In Andaman and Nicobar Islands, land emergence / subsidence due to frequent tectonic activity must be considered while designing coastal protection measures.*

The Andaman and Nicobar Islands are tectonically active causing the coastal areas to emerge or submerge. This is over and above the impacts of climate change and needs to be handled on a case-to-case basis. Avoiding development closer to the coast is the best option following the CRZ and Integrated Island Management Plan developed by the MoEF&CC. However, in already developed areas, in addition to the general Guidelines provided above, special designs to compensate for the tectonic activity may be required.

CHAPTER 5
UTILIZING THE GUIDELINES

HAJEERA
Al-Naseeha

Introduction

A means to administer and crosscheck projects for adherence to the Guidelines is presented. To assist this, two processes have been developed:

Environmental Softness Ladder (ESL) defining the soft / hard ranking of the adopted protection measure in relation to potential environmental effects;

Coastal Protection Assessment ("C-Guide") which allows the project, submitted documents, and the quality of the submission to be ranked.

Both demonstrate the utilization and relevance of the Guidelines for decision making and are needed to apply the Guidelines. The goal is to advance current practices, while preparing for climate change.

Environmental Softness Ladder

ESL is based around coastal audits, case studies of existing projects, scientific assessment and published research. The goal is to rank the potential environmental effects of structures, rather than recommending preferences for favored methodologies.

Examples can be found in Appendices 7-10 which discuss potential interventions in two categories: (i) sand-based solutions, and (ii) construction-based solutions.

A third option is "planned retreat" (or "do nothing"), which identifies regions as sacrificial. No relief is provided for erosion, overtopping or flooding. The "do nothing" option is adopted when the processes are natural and cyclic and no population or economic activity is affected. While "planned retreat" has potential for an unmanageable erosional site or under advanced regional planning, it remains outside the bounds of coastal protection. Such decisions are often within the domain of city planners directed by decision makers (arising when unplanned storms arrive!) and are also addressed in the CRZ Notification. Thus, "planned retreat" is not considered here.

ESL for coastal protection solutions. Hardness relates to potential environmental impacts, rather than cost of construction, method of construction, materials adopted or preferences for coastal protection methods.

Table 5. Environmental Softness Ladder

TITLE	METHODOLOGY	ENVIRONMENTAL IMPACT	RANKING
Steep Seawalls	A longshore wall is built to protect the land with front slope gradient >1:15	12	Hard
Low Gradient Seawalls	A long shore wall is built to protect the land with front slope gradient <1:15	11	Hard
Headland Groynes	Groynes / headlands longer than 300 m with high crest	10	Hard
Long, High-crested Groynes	Groynes longer than 100-300 m with crest above high tide	9	Hard
Short, High-crested Groynes	Groynes with crest above high tide, but less than 100 m long	8	Hard
Low-crested Groynes	Series of groynes with crests lower than high tide, and less than 100 m long	7	Moderate
Nearshore Reef	A reef is built close to shore or on the inter-tidal beach	6	Moderate
Offshore Islands / Breakwaters	Emerged offshore structure	5	Moderate
Offshore Reefs	Reef is built offshore, normally in 3-8 m depth	4	Moderate
Nourishment	Major sand replenishment; sand source is offshore or external	3	Soft
Dune Restoration	Sand replacement from the beach or surf zone	2	Soft
Dune Care	Replanting, fencing, walkways on dunes	1	Soft

ESL is a process to be followed by proponents, rather than a point scoring system. As in the Guidelines, softer projects lower on the ladder will find it easier to gain approvals. All rungs on the ladder represent a stage.

This means that options lower on the ladder must be fully considered and eliminated with proper justification before proceeding to a harder protection methodology which is higher. With full adoption by the coastal states, projects at the top of the ladder will need considerably more studies and investigations than those at the base. The goal is to: (i) encourage the use of the softest possible solutions, and (ii) ensure that softer options have been formally ruled out as unsuitable.

There are many shades between the two extremes of soft and hard and their combinations which make it difficult for inexperienced adjudicators to rank the various coastal protection methods. Thus, the ESL overcomes that difficulty. The ladder representation is a gentle reminder that the higher you go up the ladder, the harder it gets.

Ranking of the Methodologies

Seawalls

Seawalls are placed at the top of the ESL (i.e. the hardest option). Seawalls are unlikely to be ideal in the future for the following reasons:

- Seawalls block land erosion, but erosion continues underwater in front of the walls.
- Through greater wave turbulence at the base of the wall and because of the imposition they create by burying the primary dune and berm of the beach, most case studies show that the beach will be lost in front of the walls (Appendix 8).
- With a deeper profile offshore, larger storms and higher sea levels, the walls are attacked by larger waves.
- Eventually, the armor unit sizes required for stability of the wall become untenable. Very large rocks are needed (or highly permeable concrete units like tetrapods) to keep the wall stable (with no beach).

The common assumption is that the crest level can be easily raised to fight storms and SLR. However, our calculations in Appendix 8 demonstrate that such large units will not be transportable, or potentially not available from the rock quarries. Hence, the seawall is not ideal for future climate change, as sea level rises and storm intensity increases.

In combination with the environmental impacts, loss of amenity and loss of the beach, the seawall ranks hardest of suitable methods for preparation against climate change. Such walls may be best restricted to port area protection, subject to provisions contained in these Guidelines, or river bank stabilization, rather than being adopted on beaches for coastal protection.

Figure 22. Seawall with Gaps and Short Groynes on either side of the Gaps, Puducherry

Source: Google Earth

Seawalls with Gaps

The analysis has shown that existing seawalls could be modified to have gaps, e.g. some 300 m long every two kilometers of coast (Appendix 8). These gaps open fishing boat spaces, provide a useful beach and storage of sand within the beach. Examples of successful gaps are presented in Appendix 8. Accordingly, the seawall with gaps ranks lower on the ladder than seawalls alone.

Rocks from the existing seawalls could be used to help construct short groynes on either side of the gaps to widen the beach in the gap. The gap could have a shorter groyne on the upstream side and longer on the downstream end. Alternatively, an offshore reef could be constructed on the downstream end of the gap.

Groynes

Groynes rank better than seawalls on the softness ladder. They are designed to segment the sediment cell. In India, the variation in designed length and spacing of existing groynes has not been shown to relate to the local longshore sediment transport conditions or to the size and energy of the beach within the sediment cell (Appendix 9). Indeed, different lengths and spacing have been used in the same sediment cell, without plausible scientific explanation.

Groynes are known to create a downstream effect. Their job is to capture sand, and so the beach beyond the structures is likely to suffer. The designer must understand and clearly know the volumes of sand coming as longshore transport and what impacts the capture of sand around a structure will have on downstream beaches. There are numerous cases in India where groynes located amid a long sandy beach have had serious consequences in adjacent regions. The same has been seen with seawalls and their “end-effects” (Appendix 8).

There are many subcategories of groyne, such as fish-tailed, Y, and curved. However, all these are ranked together because they have similar environmental effects and interaction with the physical processes and beach.

Low-crested Groynes

These structures have the groyne crest around the high tide level (Appendix 9). The benefit is that once the compartment is full, sand can pass over the groyne during storms to reduce the downstream impacts. They remain in the upper half of the ladder because they cross the beach and change the natural sediment dynamics of a coast.

Offshore Reefs, Islands, and Breakwaters

Softer on the ladder are offshore breakwaters and offshore reefs (more details in Appendix 10). The former will be a large structure with the crest out of the water, like an island. The latter has the crest at or below high tide.

Analysis of Indian beaches has shown that islands and reefs conform to the theory presented initially by Black and Andrews (2001), which showed that offshore structures cause the beach to build out to seawards in the form of a salient or tombolo. The beach is thereby widened without the need for structures at the shoreline. This can overcome problems with urbanization which has developed too close to the sand dune and beach.

However, while the beach grows outwards, new construction of houses and infrastructure to seaward will need to be banned. For example, in many Indian coastal areas, houses have been built on the salient formed by an island. Local residents are claiming that the beach is eroding, even though the beach is actually several hundred meters seaward of the natural beach line due to the presence of the offshore island.

Numerous other benefits of offshore solutions were identified including marine habitat for fish and other marine species, the ability to add amenity like surfing or snorkeling and their minor visual impact. A salient of sand builds to a dynamic equilibrium size and then allows sand to pass freely along the beach. Thus, the downstream impacts are small, particularly if the salient formation is created using nourishment to overcome initial sand-trapping effects. The construction cost per meter of reefs is higher than a rock seawall, but a typical reef protects the beach up to eight times its longshore length (Black & Andrews, 2001) which reduces its cost disadvantage.

Reefs and islands thereby have a much lower environmental impact and are ranked in the center of the ESL. Under climate change, they provide a benefit / cost ratio that is substantial. One of the main features of reefs and islands is that they act on the waves, which is the cause of erosion, rather than trying to put a “bandage” on the effects at the beach.

The sand-based solutions include nourishment, back-passing and bypassing. Sand-based solutions rank best on the ladder (i.e. the softest) and are the preferred option for climate change adaptation. Ultimately, many studies have reinforced the notion that “the beach is the best form of coast protection” (Appendix 7) and that sand solutions have the lowest environmental impact. They also prepare the beaches for greater sea levels during climate change.

To promote these solutions, the sand resources need to be protected. Sale of sand from the coast has short-term benefits for the Indian construction industry, but the economic analysis (Appendix 15) notes that the long-term costs will be large. Without sand, the only vision for the future is barricades, i.e. large walls separating the sea from cities, country and fishing communities. Such an outcome would have large social, environmental and economic consequences that may be unmanageable by future governments. This is exacerbated by many anthropogenic and natural factors that reduce sand volumes arriving at the coast.

In addition, the beach system needs to be kept natural up to and beyond the dune. Appendices 8 and 9 illustrate that some coastal projects are currently doing the most harm along the Indian coast. The departments assume many exemptions under CRZ regulations; i.e. for ports, unfettered coastal works, reclamations, river training walls etc.

The CRZ allows “reconstruction and repair works of dwelling units of local communities including fishers in accordance with local town and country planning regulations” (Appendix 4). Consequently, many residents are essentially exempted from the building restrictions. This results in an unrestrained growth of dwellings on the top of the beach, and on the dune. Over and above, there are many unauthorized constructions adding to the degradation of the natural coastal system. India is blessed with thousands of kilometers of sandy beach. But the barricades are already being built with hundreds of kilometers of seawall, most of which have led to the total loss of the beaches.

Governments, engineers, planners, physical coastal scientists and the community at large need to visualize a future without beaches if the present unscientific developmental practices continue.

As noted, sand supplies are dwindling from the rivers and very little sand comes naturally from offshore, and this will not change when sea levels rise.

Full economic analyses, including the life-cycle costings suggested in the Guidelines (Appendix 15), will show that the use of precious beach sands for construction or in reclamation is not cost effective in the longer term.

IN A NUTSHELL

A beach extends from above water level at the dune crest to underwater, normally hundreds of meters offshore.

From the land to the deeper sea offshore, sand is readily exchanged by natural processes.

Key morphological features are: (i) offshore sand bar around the surf zone breakpoint; (ii) the inter-tidal beach face; (iii) nearly horizontal berm around high tide level, and; (iv) low dune crest at the landward extremity of the beach. In a storm during the monsoon, sand is taken from the beach berm and / or dune to the offshore bar which builds up to block the waves.

After the storm in the non-monsoon, wave swells bring the sand shorewards, i.e. back to the berm from offshore.

However, sand returns to the berm only. Sand can only reach the landward dune if: (i) big waves induce high water levels and the wave "swash" over-tops the dune to carry sand over the dune crest; (ii) winds blow the sand from the berm to the dune, or; (iii) mechanical means are adopted.

In India, wave overtopping is rare; coming only during the largest long-period swells which elevate water levels and induce strong wave uprush. Notably, coastal communities confuse this natural process with flooding or erosion. Only long-period swells have a positive benefit, while storm waves induce erosion rather than accretion.

In India, particularly along the west coast, winds are rarely strong enough to carry sand from the berm to the dune, noting that winds are mostly offshore during the non-monsoon when beaches are building up.

"Nourishment" brings back sand to eroding shorelines using sand from offshore or outside sources.

"Dune restoration" bridges the physical gap between the beach and dune by moving sand from around or below the low tide line to the top of the beach or dune.

"Dune care" nurtures the dune with plants, fences to prevent trampling, and access pathways. Sand may be carried manually from the beach to restore dune elevation.

Complex and Hybrid Solutions

*Coastal protection solutions can be **"complex"** at a single beach. Complex coastal protection solutions involve multiple structures and some examples are: (i) groyne field with seawall, or; (ii) offshore reef with shoreline-attached structures.*

In the Guidelines, complex solutions are treated as parts of the same project. The environmental effects and efficacy of multiple structures will need to be considered individually and as a joint system to demonstrate the environmental, economic and social benefits of more than one structure. The proponent will need to carefully describe why more than one structure is needed.

*Coastal protection solutions can also be **"hybrid"**, i.e. structures with nourishment. Examples are groynes with nourishment in the compartments or reefs with nourishment to form the anticipated salient.*

The hybrid solutions are beneficial because: (i) any initial trapping of natural sand by the structure can be eliminated and downstream effects are reduced, (ii) the erosion of the beach is overcome by the nourishment itself, rather than relying on natural capture of sands, and; (iii) the structures can act to reduce the need for re-nourishment.

Thus, in the Guidelines the hybrid solutions score well because of the nourishment. The proponent must show that the volume of nourishment is sufficient to mitigate the erosion in the absence of any structures. The value provided by the structures is then considered according to the longevity of the nourishment or other valid purpose. Any structure impacts over the project lifespan must be identified. The initial nourishment and re-nourishment program needs to be quantified, based on scientific findings. Moreover, the proponent would need to study the results with just nourishment and then with the structures in the cost-benefit analysis, incorporating the re-nourishment needs in both cases.

As already noted, the ESL is a process, not a points system. The key element is the need for proponents to discount all options lower on the ladder before proceeding to a harder solution. This will require justification through studies which demonstrate that the lower options are not feasible and, with state support, options lower on the ladder will receive approvals, both faster and with less intense studies. Thus, the use of nourishment with structures will allow proponents to move forward more quickly. The Guidelines indicate that the nourishment (and re-nourishment) plan must be sufficient to ameliorate the local and downstream impacts of the works over the life cycle of the project. If so, the project will be seen as a nourishment solution on the ladder.

The environmental impacts of sand-based solutions are low. However, the removal of sand and associated dredging is more contentious. Thus, sand-based projects may be more focused on the impacts at the sediment source than at the beach to be nourished.

C-Assessment

The ‘C-Guide’ methodology is based on ‘expert panel assessment’ which is now widely accepted in India as a way of making decisions based on a range of complexities. C-Guide contains a series of questions, which follow the same categories as the Guidelines. The forms to be filled out are in two sections:

Form-1: Basic Project Information: to be filled out by the proponent

Form-2: Adjudicator Assessment and Recommendations: Rating the quality of the submissions and studies undertaken.

Forms 1A and 1B describe the proposed Project and the ESL information. Form 1C provides space for justifying the inclusion or rejection of coastal protection solutions. The three forms will be completed by the project proponent. Forms 2A and 2B are completed by the adjudicators with their assessment, while form 2C is the final committee recommendation, which may be “reject”, “resubmit with minor revisions”, “resubmit with major revisions” or “accept”.

The cost of the project is treated as independent of the technical information (similar to tendering norms). The C-Guide forms are focused on the application of the Guidelines, not the cost. The goal is to identify compliance and the strengths and weaknesses in proposed schemes, and allows the adjudicator committee to recommend improvements. The forms are presented in the next page.

Table 6. Form 1A: Project details (to be filled out by the proponent)

Basic information		
Location name		
State		
District		
Village / Panchayat / Municipality / Corporation		
Name of the beach		
Latitude (decimal degrees)		
Longitude (decimal degrees)		
Engineer in charge		
Project proponent		
Project description		
Project synopsis		
Summary of ESL ranking including consideration of complex and hybrid solutions		
Length of sediment cell		
Sediment cell size and location		
Elevation of land protection structure relative to CD construction)		
Spring tidal range (m)		
MSL above CD (m)		
Beach / dune nourishment volume (cu m)		
Length of dune / beach to be nourished (m)		
Crest elevation of structure relative to Chart Datum (m)		
Offshore distance of structure (m)		
Area of structure (sq. m)		
Volume of structure (cu m)		
Life-cycle, benefit:cost ratio		
Coastal environment	**Monsoon**	**Non monsoon**
Length of beach (m)		
Elevation of dune crest (m) relative to CD		
Length of coast suffering from erosion (m)		
Beach width from dune to high tide line (m)		
Beach gradient (ratio)		
Median beach grain size (mm)		
Typical longshore currents (m / s with direction)		
Longshore sediment transport (m3 with direction)		
Wave height statistics (m)		
Extreme wave height (1 in 20 year)		
Wave angles to coast (degrees)		
Wave period statistics (s)		
Wave set-up during the one percentile event (m)		
Storm surge during the one percentile event (m)		
Calculations		
Calculated maximum water level above CD (m)		
Dune crest elevation above maximum water level (m)		

Table 7. Form 1B: ESL statement (to be filled out by the proponent)

Protection Method	Description	Selected (Yes/No)
Steep Seawalls	A longshore wall is built to protect the land with front slope gradient >1:15	
Low Gradient Seawalls	A long shore wall is built to protect the land with front slope gradient <1:15	
Headland Groynes	Groynes / headlands longer than 300 m with high crest	
Long, High-Ccested Groynes	Groynes longer than 100-300 m with crest above high tide	
Short, High-crested Groynes	Groynes with crest above high tide, but less than 100 m long	
Low-crested Groynes	Series of groynes with crests lower than high tide, and less than 100 m long	
Nearshore Reef	A reef is built close to shore or on the inter-tidal beach	
Offshore Islands / Breakwaters	Emerged offshore structure	
Offshore Reefs	Reef is built offshore, normally in 3-8 m depth	
Nourishment	Major sand replenishment. Sand source is lower beach, off-shore or external	
Dune Restoration	Minor sand replacement, from the beach	
Dune Care	Replanting, fencing, walkways on dunes	

Table 8. Form 1C: Justification of selected and rejected coastal protection methods

Justification of selected coastal protection methods:
Justification of selected coastal protection methods: Please fill out below
Justification for Rejection of non-selected coastal protection methods: Please fill out below

Table 9. Form 2A: Adjudicator assessment (to be filled out by individual adjudicators)

Project name and location: Adjudicator name:	Unacceptable	Acceptable
Administration		
Consultation with departments interested in the coast		
Consultation with stakeholders		
Provision for continuing consultation as the project develops		
Submission of standard contractual agreement		
Public access to designs, reports, and plans		
Land use		
CRZ map of the project site		
CRZ category of intervention site		
Elevation of existing land based structures		
Vulnerability to coastal hazards		
Assessment of future development plans in the sediment cell		
Mining and dredging (extractive)		
Source of sediment		
Nourishment site		
Sediment quality (muds, contaminants, plastics, and debris)		
EIA		
EIA		
Social impact assessment		
Clear definition of issues (cause, consequences, spatial extents)		
Field data collection and utilization in the project		
Numerical modeling		
Effectiveness for climate change adaptation		
Downstream impacts		
Monitoring and maintenance strategy		
Peer reviews		
Ecology		
Ecological impacts assessment		
Impact on mangroves, if any		
Impact on coral reef, if any		
Economics		
Life-cycle costing		
Benefit-cost ratio		
Coastal protection solution		
ESL ranking		
Plan for nourishment		
Beach length, width, and gradient		
Obstruction to littoral drift		
Security of beach in storms		
Beach access		
Plan for added or existing amenities and public activities		
Aesthetic impact		
Construction impacts		
Climate change		
Consideration and adaptation to climate change		

Table 10. Form 2B: Adjudicator summary assessment

Committee Chairperson				
Project name and location				
Project proponent				
Meeting date				
Recommendation	Accept	Resubmit after revisions	Reject	Remarks
Member 1				
Member 2				
Member 3				
Member 4				
Member 5				
Member 6				
Member 7				

Table 11. Form 2C: Committee final recommendation

Recommendation	Remarks
Accept	
Resubmit with minor improvements	
Resubmit with major improvements	
Reject	

CLIMATE CHANGE ADAPTATION GUIDELINES FOR COASTAL PROTECTION AND MANAGEMENT IN INDIA

VOLUME 1

CHAPTER 6

WHAT MUST BE DONE TO ADAPT TO CLIMATE CHANGE?

ADB TA-8652 IND:

CLIMATE RESILIENT COASTAL PROTECTION AND MANAGEMENT PROJECT

How are the Guidelines Useful?

The Guidelines provide scientifically-founded and structured methods to develop responses to coastal erosion, which are primed to deal with climate change.

Sound decisions are needed because coast protection expenditure is already large and likely to become a significant fraction of Gross Domestic Product in future in a climate change scenario.

While investment in coastal structures for the year 2100 is not likely to occur now, at least the methods adopted can be the most appropriate for both current situations and the future. While proposed solutions may not be specifically designed to deal with future conditions, they need to be amenable to adjustment in the future. Moreover, the Guidelines advise about the methods that would not be ideal under higher sea levels and larger storms.

The ESL formally ranks the potential environmental impacts of coastal protection solutions. In this way, a structured approach can be now adopted with a clear knowledge of the potential effects. In addition, the ladder distinguishes the solution from the construction materials. There have been recent cases in India when the same solution, like a seawall, has been built from softer materials, but this does not change the hardness of the solution. The softness degree of the solution is defined by the interaction of the structure with the physical environment and its environmental consequences.

The C-Guide system is a checklist which allows adjudicators to check how many elements of the Guidelines are being followed, to identify strengths and weaknesses in applications and to consider if the EIA is adequate.

Sand and Hybrids can Protect the Coast

Beach erosion in India is intrinsically connected to sand deficiency associated with social demands for building material, changes to the river supplies and gross ocean dynamics (whereby incoming sand from offshore on the continental shelf is now very limited). Building too close to the sea is a strong exacerbating factor including government projects like ports, training jetties and coastal protection measures which disrupt the natural beach and dune. In addition, Indian beaches are eroding because of large sand volumes being used in construction. It is fundamentally important to stop mining of sand from the coastal zones. Similarly, port reclamation using sand from beaches must be prohibited and enforced. A key conclusion is that “beaches are the best form of coastal protection” and the alternatives are limited. Barricading with seawalls has been found to be impractical and unsustainable under climate change.

However, hybrid solutions of nourishment with structures can help. Groynes can assist if the full sediment cell is considered and the groyne length is adequate to deal with seasonal beach width fluctuations and nourishment is applied to fill the compartments. Alternatively, offshore reefs or islands will widen the beach while also beneficially allowing natural movement of sand along the coast. Reefs / islands act to break the waves offshore, leaving a sheltered “lagoon” in their lee which is similar to the many low energy beaches on tropical islands with a fringing reef. Once again, nourishment will be needed to construct the salient which forms in the lee of the reef and bring the beach into its new stable condition.

Natural Capture of Sand is no Longer Advisable

Many structures have been built to capture natural sand from the littoral system. However, if no sand is coming, then they will fail to capture. And if they succeed to capture, then downstream beaches will be impacted.

Sand capture using a structure on an eroding beach is like asking a poor man for money.

When sand resources are limited and a beach is already eroding, natural capture of sand is not advisable. Nourishment will be needed, rather than relying on natural capture.

Engineering Considerations

The specific design of a reef, groyne field or even a seawall is beyond the domain of this document. However, it has been noted that designs will normally be site specific and that the most appropriate structure for one location may not be the same in another. Turnkey protection options prescribed here as a recipe for solving India's coastal protection needs are not possible. Indeed, the recipe would be at odds with the Guidelines which recommend full detailed investigation at each site to find the best solution. However, an attempt is made in Appendices 4, 7, 8, 9 and 10 to provide important considerations required in the design of climate resilient coastal protection measures.

There are numerous manuals available for the practicing engineer to determine rock sizes in a seawall, groyne heights and groyne spacing and the most used ones are listed in the bibliography and in Appendix 4. The basic input data of waves, currents, longshore transport and other physical factors, however, needs to be determined for the site and analyzed. And the decision about the best structure or the shape of that structure for a specific site can be complex and requires a range of numerical and / or physical models, access to basic data and a series of complex decisions that may be tempered by available budget.

Consequently, the "one design fits all" is not possible given the wide ranging tidal, wave, sediment, geomorphology and budget conditions across Indian states, within the states and union territories. More specific studies are required, potentially starting with better quality state or district shoreline management plans (Appendix 4).

Further engineering assessments are needed to develop cost-benefit data (Appendix 15). This will lead to a better understanding of the lifespan, durability and maintenance requirements / costs of structures. For example, the lifespan of geotubes has proven to be very short in India, while the cost of placement has been high in some cases. On the other hand, large rocks are becoming less readily available and sand is scarce. Most port walls, groynes and other rock structures (especially rock seawalls) require regular and costly maintenance. Engineers need to address these matters in a systematic and comprehensive way to bring an Indian context to the selection of construction methods and materials.

Coastal protection requires greater scientific investigation, data collection and numerical modelling.

Research on beaches and the assessment of performance of structures is limited in India. A sad reality is that while hundreds of kilometers of seawall have been built, there are no reported studies of their physical behavior in surf zones. Even basic measurements like seabed profiles in front of the seawalls are scarce and do not find any place in the Indian scientific literature (Appendix 5).

While offshore wave and current measurements are more numerous, the dynamics from the sand dune to the breakpoint has been ignored by the research community (Appendix 5). This is a specialist region, which requires substantially more technical equipment designed for the surf zone. Central government funding is required to upskill the researchers (with international collaborators) and to focus research on the beaches and coastal dynamics.

Understand the system before choosing the solution

Problems are being examined at a local spatial scale, without consideration of the broader domain.

Beaches (here synonymous to sediment cells) have been divided with two easily understood terminologies. The 'happy' beach has net neutral sediment transport. That is, while sand may move up or down the beach in the wet and dry seasons, the overall sand movement is close to zero when averaged over the year. On the contrary, 'hungry' beaches have a strong net sediment transport. This means that they need regular new sand inputs at the upstream end of the beach to remain stable. Many of these were built by nature thousands of years ago, when the river deltas were delivering sand to the coast. These deltas are still abundant, e.g. Cauvery, Odisha, Puduchery, etc. and the downstream beaches have orientations which are out of alignment with the wave climate which allows the new sand from the river to be distributed down the coast. Unfortunately, this also means that the 'hungry' beaches are intrinsically unstable. Any change in waves, storms or sediment supply from the rivers will lead to erosion on a grand scale. Even large nourishment programs may struggle to keep up with the sediment losses.

Thus, 'happy' beaches are fundamentally easier to deal with. To find long-term solutions which are suitable under climate change, many benefits would accrue if the 'hungry' beaches could be re-aligned to be more neutral or 'happy'.

Puri–Gopalpur (Odisha), Digha (W. Bengal), southern Tamil Nadu, Netravati – Talappady (Karnataka), south Gujarat and parts of Kerala are large zones which are affected by zonal erosion. It has been found that these beaches are 'hungry' and so small changes in the input sand rates can lead to large-scale impacts. Solutions in those zones will need investment, particularly to prepare them for climate change.

These zones may need 'grand solutions'. These are large infrastructure projects, such as: (i) artificial headlands (e.g. 1000 m long) to create sub-cells and better aligned beaches, or (ii) habitable offshore islands. Both must be accompanied by major nourishment. The goal is to realign a large section of coast, to change the coast from 'hungry to happy' and stabilize the nourishment. For example, the Kerala or Tamil Nadu coast may benefit from grand solutions, while Maharashtra already has many stable embayed beaches and would need to be treated differently. In India, money is insufficient to fix beaches if the nourishment all gets swept away quickly. Sand is scarce, people want it for buildings, etc. Embayed beaches are very stable and will survive climate change better than 100 km of open beach, like in Kerala.

Embayed beaches are very stable and so the long-term nourishment costs are substantially less than on an open coast.

The use of artificial headlands or large offshore islands to sub-divide a large sediment cell may partially overcome past problems with groynes which have been: (i) reliance on natural capture of sand; (ii) length too short (i.e. less than the beach width change between dry and wet seasons); (iii) length too long in the absence of nourishment to fill the compartments, or; (iv) not treating the full sediment cell.

Unfortunately, it may be too late to simply return beaches to their natural state. The rivers and sand mining have changed all that. Large scale research studies and numerical models, willingness to act, and an open mind to solve India's problems are all needed. If we do not engage now, the future for India's coast is dire.

Public-private partnership opportunities, such as development of the public islands, land additions in headlands, lee port regions, safer beaches and marine habitat, are possible ways to approach such large investments. However, these projects cannot go forward in isolation of their responsibility to solve downstream effects.

More Profound EIA Content

Casual studies or quick decisions about local coastal protection issues have led to a plethora of different solutions, some of which have failed completely. Others have simply moved the erosion downstream. Some relate to the demand for access to the sea with ports and river training breakwaters.

There is no suggestion in the Guidelines that these activities can be prohibited. However, the studies prior to construction have not identified the issues which have led to emergency mitigation measures and high costs over the full life-cycle of the projects. This can be rectified by strengthening the requirements of the EIA for each project. The additional inputs required in an EIA report for coastal projects are given in Appendix 14.

Soft Solutions

The Guidelines have revealed that the best solution to be adopted under climate change is beach nourishment, dune restoration, or dune care. However, some difficulties need to be overcome: (i) social reluctance to the use sand only on beaches as many villagers feel safer behind a large rock wall; (ii) source of the sediment for nourishment, and; (iii) suitability of the beaches for protection, as some may be too degraded by construction works or other factors.

Social Reluctance

India has inadequate supplies of sand for building which leads to a social and financial reluctance to use the remaining sands for beaches. Such a decision will rest with the government, who may choose to enforce the CRZ regulations forbidding sand extraction from the coastal zone and permit offshore sand mining, of course with EIA.

Sand Sources

There are few easy sources for the sand. Currently, states are opening river mouths for navigational purposes which can provide sand for the beaches. However, the river entrances are connected to the beach and many infill quickly with beach sand. As such, the net volume increase to the beach is negligible and the disruption of the system may be detrimental.

Although expensive, an alternative source could be crushed rock for short and important beaches. If the grain size was about 2-5 mm, the beaches would be steeper along the shore and more resilient to storms. Notably, steep beaches are not ideal for the public.

Another source is the surf zone around the low tide line or deeper. This zone is very mobile and so environmental impacts on marine biota are minor. Assisting nature by dune restoration on beaches (whereby sediment is moved from below the low tide line to the upper beach) provides a good source for many beaches. This method is sometimes known as 'beach re-profiling'.

The largest remaining sources are along the banks of major rivers or offshore in 10-40 m depths. Many of the river banks have been colonized by mangroves and / or reclaimed by the public. Access to these zones is politically difficult but well-planned works may lead to favorable development of river flooding protection and the collection of sediment for the beaches.

Offshore extraction may prove to be financially viable, as some of these sands contain heavy minerals that could be extracted with the residual sands coming to the beaches. More detailed studies are needed to investigate the social and environmental impacts of offshore sand extraction for beaches.

Suitability of the Beaches

Many of the Indian beaches have net longshore transport rates that move nourishment along the shore. This means that large volumes of sand may be needed to fill and nourish a long sediment cell (e.g. 100-200 million m^3). In these cases, a hybrid solution of nourishment with grand structures may be needed, given the shortage of sand.

The second factor is that many of India's beaches already have structures on the primary sand dune and residents in many places living very close to the sea. If these buildings cannot be moved to restore the natural system, then it would be necessary to bring the beach further to seaward. As the depths increase quickly offshore, the total volumes of sand needed rise exponentially. Once again, grand structures may be needed to help reduce the sediment losses if there is reluctance to enforce CRZ set-backs.

Thirdly, many beaches have a width which is approximately equal to the beach width changes that occur between the wet and dry seasons. Thus, the monsoon cuts to the back of the berm, which is then subsequently returned in the dry season. This means that the space available to fit a dune is limited in many cases. The use of inexpensive beach re-profiling will be the best option in these cases.

Research and Training Needs

More research, better overviews on the coastal dynamics, consideration of the longshore transport, blocking sand removal from the beaches etc. are essential for preparation against climate change. Some additional facts given below are outside and beyond the Guidelines but they provide valuable insights for the way forward.

Establish a national multidisciplinary coastal research program (with modern scientific equipment) focusing on the development of essential datasets and computer modelling skills. Key gaps are: (i) surf zone dynamics on natural beaches and around structures; (ii) large-scale overviews on India's coastal dynamics and planning of grand schemes over larger zones, and; (iii) offshore sediment sources and associated environmental effects.

Coordinate multiple national and state research agencies through the development of a multidisciplinary research fund focused on the coast with sharing of data and information.

Strengthen the link between science, engineering, biology, management, and economics for informed decision making using multidisciplinary teams. A better unification of science (to investigate nature) and engineering (for construction design) is a high priority. The science needs to be strengthened.

Each coastal state and territory should have a separate coastal science and engineering department / wing to deal with the projects related to the coast.

The engineers and officials dealing with the coast should undergo periodic training in climate resilient coastal protection and management, a module for which is provided in Appendix 18.

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