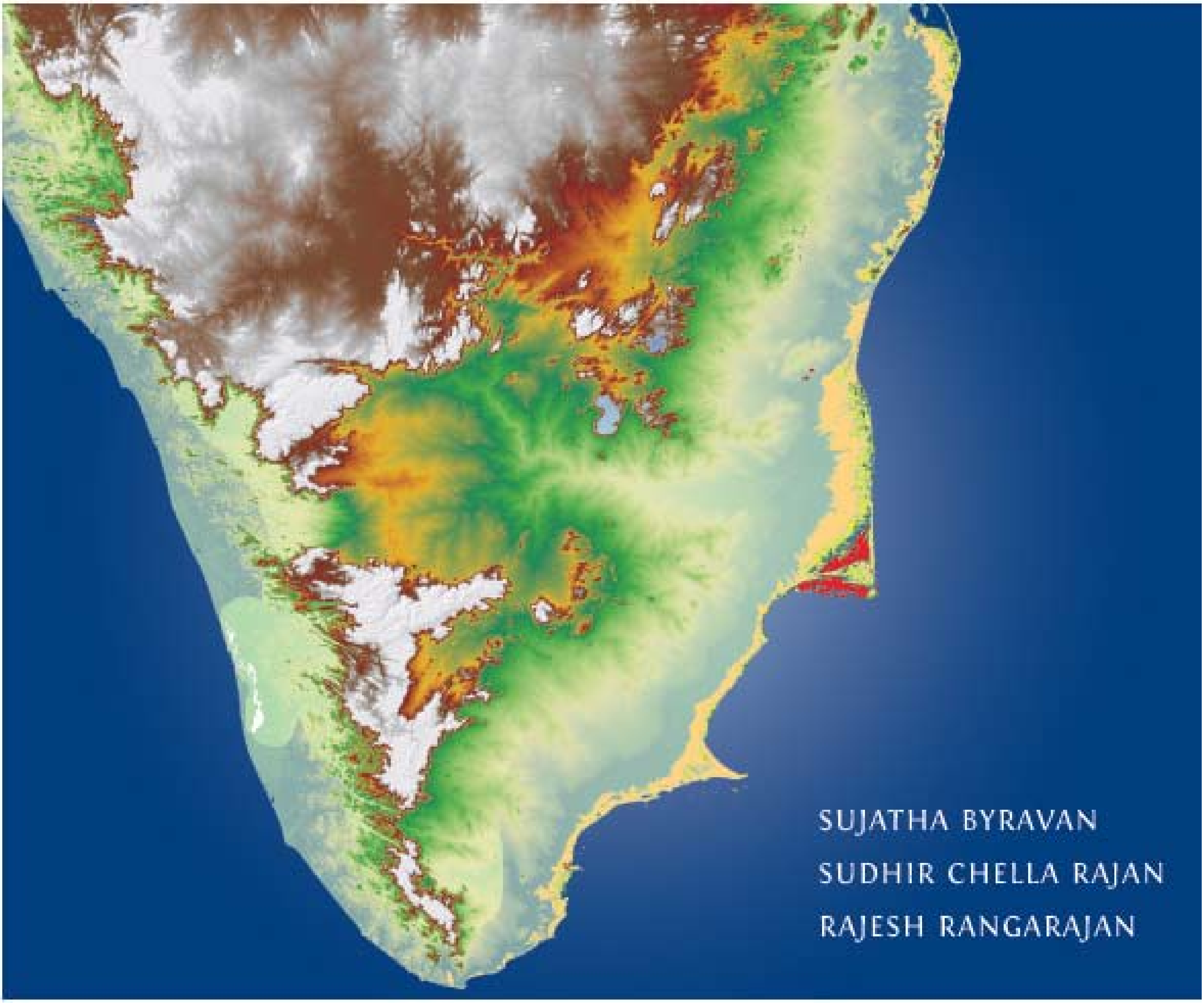
Sea Level Rise:

impact on major infrastructure, ecosystems and land along the Tamil Nadu coast



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Abbreviations

CEA	Central Electricity Authority
CIAT	International Centre for Tropical Agriculture
CRZ	Coastal Regulation Zone
ECR	East Coast Road
GIS	Geographic Information Systems
IPCC	Intergovernmental Panel on Climate Change
LECZ	Low Elevation Coastal Zone
MAPS-1&2	Madras Atomic Power Station (Units 1&2)
MoEF	Ministry of Environment and Forests
MOSPI	Ministry of Statistics and Programme Implementation
NHAI	National Highways Authority of India
PMSS	Probable Maximum Storm Surge
RTI	Right to Information
SLR	Sea Level Rise
SRTM	Shuttle Radar Topography Mission
SEZ	Special Economic Zone
TN	Tamil Nadu
TNMB	Tamil Nadu Maritime Board
UNEP-GPA	United Nations Environment Programme, The Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities

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Executive Summary

South Asia is expected to experience a wide range of effects due to global warming. In India these various impacts will, of course, occur concurrently with existing development challenges. Therefore, there is a crucial need to start integrating development and environment problems with climate change mitigation and adaptation. Unless advanced planning to deal with climate change impacts — adaptation to climate change — takes place as an ongoing and integral part of the planning process, the country is in danger of finding itself in extremely dire circumstances.

Sea level rise will affect the coastline in India in a variety of ways, including inundation, flood and storm damage associated with severe cyclones and surges, erosion, saltwater intrusion, and wetland loss. There are major, existing and proposed, economic and infrastructure developments, including ports, power plants, highways and even airports, which are being planned very close to the shoreline along India's coast. Furthermore, there are many thousands of crores of new investment being considered along the coast in cities such as Mumbai, Chennai, and Kolkata in addition to the substantial existing infrastructure.

This report concentrates on the impacts of sea level rise on coastal infrastructure, ecosystem and land in the state of Tamil Nadu, India. It aims to highlight the financial implications of sea level rise on existing and proposed infrastructure along the Tamil Nadu coast and to provide thereby an "early warning" of the implications of indiscriminate development close to the shoreline. In this study, we do not evaluate the impact on human populations along the coast from SLR, which will likely be devastating, as recent experience from cyclones and the tsunami indicate. Our intent here has been to focus on the financial implications of infrastructure, ecosystem and land loss. The study employs Geographic Information Systems and information available in the public domain. The analysis performed here is indicative rather than comprehensive, primarily because of data constraints, but it is hoped that its findings will provide the basis for conducting more detailed studies covering larger portions of the Indian peninsula.

The Tamil Nadu coastline is about 1,076 km, with thirteen coastal districts, and it forms a fairly large contiguous and narrow coastal strip dotted with fragile ecological features and rampant development activities. *Using Tamil Nadu as a case study, the analysis in this report provides preliminary estimates of the replacement value of major infrastructure, the present value of ecosystem services associated with damage to wetlands and the market value of land at risk from 1m of sea level rise by 2050.* Since the area at risk from SLR is much larger than the area that is actually inundated, the area at risk for a 1m rise in mean sea level is also identified.

The area at risk from a 1m SLR is estimated on the basis of district-level analyses of the likely impacts from storm surges. For five coastal districts, Nagapattinam, Thiruvarur, Thanjavur, Pudukottai, and Ramanathapuram, the area along the coast that is below 10m above current mean sea level is estimated to be at risk from a 1 metre SLR, because of the very high storm surges that already affect them. For the remaining eight coastal districts, the coastal area that lies below 5m elevation relative to current mean sea level is estimated to be at risk from a 1 metre SLR. A 1m rise in average sea level would permanently inundate about 1091 square kilometres along the Tamil Nadu coast, but the total area at risk would be nearly six times as much.

The study estimates the total replacement value of infrastructure (ports, power plants and major roads) impacted by sea level rise to be between Rs. 47,418 and Rs. 53,554 crores (in 2010 terms). The present value of wetlands (estimated in terms of foregone ecosystem services through 2050) impacted by sea level rise is estimated to be between Rs. 3,583 and Rs. 14,608 crores. By far the largest impact will be on the land at risk, whose market value is estimated to be between Rs. 3,17,661 and Rs. 61,15,471 crores. In comparison, Tamil Nadu's annual Gross Domestic Product is estimated to be around Rs. 2,50,000 crores, indicating that very significant value is at risk along the coast due to climate change impacts from sea level rise alone.

The report recommends a comprehensive vulnerability assessment of the entire coast, the integration of climate change considerations into all coastal infrastructure development, special efforts to protect wetlands, and the careful assessment of coastal protection measures and implementation of these where they may be useful.

Background and Objectives

Coastal planning and development must integrate expected impacts from sea level rise due to climate change.

South Asia is expected to experience a wide array of effects due to human-induced global warming. The main impacts will be variability in monsoon patterns with a likely increase in the number of days with heavy precipitation and flooding, the melting of Himalayan glaciers, drought, an increase in the severity of vector-borne diseases such as malaria, reduction in agricultural yield resulting in severe famine in parts of the region, and sea level rise (IPCC 2007). Since this region includes small islands, delta regions and long coastlines, sea level rise (SLR) will most likely force people to move inland or out of their islands and delta regions. Being one of the most densely populated areas of the world, the adverse impacts of climate change will be experienced by tens of millions of people. Each one of these effects will by itself further unleash a number of effects that have the potential to leave South Asia devastated over a fairly short period of time. According to the Intergovernmental Panel on Climate Change (IPCC), Asia will be one of the most severely affected regions of the world as a result of "business-as-usual" global warming.

In India these various impacts will, of course, occur concurrently with existing development challenges in many sectors. Poverty alleviation, literacy for all, public health services, infrastructure development, air and water pollution, economic growth, and so on will continue to remain major challenges. Therefore, there is a crucial need to start integrating development and environment problems with climate change mitigation and adaptation. Unless advanced planning to deal with climate change impacts adaptation to climate change takes place as an ongoing and integral part of the policymaking process, India is in danger of finding itself in extremely dire circumstances.

The government of India's National Action Plan on Climate Change concentrates on eight climate missions: Solar, Enhanced Energy Efficiency, Sustainable Habitat, Water, Himalayan Ecosystem, Green India, Sustainable Agriculture, and Strategic Knowledge for Climate Change. SLR and associated impacts appear to have been left out of this initial proposal.

Our focus in this report is on SLR and the impacts that it will have on coastal infrastructure, ecosystem and land in the state of Tamil Nadu, India. SLR will of course also have serious consequences for people and livelihoods, but we do not address these explicitly in this report, given the complexity in making assumptions about future population and occupational changes along the coast. SLR will affect the coast in a variety of ways, including inundation, flood and storm damage associated with severe cyclones and surges, erosion, saltwater intrusion, and wetland loss. While it is likely that significant SLR will not occur for some time, addressing the challenges posed by the phenomenon, such as taking an integrated approach to coastal management, emergency preparedness, sea walls where useful, phased migration from the most vulnerable portions of the coast and so on, are likely to require considerable advance planning and preparation.

One needs to consider major economic and infrastructure developments, including ports, power plants, highways and even airports, which are being planned very close to the shoreline all along India's coast. There are many thousands of crores of new investment being considered along the coast in cities such as Mumbai, Chennai, and Kolkata in addition to the substantial existing infrastructure. The proposed international airport in Navi Mumbai, the numerous ports and special economic zones (SEZs) planned along the coast in various states, the building of highways, and the placement of sensitive structures such as power plants and nuclear facilities not far from the coast are examples of the absence of careful assessment of the many impacts of sea level rise on coastal infrastructure.

This report aims to highlight the financial implications of SLR on existing and proposed infrastructure along the Tamil Nadu coast and to provide thereby an "early warning" of the implications of indiscriminate development close to the shoreline. The analysis performed here is indicative rather than comprehensive, primarily because of data constraints, but it is hoped that its findings will provide the basis for conducting more detailed studies covering larger portions of the Indian peninsula.

How much SLR can we expect?

The IPCC expects a maximum SLR of 59cm by 2100. This is widely acknowledged as being a conservative estimate since it excludes future dynamical changes in ice flow, including some very important ice sheet processes that speed up the movement of glaciers, particularly in the polar ice caps (IPCC 2007). Most estimates also assume that the West Antarctic ice sheet will stay stable, but sub-surface warming, thinning of ice, changes in wind patterns and the effect of feedbacks altering the speed at which warming takes place are not well understood. The Scientific Committee on Antarctic Research suggests a rise in mean sea level of up to 1.4m by 2100 and other scientists anticipate SLR of one to several metres (Rignot and Kanagaratnam, 2006; Ivins and R. 2009; SCAR 2009) in the same period. The seas, of course, will continue to rise even beyond 2100 if warming is not stabilised. The German Advisory Council on Global Change (WBGU) expects around a metre rise by 2100 and several metres by 2300 (WBGU 2006).

The renowned scientist James Hansen (Hansen 2007) and others (e.g., Oppenheimer et al. 2007) believe that the low end of these expectations are a serious underestimate and that under "a business as usual" scenario, climate change can result in SLR measured in metres within a century. Paleoclimatic data appear to support these claims. The Plio–Pleistocene records tell us that with a global warming of only 2–3 °C, the planet was a dramatically different place with average sea level

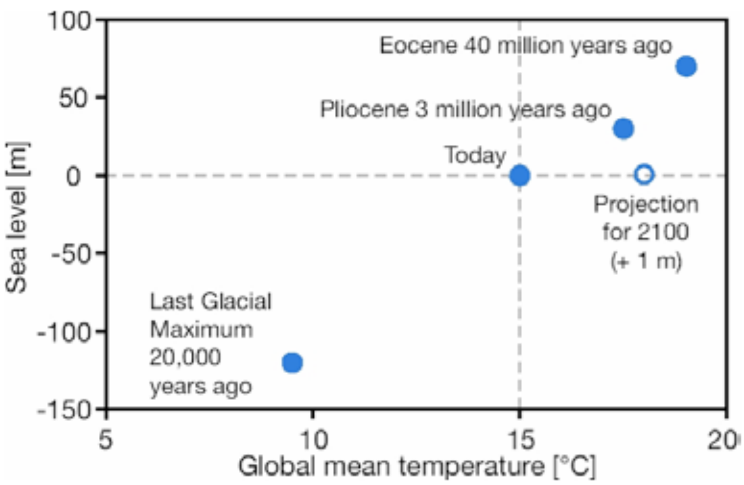

Figure 1: Global mean temperatures and sea levels (Reprinted with permission from WBGU 2006)

about 25 metres higher than it is today (See Figure. 1). Moreover, there is also evidence for at least three separate events involving catastrophic rises in sea level between about 6,500 and 14,500 years ago, when the rate of SLR exceeded 45mm/year (Blanchon and Shaw, 1995).

For the purposes of this report, we assume that average SLR of 1 metre may be expected as early as 2050, a somewhat conservative estimate especially if large portions of the West Antarctic Ice Sheet were to break off or if ice streams from Greenland were to accelerate, both of which being widely believed as possible occurrences in this century. We therefore estimate the coastal impacts in Tamil Nadu on the basis of a 1 metre SLR, including the replacement value of infrastructure, the present value of the foregone ecosystem services associated with the loss of wetlands, and the market value of property losses associated with damage to usable coastal land.

What will the impacts be?

India has a coastline of over 7,500 km, including the mainland and the islands, with nearly a third of its population living within 50 km from the shore. SLR will affect the coastal zone in multiple ways. Warmer waters will lead to *more intense storms accompanied by storm surges* with coastal structures having to withstand the force and impact of higher winds and water (Emmanuel 2005; Bengtsson et al. 2006; cf. Landsea et al. 2006). The physical changes associated with SLR may take place in abrupt nonlinear ways as thresholds are crossed. For example, rising sea levels will result in the increased frequency of coastal flooding due to storm-surge events, even in the absence of increased storm intensities (Zhang et al. 1997). Similarly, dramatic *retreat of sandy beaches is expected*; beach *erosion* typically takes place at tens to hundreds of times the rate of sea-level rise and will degrade or remove protective coastal features such as sand dunes and vegetation, further increasing the risk

NATURAL SYSTEM EFFECTS	
1. Inundation, flood and storm damage	Surge (sea)
	Backwater effect (river)
2. Wetland loss (and change)	
3. Erosion (direct and indirect morphological change)	
4. Saltwater intrusion	a. Surface waters
	b. Groundwater
5. Rising water tables/impeded drainage	

Table 1. Major Impacts and Selected Responses to Sea Level Rise (Source: Nicholls 2009)

of *coastal flooding* (Church et al. 2008; see also Table 1). In addition, *ecosystem changes* and *saltwater intrusion* into groundwater are expected to take place.

The Bay of Bengal is already vulnerable to storm surge events. Since 1737, there have been 23 major surge events, with over 10,000 people killed in each (Murty et al. 1986; Murty and Flather 1994). While Andhra Pradesh, Orissa, West Bengal and Bangladesh have seen the most severe events, there have also been devastating storm surges in Tamil Nadu, as far south as the Kaveri delta, with maximum wind speeds as high as 220 km/h and maximum surge height and tide exceeding 9m (Kalsi et al. 2007).

Sea level rise is expected to increase the vulnerability of coastal areas to flooding for several reasons. A rise of 1 metre provides a higher base for storm surges and would increase the frequency of flooding associated with storms. Therefore, a 15-year storm may flood many areas that today are only flooded by a 100-year storm. Moreover, beach erosion and wetland loss will leave some properties more vulnerable to storm waves. Finally, higher surface and groundwater levels will reduce drainage and thus increase flooding from rainstorms (Titus 2005).

Intense storms accompanied by surges and flooding along with the SLR will also result in an increase in coastal erosion and in the intrusion of salt water, as well as adverse impacts on coastal wetlands and ecosystems. In addition, SLR will likely transform coastal morphology and soil characteristics. Human activities along the coast such as the building of ports, ground water extraction, shrimp farming and agriculture will all simultaneously play a role in shaping the coastal changes that take place along with global warming. Built-up areas tend to be more vulnerable than those protected by mangroves, deltas, low-lying coastal plains, coral islands, beaches and barrier islands. Degradation of coastal ecosystems by human activity will generally aggravate the problems caused by SLR, increasing shoreline retreat and coastal flooding in cities. For example, it is estimated that the area of the Tamil Nadu shore north of Ennore port will have an erosion rate of 20m/year if no intervention is planned (ENVIS 2008: 29) and there is already silting in Ennore Creek due to accretion.

Protection by breakwaters, dikes, levees and sea walls such as that undertaken in some vulnerable coasts such as in the Netherlands and New Orleans need to consider not just the extent of average SLR but also the effect of more frequent and intense storm surges. Protection from SLR using engineering solutions is in any case not a viable option for many developing coun-

SELECTED ADAPTATIONS

Dikes/surge barriers Building codes/floodwise buildings Land use planning/hazard delineation
Land use planning Managed realignment/forbid hard defences, Nourishment/sediment management
Coastal defences Nourishment Building setbacks
Saltwater intrusion barriers Change water abstraction Freshwater injection
Upgrade drainage systems Polders Change land use Land use planning/hazard delineation

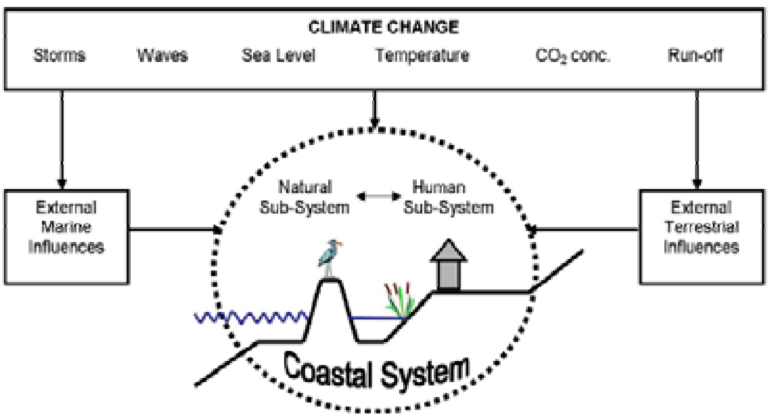

Figure 2: The Coastal System (Reprinted with permission from IPCC 2007)

State	Sandy Beach	Rocky Coast	Muddy flats	Marshy coast	Total length*	Length of coast affected by erosion**
	%	%	%	%	(km)	(km)
Gujarat	28	21	29	22	1,214.70	36.40
Maharashtra	17	37	46	-	652.60	263.00
Goa	44	21	35	-	151.00	10.50
Karnataka	75	11	14	-	280.00	249.60
Kerala	80	5	15	-	569.70	480.00
Tamil Nadu	57	5	38	-	906.90	36.20
Andhra Pradesh	38	3	52	7	973.70	9.20
Orissa	57	-	33	10	476.40	107.60
West Bengal	-	-	51	49	157.50	49.00
Daman and Diu					9.50	-
Pondicherry					30.60	6.40
Total mainland	43	11	36	10	5,422.60	1,247.90
Lakshadweep					132.00	132.00
Andaman and Nicobar					1,962.00	-
Total					**7,516.60**	**1,379.90**

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

Table 2. Coastal properties of different states in India (Source: Kumar et al., 2006).

tries, especially for increases greater than a few tens of centimetres. A recent report by the Dutch Delta Committee proposes annual investments of about 1.5 billion Euros for the rest of the century to protect the country from a 1.3 metre SLR in 2100 (Deltacommissie 2008). Another study using global estimates shows that costs of protection may be about 2-4 million dollars per kilometre of coastline (in 2010 US dollars) for a 1 metre SLR, but even then the coast may not be fully protected (Tol 2002).

Coastal wetlands, particularly mangroves, on the other hand, play a very important role in coastal protection and can be regarded as a resource having high direct as well as indirect value. Mangroves and other coastal ecosystems provide substantial services such as subsistence fisheries, timber and firewood, physical coastal protection, carbon storage, medicinal remedies and tourism. Most importantly, studies have suggested that mangroves provide considerable coastal protection from storm surges and high winds and have played a significant role in saving lives (Das and Vincent 2009).

The Tamil Nadu Coastline

As India's Southern-most state, Tamil Nadu constitutes about 15% of India's coastline. With a total length of about 1,076 km with thirteen coastal districts (see **Table 3**), it

S.No.	Coastal District	Coastal Length (Km)
1	Chennai	19.0
2	Thiruvallur	27.9
3	Villupuram	40.7
4	Pudukottai	42.8
5	Thanjavur	45.1
6	Thiruvarur	47.2
7	Tirunelveli	48.9
8	Cuddalore	57.5
9	Kanyakumari	71.5
10	Kanchipuram	87.2
11	Tuticorin	163.5
12	Nagapattinam	187.9
13	Ramanathapuram	236.8
	Total	**1076.0**

Table 3. Tamil Nadu Coastal Districts

forms a fairly large contiguous and narrow coastal strip dotted with fragile ecological features and rampant development activities.

According to information shared by the State Department of Environment through the Environmental Information System (ENVIS), the major ecological systems along the Tamil Nadu coast are the Pulicat Lake in North Chennai, the mangrove ecosystems of Pichavaram and Muthupet, the swamps of Vedaraniyam, which is host to migratory bird population and the Gulf of Mannar biosphere reserve. Collectively, these ecosystems alone contribute significantly to the coastal biodiversity of India of which a major portion comprises of coral reefs and mangroves, the presence of which form natural barriers from coastal hazards.

ACTIVITIES	PLACES
Discharge and disposal of Domestic wastes	Chennai, Pondicherry, Cuddalore, Tuticorin
Discharge and disposal of sewage and industrial wastes	Chennai, Pondicherry, Kayalpattinam, Tuticorin
Harbour activities and maritimeTransport	Chennai, Cuddalore, Nagapattinam, Tuticorin, Colachel, Vallinokkam
Fishing activities	Throughout the coast
Oil exploration, production and Refining	Chennai, Cauvery delta, Nagapattinam, Palk Strait
Recreation and tourism	Chennai, Pondicherry, Tranquebar, Rameswaram, Thiruchendur and Kanyakumari
Salt production	Kovalam, Marakkanam, Vedaranyam, Tuticorin

Table 4. Major coastal activities leading to coastal/marine pollution in Tamil Nadu

The coast of Tamil Nadu, as elsewhere in India, faces severe development pressures which lead to problems such as pollution, coastal erosion, damage to the coast and so on. **Table 4** identifies some of the main activities along coastal Tamil Nadu. In addition to these there is erosion and accretion that test the vulnerability of the coast. As part of natural processes, sediment movement northward and southward (called littoral drift) is a unique feature of the east coast, which ties in with the activity pattern of the Indian monsoons. Any hindrance to this process alters the coastline rendering it vulnerable to storm surges, cyclones and consequent inundation of low-lying areas. The Tamil Nadu coast has already undergone such alterations and is also witness to frequent cyclonic storms. The 2004 tsunami demonstrated the level of vulnerability that the coast faces and triggered many studies that have only heightened the concerns.

The CRZ Notification and its implications for the Tamil Nadu coast

The absence of a robust legal framework and the failure to implement the Coastal Regulation Zone Notification of 1991 have exacerbated the problems of the coast. Enacted with a view to regulate development activities along the coast with an understanding that the shore and the coastal ecosystems are significant ecological entities, the Coastal Regulation Zone (CRZ) Notification is considered to be a unique piece of legislation. The CRZ classifies the coastal areas into four zones depending on their ecological significance and land use and using a combination of regulation and prohibition attempts to render coastal protection. CRZ I pertains to ecologically sensitive areas, CRZ II relates to urbanised areas, CRZ III to non-urban/rural areas and CRZ IV to the islands of Andaman & Nicobar and Lakshadweep.

During its 19-odd years of existence, the two main problems with the CRZ have been its dilution through repeated amendments, and the lack of implementation of several of its provisions. The CRZ has been widely used, differently interpreted and, above all, poorly implemented. Without doubt, the CRZ 1991 was ambiguous and the courts had to get used to interpreting and subsequently enforcing the law. In most cases, court interpretation too appears not to have achieved the desired result espoused by the Notification. Twenty-five amendments have further weakened the notification thus allowing many development projects to be established on the coast without any systematic approach to coastal management and planning. Owing to this endless dilution, the Ministry of Environment & Forests (MoEF) has still not issued a consolidated notification in the official gazette, incorporating all the changes to the original notification. The situation has led to repeated violation of the notification resulting in the proliferation of road construction, tourism infrastructure and industrial establishment along various parts of the Tamil Nadu coast. Currently, the MoEF is in the process of strengthening the CRZ. The revised draft notification has now been made available for public comment.

Objectives

Using Tamil Nadu as a case study, the analysis in this report provides preliminary estimates of the replacement value of major infrastructure, the present value of ecosystem services associated with damage to wetlands and the market value of land at risk from 1m of sea level rise by 2050. Since the *area at risk* from SLR is much larger than the area that is actually inundated, the area at risk for a 1m rise in mean sea level is also identified. The report aims to be indicative, rather than comprehensive, and highlights the need for a more detailed study of the vulnerability of the coastline in Tamil Nadu to SLR.

In this study, we do not evaluate the impact on human populations along the coast from SLR, which will likely be devastating, as recent experience from cyclones and the tsunami indicate. Our intent here has been to focus primarily on the financial implications of infrastructure, ecosystem and land loss.

Data and Methods

The analysis carried out in this study was based on publicly available information on infrastructure location and investments. GIS baseline information was taken from sources such as LandSat 7 and OpenStreetMaps as well as government agency websites. In some cases, this information was obtained through Right To Information (RTI) requests. Market values for coastal land were estimated on the basis of interviews with real estate agents, after collecting around 80 data samples of agricultural, commercial and residential price estimates all along the Tamil Nadu coast.

Ports, power plants, the ECR (including its possible extension along the coast), wetlands and land were considered in the analysis. Other private and public investments, such as hotels and resorts, housing developments, shrimp farms and other commercial establishments were not included, in part because of the lack of available data, but also because the details needed for the analysis would have been overwhelming.

Detailed geomorphological analysis and modelling of the coastline would need to be carried out in order to provide precise estimates for the land area at risk of inundation, storm surges and erosion as a result of SLR. Such techniques were well beyond the scope of this preliminary study. Instead, an important simplification in this analysis is that district-level Probable Maximum Storm Surge heights obtained from Kalsi et al. (2007) have been used as the basis on which to estimate the land areas in each district that would be at risk from *future* storm surges, flooding and erosion associated with SLR.

Further information on the data and methods used for the analysis are provided in **Appendix 1**. Details on the valuation are provided in **Appendix 2**.

Results

Figure 3 shows the average elevations above current mean sea level along the coast of Northern, Central and Southern Tamil Nadu and corresponding infrastructure – ports, power plants, and the ECR. Two areas are shown in detail in **Figures 4a and 4b**.

Table 5 is a summary of the analysis carried out, showing the replacement value of different types of infrastructure, market value of land and present value of wetlands associated with a 1 metre SLR. It should be noted that two major nuclear power plants and their associated infrastructure are located just beyond the zone estimated to be directly at risk from storm surges from a 1 metre SLR. MAPS 1&2 are at elevations of 5-10m above current mean sea level, while the Kudankulam nuclear power plant is higher than 10m above current mean sea level. Nevertheless, both are very close to the shoreline and are of concern because of the risk associated with coastal erosion (see **Figures 5** and **6**).

The area at risk from a 1m SLR is estimated on the basis of district-level analyses of the likely impacts from storm surges, as described in **Appendix 1**. For five coastal districts, Nagapattinam, Thiruvarur, Thanjavur, Pudukottai, and Ramanathapuram, the area along the coast that is below 10m above current mean sea level is estimated to be at risk from a 1 metre SLR, because of the very high storm surges that already affect them. For the remaining eight coastal districts, the coastal area that lies below 5m elevation relative to current mean sea level is estimated to be at risk from a 1 metre SLR. A 1m rise in average sea level would permanently inundate about 1091 square kilometres along the Tamil Nadu coast, but the total area at risk would be nearly six times as much.

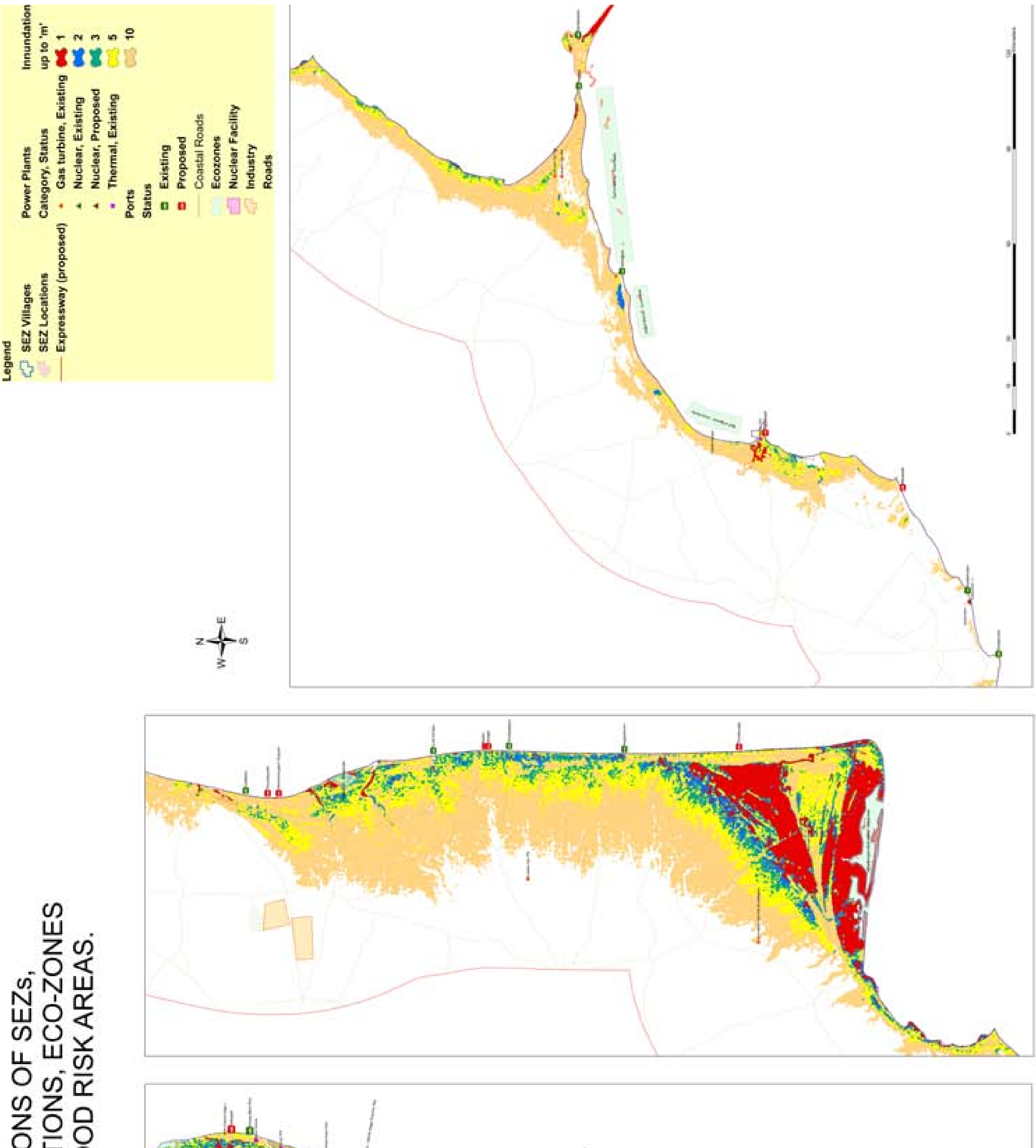

Figure 3: Coastal elevation and associated infrastructure in Tamil Nadu

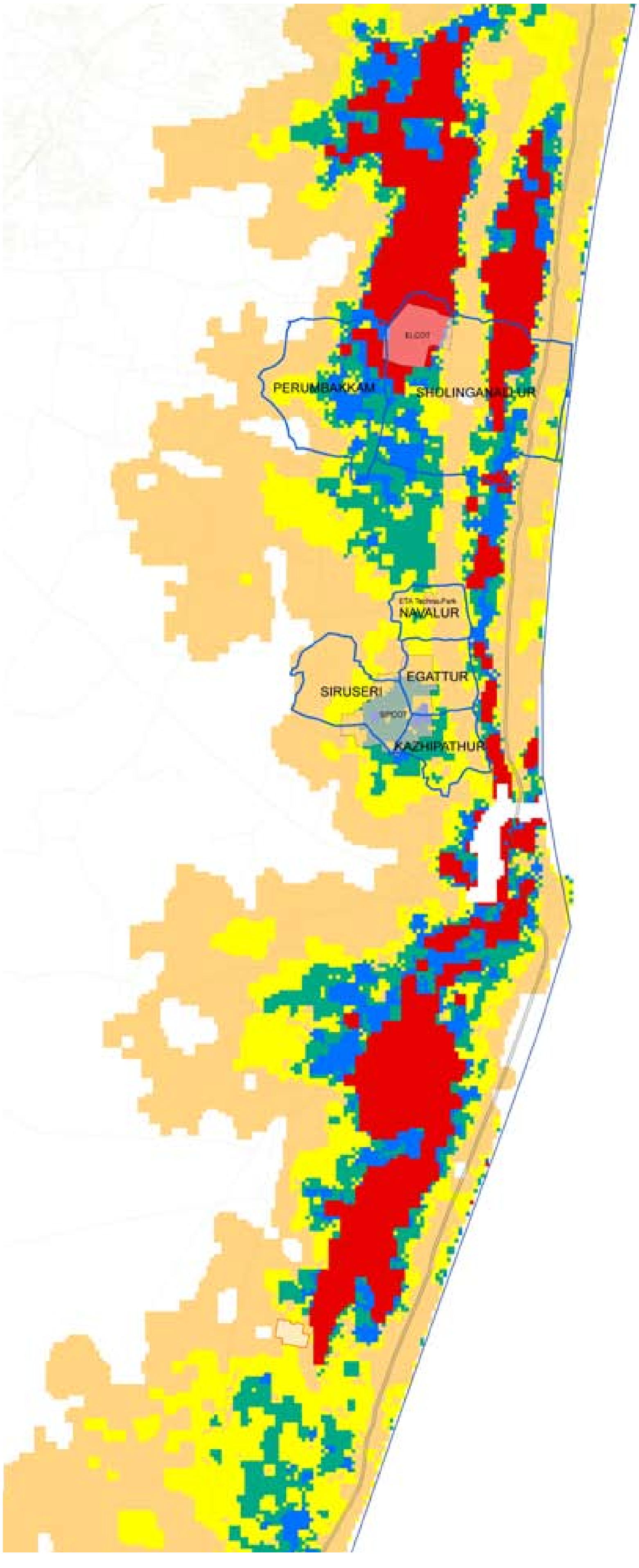

Figure 4a. Detailed map of area south of Chennai

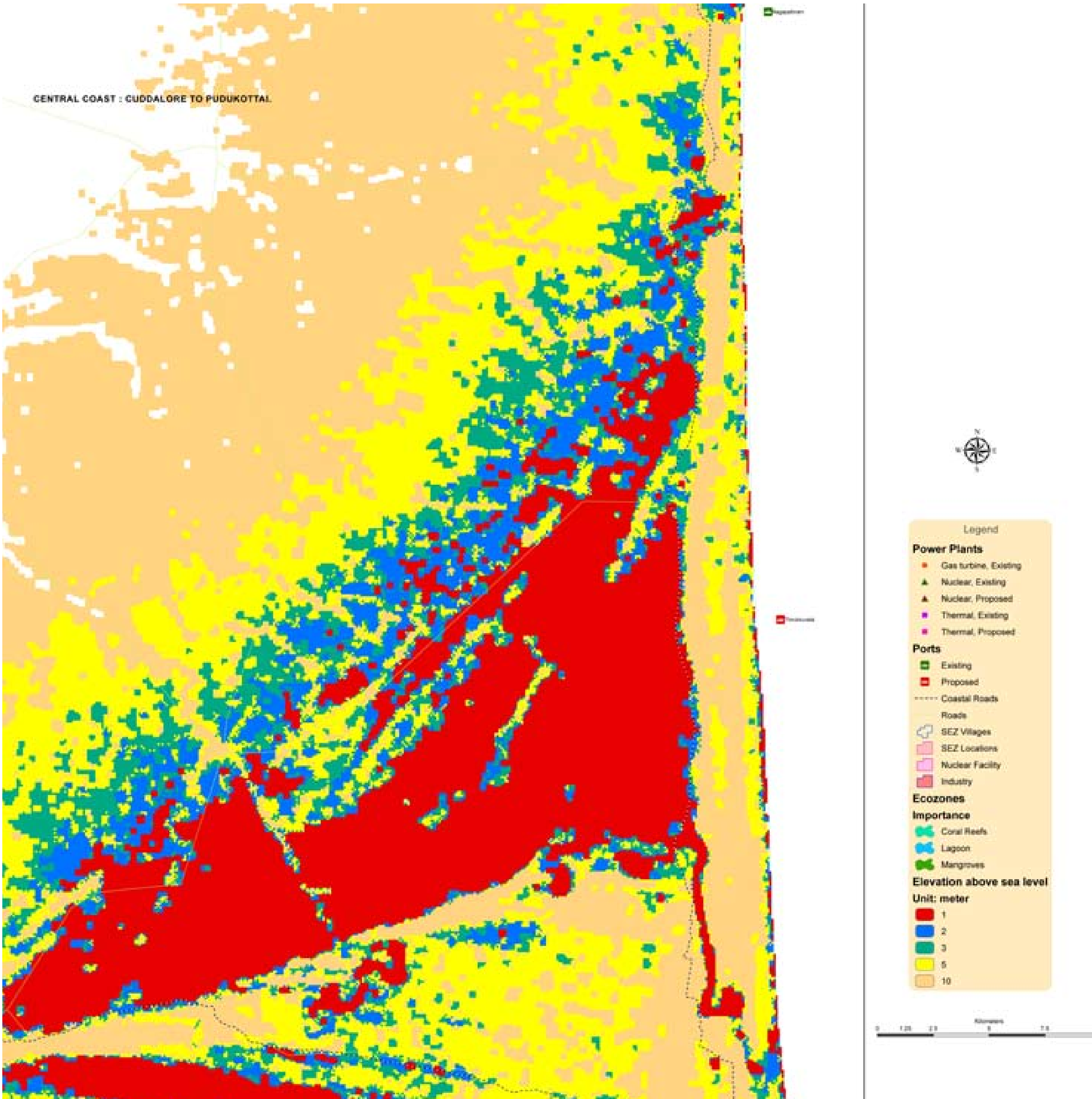

Figure 4b. Detailed map of portions of Nagapattinam and Thiruvarur Districts.

Coastal Districts	Ports		Power plants		Mangroves		Roads		Land	
In Rs. crores	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Thiruvallur	9,106	9,794	13,814	13,814	-	-	-	-	33,939	9,24,130
Chennai	7,639	9,786	-	-	-	-	6	16	2,29,976	4,59,951
Kanchipuram	500	500	-	-	-	-	63	173	7,882	14,30,749
Villupuram	400	830	-	-	-	-	24	65	5,277	63,871
Cuddalore	3,825	3,825	-	-	710	2,894	64	176	7,615	4,64,531
Nagapattinam	1,873	1,873	-	-	2,421	9,871	374	1,029	7,120	22,33,596
Thiruvarur	-	-	-	-	-	-	57	157	4,347	2,08,356
Thanjavur	-	-	-	-	-	-	122	336	1,860	94,547
Pudukottai	-	-	-	-	-	-	117	321	874	10,930
Ramanathapuram	-	-	-	-	452	1,842	301	827	17,344	1,30,021
Tuticorin	8,585	9,456	-	-	-	-	16	44	1,149	86,151
Thirunelveli	532	532	-	-	-	-	-	-	33	7,160
Kanyakumari	-	-	-	-	-	-	-	-	246	1,479
TOTAL	**32,460**	**36,595**	**13,814**	**13,814**	**3,583**	**14,608**	**1,144**	**3,145**	**3,17,661**	**61,15,471**

Table 5. Summary table with replacement value for infrastructure, present value of ecosystem services for wetlands, and market value for land in different coastal districts of Tamil Nadu with a 1 metre sea level rise.

Figure 5. Satellite image of Kudankulam nuclear facility (Source: Google Earth, accessed August 24 2010).

Figure 6. Satellite image of Madras Atomic Power Station (Source: Google Earth, accessed August 24, 2010).

Discussion and future directions

The total replacement value of infrastructure (ports, power plants and roads) impacted by sea level rise is estimated to be between Rs. 47,418 and Rs. 53,554 crores (in 2010 terms). The present value of wetlands (estimated in terms of foregone ecosystem services through 2050) impacted by sea level rise is estimated to be between Rs. 3,583 and Rs. 14,608 crores. By far the largest impact will be on the land at risk, whose market value is estimated to be between Rs. 3,17,661 and Rs. 61,15,471 crores. In comparison, Tamil Nadu's annual Gross Domestic Product is estimated to be around Rs. 2,50,000 crores, indicating that very significant value is at risk along the coast due to climate change impacts of SLR alone.

The Tamil Nadu government and other state governments with large tracts of coastal land may want to consider the implications of extensive infrastructure development in coastal areas in light of these findings. The analysis carried out here is based on commonly accepted methods and data that are publicly available (except for land estimates, which were based on interviews with real estate agents). Similar studies may well be conducted for states such as Andhra Pradesh, Orissa and West Bengal – all subject to even more severe cyclones from the Bay of Bengal than Tamil Nadu – as well as Maharashtra and Gujarat, which have much higher levels of investment along the coast.

Recommendations

Comprehensive vulnerability assessment of the entire coast should be conducted

This report is a first approximation of the replacement value of coastal infrastructure, market value land and present value of ecosystems at risk from SLR. Further analysis at higher levels of resolution and more detailed information for the entire coastal region of India needs to be conducted in order to estimate the total risk to land, infrastructure, ecosystems, human population and livelihoods. This must include analysis of the potential for erosion and shoreline retreat, expected flooding and storm surges at different levels of SLR, subsidence, and the impact of other human activities such as ports, commercial activity and groundwater withdrawal on the coastal zone.

Climate Change considerations should be integrated into all coastal infrastructure development

Existing structures in the area of high risk will need to be modified to withstand SLR and its impacts. Development in areas of high risk needs to be limited and proposed structures need to consider SLR and its associated impacts in the evaluation. Except for infrastructure that is essential along the coast, including indispensable ports, new development should be planned at considerable distance from the shoreline.

Wetlands need to be protected

The high protection value of wetlands along the Tamil Nadu coast as well as elsewhere in the peninsula needs to be taken into consideration whenever any development threatening their survival is proposed. To the extent existing threats to wetlands can be mitigated or removed, necessary actions should be carried out.

Coastal protection measures should be carefully assessed and carried out if necessary

These could include the following:

- Provide assistance to at risk communities, building resilience;
- Early warning systems;
- Better understanding of the role of coastal ecosystems acting as a guardrail;
- Anticipate migration and prepare inland facilities and prepare at risk communities;
- Plan for and implement shoreline protection measures, where feasible and necessary.

Appendix 1: Data and Methods

For this study, we have adopted a simple GIS framework using ArcGIS software. An application was then developed using publicly available Shuttle Radar Topography Mission (SRTM) 90 elevation datasets for the South Asian region and determining contour lines along the coastal region at 1 metre intervals. The following types of major infrastructure along the coast were identified: ports, power plants, nuclear facilities, major roads and highways.

For each of these, investment costs were obtained, directly from public agencies, through Right to Information (RTI) requests or from published data in the public domain. The data was processed using ArcGIS software as both raster and vector data types.

Raster Data:

- SRTM elevation data
- Landsat 7 satellite images

Vector Data:

- Line dataset: Openstreet map for road network
- Point data sets for power plants and ports generated with Long/Lat information
- Polygon dataset: Industry clusters generated with inputs from Keyhole Markup Language files.

1. GIS Data Processing

Processing of the raster SRTM data was done using Spatial Analyst module of ArcGIS software. It involved using simple map algebra queries to reclassify bands of elevation into 1,2,3,5 and 10 metre zones. They were then used as an intersect overlay over the coastal road network vector data to determine the length of the coastal road in each elevation band. This was then tabulated. Similar analyses were carried out to determine district level land areas at different contour levels.

Plotting the point data e.g. Ports, provided as Longitude / Latitude values was done using a simple "Add XY" tool in the ArcGIS software. This created the necessary point shapefiles. For the polygon data sets, e.g. industrial clusters, the Keyhole Markup Language files were converted into shapefiles. Attributes for these were entered manually in ArcGIS. The same procedure was adopted for the linear road data.

Coastal Roads

Coastal roads were obtained partly from data provided by openstreetmaps.org and partly by tracing satellite images. Coastal roads in some cases are far away from the coast as the area is marshy as in Vedaraniyam. In other places they are as close as 600m from the coastline. On the stretch between Tuticorin and Ramnad, State Highway 49 is located further in from the coast.

Data Used:
Openstreetmaps
SRTM version 3 Elevation Dataset
Landsat 7 panchromatic band 8

Data Scale: 1:50,000
Horizontal Accuracy: 10m
Citation:
Openstreetmaps: "Map data © OpenStreetMap contributors, CC-BY-SA".
http://www.openstreetmap.org/
http://creativecommons.org/licenses/by-sa/2.0/.
Landsat images: These data are part of NASA's contribution to the global research community and are being provided through Landsat.org and the Tropical Rain Forest Information Center, a member of NASA's Federation of Earth Science Information Partners.

Wetlands

Data on the four major ecological important areas of Tamil Nadu along the coast were identified by The Institute for Ocean management at http://www.io-menvis.nic.in/EIA%27s.htm

Among these, Pulicat Lake is in Andhra Pradesh, except for a very small portion of the mouth the lagoon.

Land Area

The area has been computed based on the SRTM elevation data used in the form of raster pixels. As we have an exact count on the number of pixels falling in a zone for each elevation and compute the area as: 90 x 90 meters x the number of pixels in each zone in Tamil Nadu. (The pixel size of SRTM data is 90 meters)

Contour Height (m)	Land area below contour (sq km)
1	1091
3	2289
5	3835
10	7796

Table 6. Area under each contour level in coastal Tamil Nadu

2. Sea Level Rise estimates

For this study we have assumed about 1 metre in mean sea level rise relative to 2000 levels by 2050.

Area at risk from SLR

Future storm surge heights along the Tamil Nadu coast will be influenced by several factors, including increased storm intensity, higher mean sea levels, and continental uplift and subsidence, particularly in delta areas. Dasgupta et al (2009) and Nicholls et al (2008) provide a simple approach to estimate future storm surge heights:

Future storm surge = S100 + SLR + (UPLIFT * 100 yr) / 1000 + SUB + S100 * x

Where:
S100 = current 1 in 100 year surge height (m);
SLR = 1m;
UPLIFT = continental uplift/subsidence in mm/yr;
SUB = total subsidence 0.5m (applies to deltas only);
x = 0.1, or increase of 10%, in coastal areas prone to cyclones.

In this analysis, we have ignored the uplift and subsidence values, primarily because of the lack of reliable data for this purpose. Kalsi et al (2007) report that the probable maximum storm surge (PMSS) heights along the Tamil Nadu Coast vary from about 3 to 9.8m, with a median of about 4.5m along the coast. For the purposes of this report, we have assumed the district level PMSS levels to be equivalent to the S100 value and calculated future storm surge heights on that basis. Furthermore we have defined an "area at risk" that roughly corresponds to the land area vulnerable to future storm surges. Flooding associated with storm surges is also a major cause of coastal erosion, causing damage to buildings and other structures by direct wave impact, hydraulic forces associated with waves and sub-surface water beneath buildings, wave energy reflected from protruding structures such as ports and battering from floating debris (Coch, 1995).

As shown in Table 7, 5 districts in Tamil Nadu are at risk in the zone below the current 10m coastal contour, while the others are at risk below the 5m coastal contour. For purposes of simplicity, we have assumed that even those districts where future storm surges may slightly exceed 10m are at risk only below 10m. Similarly, Nagapattinam and Thiruvarur are expected to have future storm surges up to around 5.6 and 6.9m, but we have assumed that the coastal zone up to 10m are at risk in these districts. Given the likelihood of more frequent, if not more intense, storm surges and associated coastal erosion, the coastal area at risk from a given level of SLR will involve land that is well above the area below mean sea level. It should be noted that in other studies, e.g., McGranahan et al. 2007, the entire region below 10m elevation near the coastline is delineated as the "Low Elevation Coastal Zone" to designate the population affected from SLR.

District	S100(m)	Future Storm Surge (m)	Area at Risk
Thiruvallur	3.6	4.96	Below 5m
Chennai	2.9	4.19	Below 5m
Kanchipuram	2.9	4.19	Below 5m
Villupuram	2.9	4.19	Below 5m
Cuddalore	2.9	4.19	Below 5m
Nagapattinam	4.2	5.62	Below 10m
Thiruvarur	5.4	6.94	Below 10m
Thanjavur	8.3	10.13	Below 10m
Pudukottai	8.5	10.35	Below 10m
Ramanathapuram	8.3	10.13	Below 10m
Tuticorin	3.7	5.07	Below 5m
Tirunelveli	3	4.3	Below 5m
Kanyakumari	2.4	3.64	Below 5m

Table 7. Future storm surge heights and corresponding areas at risk for different districts.

private investments, such as hotels and resorts, housing developments, shrimp farms and other commercial establishments have been excluded from the analysis.

This study concentrates on major and primary aspects of the impact of SLR along the coast. Spatial resolution is relatively coarse – SRTM 90 has 90m horizontal resolution. This is the resolution used for other coastal impact of SLR studies in other parts of the world. It does not examine the impact of protective measures, pollution impacts, human activities such as agriculture, erosion along the coast and detailed impacts of coastal geomorphology.

While funding for this initial work has been generously provided by the ICICI Foundation for Inclusive Growth and the Technology Finance Group at ICICI bank and Trust, additional support in terms of both financial resources as well as information would be essential to carry out a more detailed study along the Tamil Nadu coast and along other coastal areas in India.

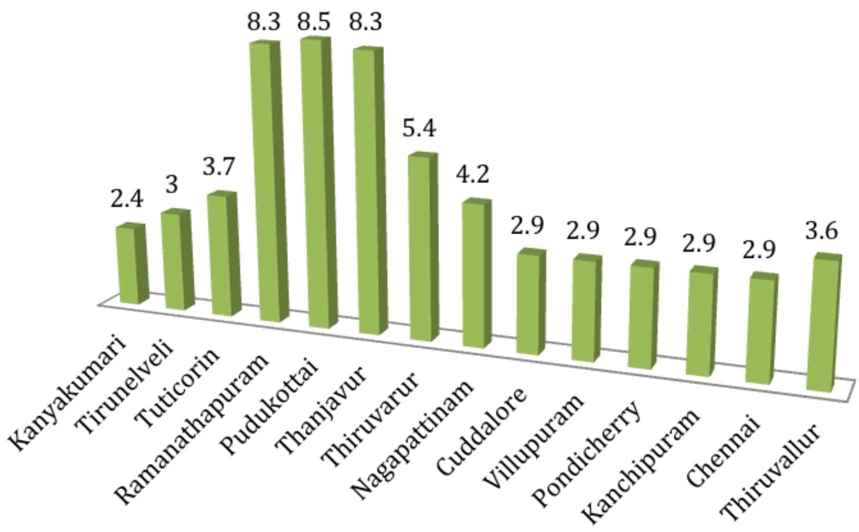

Figure 7 Probable Maximum Storm Surge (PMSS) above tide level in Tamil Nadu districts (Kalsi et al. 2007)

3. Limitations

The study is limited by data, methodology and funding. Only data that is publicly available has been used for this research except for the market value of different types of land in each district, which was obtained on the basis of personal interviews as described below. Apart from ports and power plants, other public and

4. Valuation and replacement costs

Power plants

Coastal Tamil Nadu has 8 power plants (4 thermal power plants, 1 gas turbine power plant and 3 nuclear power plants) lying below or just above the 10 metre elevation from sea level.

Data was obtained from:

- Project Monitoring by the Central Electricity Authority (CEA) of India;
- Project Implementation status report of central sector projects exceeding Rs.20 crores by Ministry of Statistics and Programme Implementation (MOSPI);
- Tamil Nadu Electricity Board (TNEB);
- Nuclear Power Corporation of India;
- Report in projectsmonitor.com;
- Newspaper reports;
- SRTM elevation data;
- Landsat 7 satellite images;
- Wikimapia.org;
- Tamil Nadu Pollution Control Board and
- Bhartiya Nabhikiya Vidyut Nigam Limited.

Replacement cost of existing power plants

CEA, TNEB and MOSPI provide details of project cost and capacity of various thermal, gas turbine and nuclear power plants under construction/recently commissioned in India. We studied the project cost and capacity details of 5 thermal power plants, 5 gas turbine power plants and 4 nuclear power plants under construction/recently commissioned in India. Based on this information we arrived at the minimum and maximum set up costs per MW of capacity of thermal/gas turbine/nuclear power plants.

Replacement cost of power plants under construction

The CEA of India, TNEB, and MOSPI provide the project cost[2] details of thermal/gas turbine/nuclear power plants under construction. The project cost is assumed to be the replacement cost of the thermal/gas turbine/nuclear power plants under construction in coastal TN[3].

Ports

TN State has 3 major ports and 22 minor ports (including 8 ports under construction and 3 proposed ports) lying below one metre elevation from sea level[4].

Data was obtained from:

- Chennai port, Ennore port and the Tuticorin port company websites;
- Initial Public Offering Prospectus of Mundra Port and SEZ filed with Securities Exchange Board of India;
- Indian ports association;
- Tamil Nadu Maritime Board (TNMB);
- TNMB under the RTI Act;
- Newspaper reports;
- SRTM elevation data;
- Landsat 7 satellite images;
- Personal Interview with TNMB official on 20 September 2010.

Type of Plant	Min plant set up costs per MW of capacity	Max plant set up costs per MW of capacity
Thermal power plant	Rs. 4.0 crores	Rs. 5.9 crores
Gas turbine power plant	Rs. 2.4 crores	Rs. 3.9 crores
Nuclear power plant	Rs. 6.6 crores	Rs. 11.2 crores

The minimum and maximum replacement cost of thermal/gas turbine/nuclear power plants is computed in the following manner:

Capacity of thermal/gas turbine/nuclear power plants x Minimum/Maximum plant set up costs per MW of capacity[1].

The replacement cost of ports is computed in the following manner[5]:

1. The existing infrastructure of the *operational ports* in Tamil Nadu State have been valued based on one of the four following ways:

   - Minimum/Maximum set up costs per unit of the port capacity x Capacity of the Port
     We have valued the ports based on their investment in container terminals and other terminals. We evaluated 2 container terminal projects and 3 other terminals projects to arrive at the minimum and maximum set up costs per unit of port capacity for container/ other terminals (refer table below);
   - The associated investments in ports have not been included due to lack of information. Hence the replacement cost of ports computed through this method is a very conservative estimate;
   - The project cost details provided by the TNMB under the RTI Act;
   - Interviews with TNMB official. or;
   - The project cost details provided in newspaper articles.

2. The *proposed projects* of the *operational ports* in TN State are valued based on information sourced from the respective company websites.

3. The project cost details provided by the TNMB under the RTI Act is assumed to be the replacement cost of *ports under construction* in TN State. The project cost details as provided in newspaper articles/reports is assumed to be the project cost of the *proposed ports* in TN.

Average set up cost	Min replacement costs	Max replacement costs
Container Terminal (Rs. crores per Million Twenty-foot Equivalent Units)	781.3	938.0
Other Terminals (Rs. crores per Million Tonnes Per Annum)	40	83.0

1 Computed as Total project cost/Total Capacity.
2 The project cost of the prototype fast breeder reactor at Kalpakkam was revised upwards in a recent newspaper report. Hence the revised project cost is assumed to be the replacement cost of the plant.
3 The project cost of the thermal and gas turbine power plants includes cost of land and construction. This applies to existing power plants as well as to those under construction.
4 The valuation exercise excludes the Kanyakumari, Colachel, Valinokkam, Rameshwaram and Pamban ports as these have no activity, offer only ferry services or have low capital investments.
5 The project cost of the operational ports, ports under construction and the proposed ports in TN State, includes the cost of built up infrastructure only.

Mangroves

There have been several studies conducted on valuation of wetlands/mangroves world over. One method of valuing the mangroves is identifying the actual cost incurred to regenerate the mangroves. A study sponsored by the Gujarat ecology commission values this at approx. Rs.12,000 per hectare. However this method fails to capture the various benefits that mangroves offer to the society.

The methodologies adopted here are based on or derived from the following:

- UNEP/GPA 2003;
- Sathirathai and Barbier 2001;
- Stern 2007;
- Govt. of TN – Department of Economics and Statistics;
- Jarvis et al. 2006;
- Landsat 7 satellite images.

TN State, which has approx. 1,076 km long coastline, has mangrove forests in Pichavaram, Vedaraniyam and Gulf of Mannar.

The following table summarises estimates of annual economic value of mangroves on a per hectare basis compiled from two international studies:

Study	Min. Value (ha-1 yr-1)*	Max. Value (ha-1 yr-1)*
Sathirathai and Barbier 2001	Rs. 170,442.9	Rs. 172,606.5
UNEP/GPA 2003	Rs. 638,770.5	Rs. 694,930.5

**Assumed an exchange rate of Rs. 45/USD*

The study by Sathirathai and Barbier (2001) arrives at the economic value of mangroves by valuing one direct use benefit and two indirect use benefits. The UNEP/GPA study on the other hand focuses on a range of benefits including direct use value, indirect use value, option value and non-use value. Given the long-term social benefits of mangroves, a social discount rate of 1.4% is used, following the recommendations of the Stern Review (Stern 2007) and others (e.g., Gunawardena and Rowan 2005). Based on the valuation range from the two international studies, the minimum and maximum annual economic value of mangroves has been derived on a per hectare basis.

Type of wetland	Min. Value (ha-1 yr-1)	Max. Value (ha-1 yr-1)
Mangroves	Rs. 170,442.9	Rs. 694,930.5

The range of *annual economic values* for Pichavaram, Vedaraniyam and Gulf of Mannar is computed in the following manner:

Minimum annual economic value of mangroves/hectare x Area under mangrove cover
Maximum annual economic value of mangroves/hectare x Area under mangrove cover

The present value of the mangroves lying below 10metre elevation from sea level over a 40-year horizon was estimated between Rs.3,607.8 – Rs.14,709.5 crores at a 1.4% discount rate.

Land

The methodology adopted was based on or derived from the following:

- Jarvis et al. 2006
- Interviews with real estate agents

The coastal strip of TN State is situated at various levels of elevation above current mean sea level. TN State has approximately 19 lakh acres of coastal land lying below the 10-metre elevation above current sea level. The value of property below 10 metres is computed in the following manner: Area of coastal TN below 10 metre elevation above sea level x maximum/minimum market value of land in coastal TN on a per/acre basis.

The maximum and minimum market value of land across various locations in TN within 1 km from the coast was obtained in the following manner:

1. Telephonic interviews with real-estate agents operating in various coastal locations of TN State

to obtain prices of agricultural/ residential/ commercial properties.
and/or;
2. Referring to online real estate websites to obtain prices of agricultural, residential and/(or) commercial properties in coastal TN.

East Coast Road (ECR)

East coast road in TN State runs from Chennai in the north to Tuticorin in the south (including existing roads and the proposed road development plan).

We gathered information on project cost, number of lanes and length of 23 national highway projects awarded in 2010 from National Highways Authority of India (NHAI) and other sources. Based on this information we arrived at the minimum and maximum cost of constructing a lane km of road in India, which falls in the range of Rs.1.5 crores to Rs.4.1 crores.

The analysis was based on information from the following:

- NHAI – PPP projects awarded during 2008-09 and 2009-10;
- NHAI – National Highway Development Programmes;
- Tamil Nadu Road Development Company;
- Newspaper articles;
- Industry interaction;
- Landsat 7 satellite images.

The replacement value of ECR is computed in the following manner:

Length of the ECR below 10 metre elevation x No of lanes on ECR x Minimum/Maximum cost of laying a lane km of road[1].

6 Computed as follows:
Total project cost/((Existing no of lanes*50% + New lanes constructed*100%) x Total length of the road)

Project cost includes cost of construction while excluding land acquisition costs and rehabilitation & resettlement costs. NHAI undertakes projects for (1) constructing 2 lane highways, (2) upgrading 2 lane highways to 4 lane highways and (3) upgrading 4 lane highways to 6 lane highways. Based on industry interaction it was understood that, the cost and effort incurred to construct new lanes is twice that incurred for improvements to the existing lanes. Hence the total number of lanes is adjusted for the same while computing the cost per lane km (refer to the formula left).

Appendix 2: Valuation

1. Mangroves

The following table summarises the area of the wetlands in Pichavaram, Vedaraniyam and Gulf of Mannar under various elevations above sea level:

		AREA (IN HECTACRES)				
Mangroves	District	Up to 1 metre	Up to 2 metres	Up to 3 metres	Up to 5 metres	Up to 10 metres
Pichavaram	Cuddalore	551.0	892.0	1,163.0	1,367.0	1,415.0
Vedaraniyam	Nagapattinam	3,970.0	4,376.0	4,537.0	4,654.0	4,662.0
Gulf of Mannar	Rameshwaram	115.0	220.0	378.0	674.0	870.0
Total (Hectares)		**4,636.0**	**5,488.0**	**6,078.0**	**6,695.0**	**6,947.0**

The annual economic value of the mangroves in Pichavaram, Vedaraniyam and Gulf of Mannar at different levels of elevation from sea level is as given below:

	ANNUAL ECONOMIC VALUE OF ECOSYSTEM SERVICES									
Cumulative	Up to 1 metre		Up to 2 metres		Up to 3 metres		Up to 5 metres		Up to 10 metres	
In Rs. crores	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Pichavaram	9.4	38.3	15.2	62.0	19.8	80.8	23.3	95.0	24.1	98.3
Vedaraniyam	67.7	275.9	74.6	304.1	77.3	315.3	79.3	323.4	79.5	324.0
Gulf of Mannar	2.0	8.0	3.7	15.3	6.4	26.3	11.5	46.8	14.8	60.5
Total (Hectares)	**79.0**	**322.2**	**93.5**	**381.4**	**103.6**	**422.4**	**114.1**	**465.3**	**118.4**	**482.8**

The total value of mangroves at various elevations above current sea level is represented in the table below. The table represents in present value terms the annual economic value of mangroves in TN State over a 40-year horizon at a 1.4% discount rate.

	PRESENT VALUE (Discount rate – 1.4%)									
Cumulative	Up to 1 metre		Up to 2 metres		Up to 3 metres		Up to 5 metres		Up to 10 metres	
In Rs. crores	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Pichavaram	286.1	1,166.7	463.2	1,888.7	604.0	2,462.5	709.9	2,894.5	734.8	2,996.1
Vedaraniyam	2,061.7	8,406.1	2,272.6	9,265.7	2,356.2	9,606.6	2,416.9	9,854.4	2,421.1	9,871.3
Gulf of Mannar	59.7	243.5	114.3	465.8	196.3	800.4	350.0	1,427.1	451.8	1,842.1
TOTAL	**2,407.6**	**9,816.2**	**2,850.1**	**11,620.3**	**3,156.5**	**12,869.5**	**3,476.9**	**14,176.0**	**3,607.8**	**14,709.5**

Scenario Analysis

For comparison purposes, the following tables show the present value of the annual economic value of the mangroves in TN State over a 40-year horizon at different rates of discount i.e. 10%, 12% and 15%.

PRESENT VALUE (Discount rate – 10%)										
Cumulative	Up to 1 metre		Up to 2 metres		Up to 3 metres		Up to 5 metres		Up to 10 metres	
In Rs. crores	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Pichavaram	91.8	374.4	148.7	606.2	193.8	790.3	227.8	929.0	235.8	961.6
Vedaraniyam	661.7	2,697.9	729.4	2,973.8	756.2	3,083.2	775.7	3,162.7	777.0	3,168.2
Gulf of Mannar	19.2	78.2	36.7	149.5	63.0	256.9	112.3	458.0	145.0	591.2
TOTAL	**772.7**	**3,150.5**	**914.7**	**3,729.5**	**1,013.1**	**4,130.5**	**1,115.9**	**4,549.8**	**1,157.9**	**4,721.0**

PRESENT VALUE (Discount rate – 12%)										
Cumulative	Up to 1 metre		Up to 2 metres		Up to 3 metres		Up to 5 metres		Up to 10 metres	
In Rs. crores	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Pichavaram	77.4	315.7	125.3	511.0	163.4	666.3	192.1	783.1	198.8	810.6
Vedaraniyam	557.8	2,274.4	614.9	2,506.9	637.5	2,599.2	653.9	2,666.2	655.1	2,670.8
Gulf of Mannar	16.2	65.9	30.9	126.0	53.1	216.6	94.7	386.1	122.2	498.4
TOTAL	**651.4**	**2,655.9**	**771.1**	**3,144.0**	**854.0**	**3,482.0**	**940.7**	**3,835.5**	**976.1**	**3,979.8**

PRESENT VALUE (Discount rate – 15%)										
Cumulative	Up to 1 metre		Up to 2 metres		Up to 3 metres		Up to 5 metres		Up to 10 metres	
In Rs. crores	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Pichavaram	62.4	254.3	101.0	411.7	131.7	536.8	154.8	630.9	160.2	653.1
Vedaraniyam	449.4	1,832.4	495.4	2,019.8	513.6	2,094.1	526.9	2,148.1	527.8	2,151.8
Gulf of Mannar	13.0	53.1	24.9	101.5	42.8	174.5	76.3	311.1	98.5	401.6
TOTAL	**524.8**	**2,139.8**	**621.3**	**2,533.0**	**688.1**	**2,805.3**	**757.9**	**3,090.1**	**786.4**	**3,206.4**

2. Ports

Replacement cost of all the ports in Tamil Nadu along with the details of district and status of the project is given in the table given below:

	Port	District	Replacement cost (Rs. Crores)		Status	Elevation Level
			Min	Max		
1	Ennore Port Trust	Thiruvallur	5,676.7	6,364.6	Existing	< 1 metre
2	Ennore Minor Port	Thiruvallur	54.0	54.0	Existing	< 1 metre
3	Kattupalli Port	Thiruvallur	3,375.0	3,375.0	Under construction	< 1 metre
4	Chennai Port trust	Chennai	7,639.3	9,786.0	Existing	< 1 metre
5	Mugaiyur Port	Kanchipuram	500.0	500.0	Under construction	< 1 metre
6	Marakkanam Port	Villupuram	400.0	830.0	Proposed	< 1 metre
7	Thiruchopuram Port	Cuddalore	1,800.0	1,800.0	Under construction	< 1 metre
8	Silambimangalam Shipyard port	Cuddalore	500.0	500.0	Under construction	< 1 metre
9	Cuddalore Port	Cuddalore	150.0	150.0	Existing	< 1 metre
10	Py-03 Oil field	Cuddalore	75.4	75.4	Existing	< 1 metre
11	Parangipettai Port	Cuddalore	1,300.0	1,300.0	Proposed	< 1 metre
12	Kaveri Port	Nagapattinam	200.0	200.0	Under construction	< 1 metre
13	Vanagiri Port	Nagapattinam	250.0	250.0	Under construction	< 1 metre
14	Thirukkuvalai Port	Nagapattinam	650.0	650.0	Under construction	< 1 metre
15	Thirukkadaiyur Port	Nagapattinam	372.6	372.6	Existing	< 1 metre
16	Nagapattinam Port	Nagapattinam	400.0	400.0	Existing	< 1 metre
17	Manappad Port	Tuticorin	1,800.0	1,800.0	Under construction	< 1 metre
18	Tuticorin Port Trust	Tuticorin	6,185.3	7,055.6	Existing	< 1 metre
19	Udangudi Port	Tuticorin	600.0	600.0	Proposed	< 1 metre
20	Kudankulam Port	Tirunelveli	531.8	531.8	Existing	< 1 metre
	TOTAL		**32,460.1**	**36,595.0**		

3. Land

The table below captures the land area in each of TN's coastal districts at various heights above current sea level:

		LAND AREA (IN ACRES)				
	District	Up to 1 metre	Up to 2 metres	Up to 3 metres	Up to 5 metres	Up to 10 metres
1	Thiruvallur	13,640	27,721	46,133	84,849	1,61,163
2	Chennai	1,241	2,073	3,139	6,335	21,655
3	Kanchipuram	21,482	34,112	49,164	78,818	1,52,629
4	Villupuram	5,518	11,853	19,010	29,317	47,248
5	Cuddalore	11,882	21,328	35,685	76,150	1,92,230
6	Nagapattinam	1,45,869	1,97,519	2,57,300	3,79,831	5,69,567
7	Thiruvarur	35,570	50,433	65,701	99,809	2,17,353
8	Thanjavur	12,867	17,321	21,926	32,602	61,996
9	Pudukottai	1,419	3,320	7,066	17,160	43,700
10	Ramanathapuram	12,086	22,326	35,314	83,684	2,88,935
11	Tuticorin	7,874	14,154	24,674	57,434	1,55,922
12	Tirunelveli	73	87	140	656	7,368
13	Kanyakumari	104	177	337	985	6,680
	TOTAL	**2,69,625**	**4,02,424**	**5,65,588**	**9,47,629**	**19,26,446**

The following table highlights the market value of land at different elevations above current sea level:

LAND VALUE (in Rs. Crores)										
District	Up to 1 metre		Up to 2 metres		Up to 3 metres		Up to 5 metres		Up to 10 metres	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Thiruvallur	5,456	1,48,558	11,088	3,01,925	18,453	5,02,460	33,939	9,24,130	64,465	17,55,309
Chennai	45,072	90,145	75,247	1,50,494	1,13,967	2,27,934	2,29,976	4,59,951	7,86,197	15,72,395
Kanchipuram	2,148	3,89,960	3,411	6,19,217	4,916	8,92,450	7,882	14,30,749	15,263	27,70,597
Villupuram	993	12,022	2,133	25,823	3,422	41,416	5,277	63,871	8,505	1,02,936
Cuddalore	1,188	72,481	2,133	1,30,107	3,568	2,17,684	7,615	4,64,531	19,223	11,72,643
Nagapatti-nam	1,823	5,72,037	2,469	7,74,582	3,216	10,09,019	4,748	14,89,533	7,120	22,33,596
Thiruvarur	711	34,098	1,009	48,345	1,314	62,982	1,996	95,678	4,347	2,08,356
Thanjavur	386	19,623	520	26,415	658	33,439	978	49,719	1,860	94,547
Pudukottai	28	355	66	830	141	1,767	343	4,292	874	10,930
Ramana-thapuram	725	5,439	1,340	10,047	2,120	15,891	5,023	37,658	17,344	1,30,021
Tuticorin	157	11,811	283	21,231	493	37,011	1,149	86,151	3,118	2,33,883
Tirunelveli	4	796	4	955	7	1,523	33	7,160	368	80,399
Kanyakumari	26	156	44	266	84	506	246	1,479	1,670	10,025
TOTAL	**58,720**	**13,57,479**	**99,748**	**21,10,237**	**1,52,361**	**30,44,082**	**2,99,205**	**51,14,901**	**9,30,354**	**1,03,75,636**

4. East Coast Road

The following table shows the length of the ECR lying at different elevations above current sea level by district:

EAST COAST ROAD (cumulative length -kms)						
District	**Up to 1 metre**	**Up to 2 metres**	**Up to 3 metres**	**Up to 5 metres**	**Up to 10 metres**	**> 10 metres**
Chennai	0.4	0.6	0.8	2.0	12.7	15.1
Kanchipuram	2.8	7.5	11.6	21.0	73.2	96.3
Villupuram	0.1	0.9	2.7	7.8	17.2	36.4
Cuddalore	1.0	3.4	7.2	21.4	52.2	56.9
Nagapattinam	26.0	41.9	56.7	81.9	124.8	130.6
Thiruvarur	2.7	4.5	5.7	8.9	19.1	19.5
Thanjavur	6.4	14.2	22.3	33.7	40.7	40.8
Pudukottai	1.2	5.5	14.4	30.2	38.9	38.9
Ramanathapuram	2.4	7.4	15.7	46.4	100.3	137.1
Tuticorin	-	-	0.4	5.4	36.0	47.3
TOTAL	**43.1**	**86.0**	**137.5**	**258.6**	**515.1**	**618.9**

The minimum and maximum cost of replacing the ECR at different elevations above current sea level is summarised in the table below

EAST COAST ROAD (replacement value in Rs. Crores)												
Elevation Level	**Up to 1 metre**		**Up to 2 metres**		**Up to 3 metres**		**Up to 5 metres**		**Up to 10 metres**		**> 10 metres**	
In Rs. crores	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Chennai	1.2	3.2	1.8	5.1	2.4	6.7	5.9	16.3	38.0	104.3	45.3	124.6
Kanchipuram	8.5	23.3	22.6	62.2	34.9	95.9	62.9	172.9	219.7	603.8	288.8	793.7
Villupuram	0.4	1.0	2.8	7.7	8.0	22.0	23.5	64.6	51.6	141.8	109.2	300.1
Cuddalore	3.1	8.7	10.3	28.4	21.5	59.2	64.2	176.5	156.5	430.0	170.8	469.5
Nagapattinam	77.9	214.2	125.7	345.5	170.0	467.2	245.8	675.6	374.4	1,028.9	391.7	1,076.6
Thiruvarur	8.2	22.4	13.5	37.2	17.1	47.0	26.7	73.4	57.3	157.4	58.6	160.9
Thanjavur	19.1	52.4	42.5	116.8	67.0	184.2	101.0	277.5	122.2	336.0	122.3	336.1
Pudukottai	3.6	10.0	16.4	45.1	43.3	118.9	90.7	249.2	116.7	320.9	116.7	320.9
Ramana-thapuram	7.3	20.2	22.3	61.4	47.0	129.3	139.1	382.3	300.9	827.0	411.2	1,130.1
Tuticorin	-	-	-	-	1.1	3.0	16.1	44.2	108.1	297.2	141.9	390.1
TOTAL	**129.3**	**355.4**	**258.1**	**709.3**	**412.4**	**1,133.4**	**775.9**	**2,132.5**	**1,545.3**	**4,247.2**	**1,856.6**	**5,102.6**

5. Power Plant

The following table gives a snapshot of power plants in coastal TN which fall below 10 metre elevation from sea level

Power Plant	District	Type	Status	Elevation Level
Vallur thermal power station	Thiruvallur	Thermal	Under construction	3 to 5 metres
North Chennai thermal power station Stage 2: Unit 1	Thiruvallur	Thermal	Under construction	3 to 5 metres
North Chennai thermal power station Stage 2: Unit 2	Thiruvallur	Thermal	Under construction	3 to 5 metres
Ennore thermal power station	Thiruvallur	Thermal	Operational	5 to 10 metres
Basin Bridge power station	Chennai	Gas	Operational	5 to 10 metres
Madras atomic power station 1	Kanchipuram	Nuclear	Operational	5 to 10 metres
Madras atomic power station 2	Kanchipuram	Nuclear	Operational	5 to 10 metres
Prototype Fast Breeder Reactor: Kalpakkam	Kanchipuram	Nuclear	Under construction	5 to 10 metres

The minimum and maximum replacement value of thermal/gas turbine/nuclear power plants is summarised in the table below:

Power Plant	Total Installed Capacity	Min Replacement Cost	Max Replacement Cost	Elevation
	In MW	In Rs. Crores	In Rs. Crores	
Vallur thermal power station	1,500	8,000.00	8,000.00	3 to 5 metres
North Chennai thermal power station Stage 2: Unit 1	600	3,095.30	3,095.30	3 to 5 metres
North Chennai thermal power station Stage 2: Unit 2	600	2,718.80	2,718.80	3 to 5 metres
Ennore thermal power station	450	1,800.00	2,662.50	5 to 10 metres
Basin Bridge power station	120	285.98	462.69	5 to 10 metres
Madras atomic power station 1	220	1,448.80	2,464.00	5 to 10 metres
Madras atomic power station 2	220	1,448.80	2,464.00	5 to 10 metres
Prototype Fast Breeder Reactor: Kalpakkam	500	5,600.00	5,600.00	5 to 10 metres
TOTAL		**24,396.6**	**27,467.2**	

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Glossary

Coastal Erosion:	The wearing away of coastal land from natural forces such as waves, wind, tides, uplift of land, storms, sea level rise and catastrophic events leads to erosion. Human activities such as building of ports, harbours, sea walls, water extraction also lead to erosion.
Mangroves:	Trees and shrubs that are adapted to growing in saline conditions and are generally found in coastal habitats. This term may be used generally to refer to plants in such areas or more specifically to the family of plants from Rhizophoraceae.
Sea Walls	An embankment that is used to prevent erosion of the shoreline and protect the inland from flooding due to major storms. It is typically a massive, stone and concrete structure with its weight providing stability against sliding forces and overturning moments. Groins and breakwaters are other forms of shore protection structures that attempt to reduce the impact of wave energy.
Storm Surge	The rising of the water level due to the low pressure, high winds, and high waves associated typically with a hurricane or tropical cyclone as it makes landfall. Storm surges cause water to pile up against the coast.
Storm Wave	Increased wave height and steepness of waves during storms.

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