Ocean & Coastal Management 69 (2012) 327–339

Contents lists available at SciVerse ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Predicted impact of the sea-level rise at Vellar–Coleroon estuarine region of Tamil Nadu coast in India: Mainstreaming adaptation as a coastal zone management option

A. Saleem Khan [a,*], A. Ramachandran [a], N. Usha [b], S. Punitha [c], V. Selvam [c]

[a] Centre for Climate Change and Adaptation Research, Anna University, C.E.G. Campus, Sardar Patel Road, Chennai 600 025, Tamil Nadu, India
[b] Centre for Environmental Studies, Anna University, C.E.G. Campus, Sardar Patel Road, Chennai 600 025, Tamil Nadu, India
[c] Coastal System Research, M.S. Swaminathan Research Foundation, Institutional Area, Taramani, Chennai 600 113, Tamil Nadu, India

ARTICLE INFO

Article history:
Available online 23 August 2012

ABSTRACT

Low-lying coastal areas are more vulnerable to the impacts of climate change as they are highly prone for inundation to SLR (Sea-Level Rise). This study presents an appraisal of the impacts of SLR on the coastal natural resources and its dependent social communities in the low-lying area of Vellar–Coleroon estuarine region of the Tamil Nadu coast, India. Digital Elevation Model (DEM) derived from SRTM 90M (Shuttle Radar Topographic Mission) data, along with GIS (Geographic Information System) techniques are used to identify an area of inundation in the study site. The vulnerability of coastal areas in Vellar-Coleroon estuarine region of Tamil Nadu coast to inundation was calculated based on the projected SLR scenarios of 0.5 m and 1 m. The results demonstrated that about 1570 ha of the LULC (Land use and Land cover) of the study area would be permanently inundated to 0.5 m and 2407 ha for 1 m SLR and has also resulted in the loss of three major coastal natural resources like coastal agriculture, mangroves and aquaculture. It has been identified that six hamlets of the social communities who depend on these resources are at high-risk and vulnerable to 0.5 m SLR and 12 hamlets for 1 m SLR. From the study, it has been emphasized that mainstreaming adaptation options to SLR should be embedded within a coastal zone management and planning effort, which includes all coastal natural resources (ecosystem-based adaptation), and its dependent social communities (community-based adaptation) involved through capacity building.

1. Introduction

One of the most likely consequences of global warming is an accelerated Sea-Level Rise (SLR) mainly due to oceanic thermal expansion and melting of glaciers, Greenland and Antarctic ice sheets (Ragoonaden, 2006). Comparison of the rate of SLR over the last two millennia indicates a relatively recent acceleration in the rate of SLR in the last century (IPCC, 2001). According to IPCC Third Assessment Report (TAR), the global SLR in the 20th century was between 10 and 20 cm and predicted that a further accelerated rise of 9–88 cm will occur between 1990 and 2100 with a mid-estimate of 48 cm (Kennedy et al., 2002). This faster rate of the SLR estimated at 1–2 mm per year (Boesch, 2002) is caused by human-induced global warming. Whereas, IPCC Fourth Assessment Report (AR4) projected a global SLR of 18–59 cm from 1990 to the 2090s (Rahmstorf, 2010). These ranges are narrower than in the TAR, mainly because of improved information about some uncertainties in the projected contributions (IPCC, 2007). However, the global mean SLR will not be uniform around the world since the local change in sea level at any coastal location depends on the sum of global, regional, and local factors, which is termed as relative sea-level change (Nicholls and Leatherman, 1996). Relative SLR is a major factor contributing to recent losses and projected future reductions in the area of valued coastal habitats, including mangroves and other tidal wetlands, with a concomitant increased

Abbreviations: DEM, Digital Elevation Model; DGPS, Differential Global Positioning System; GIS, Geographic Information Systems; ICZM, Integrated Coastal Zone Management; IRS, Indian Remote sensing Satellite; ISRO, Indian Space Research Organization; LISS, Linear Image Self scanning Sensor; LULC, Land Use and Land Cover; MSL, Mean Sea Level; NAPA, National Adaptation Programs of Action; NAPCC, National Action Plan on Climate Change; NRSC, National Remote Sensing Centre; RF, Reserve Forest; SLR, Sea-Level Rise; SRTM, Shuttle Radar Topographic Mission; UTM, Universal Transverse Mercator coordinate system.

* Corresponding author. Tel.: +91 44 2235 7464; fax: +91 44 2235 2244.
E-mail address: asaleemkhan.cc@gmail.com (A. Saleem Khan).

0964-5691/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ocecoaman.2012.08.005

threat to human safety and shoreline development from coastal hazards (Gilman, 2004; Gilman et al., 2007). Many of the world's coastal wetlands have suffered significant losses during this century. This is a concern because they provide valuable services, such as flood protection and fisheries production, for a global human population that is increasingly concentrated near the coast and dependent on its resources (The working group on sea level rise and wetland system, 1997). Moreover, the direct effect of inundation is the potential large loss of inhabited areas, particularly in low-lying, flat deltaic and estuarine areas. Half of humanity inhabits the coastal regions around the globe, and large areas of highly vulnerable flood prone sections are densely populated (IPCC, 1990). On the other hand, the response of coastal ecosystems to climate change and SLR is strongly influenced by continuing developments, i.e. Developments that in many cases lead to over-exploitation of resources, pollution, sediment starvation and fragmentation of ecosystems through urbanization and development of infrastructure (World Coast Conference, 1993). These developments will, on an increasing scale: lead to a decrease in the resilience of coastal systems in coping with natural climate variability; adversely affect the natural capability of the systems to adapt to changes in climate; lead to the increased hazard potential for coastal population, infrastructure and investments, therefore, the assessment of impacts of climate change in coastal areas involves the estimation of the additional risk that is posed by climate change to systems that already are under significant stress (Bijlsma, 1997). Thus, predictions of changes in coastal ecosystem boundaries, in response to projected relative SLR, enables advanced planning appropriate for specific sections of coastline to minimize and offset anticipated losses and reduce threats to coastal development and human safety (Gilman et al., 2007). The objective of this study is to identify and quantify the coastal natural resources and its dependent social communities to the adverse impact of SLR using GIS and to mainstream, the importance of coastal adaptation to SLR. The study employed two projected SLR scenarios viz., 0.5 m and 1 m. These scenarios are fixed based on the model predictions on the rise in sea level of 21st century, which is likely to be in the range of 9–88 cm (Church et al., 2001) and the impact of SLR in the study area is studied. This study assesses the vulnerability of coastal natural resources like agriculture, mangroves and aquaculture, etc., and its dependent social communities to the predicted impact of SLR at Vellar–Coleroon estuarine region of Tamil Nadu coast. Very importantly, adaptation to SLR is emphasized and recommended as a coastal zone management option.

2. Study area

The study area Vellar–Coleroon estuarine region (11°30′14.69 N, 79°46′ 38.14 E; 11°21′41.40 N, 79°49′ 51.24 E) is situated on the southeast coast of India in the Tamil Nadu State (Fig. 1). It is located at about 225 km south of Chennai and 5 km north east of Chidambaram, Cuddalore district, Tamil Nadu (Planning Commission, 2008). The district is predominantly a flood and cyclone prone district (AIMS, 2000) and the present study area is affected by frequent cyclones almost every alternate year (Muniyandi, 1986; Kathiresan, 2000). The 2004 Sumatra Tsunami left a deep and dark footprint on coastal Cuddalore in Southeast India, which was one of the worst affected districts of the mainland (Murthy et al., 2011). The recent severe cyclonic storm "Thane" was the strongest tropical cyclone of 2011 and Cuddalore has been the worst-hit district (CCFID, 2012). The present study area is located in the southern part of the coastal region of Cuddalore district with Vellar estuary located at northern part, which is dominated by mud flats, while the southern part is the Coleroon estuary which possesses predominantly mangrove vegetation. The Vellar estuary opens into the Bay of Bengal at Parangipettai and links with Coleroon river, which are distributaries to the river Cauvery. The tides of the study area are semi-diurnal and vary in amplitude from about 15–100 cm in different regions during different seasons, reaching a maximum during monsoon and post-monsoon and a minimum during the summer (Muniyandi, 1986; Kathiresan, 2000). The rise and fall of the tidal waters are through a direct connection with the sea at the Chinnavaikkal mouth and also through the two adjacent estuaries (Kathiresan, 2000; Rajkumar et al., 2009). The Mean Sea Level (MSL) at Killai railway station of the study area is noted as 3.05 m concerning the revised local reference datum of tide gauge at Cuddalore port, this may not be applicable to entire study area. However, official record of the exact MSL of the study area is not available. The nearest tide gauge station with available tidal data in the study area is Chennai. Sea level change calculated using the Chennai tide gauge data recorded for 54 years during 1952–2005 indicates a value of 0.085 mm/y (Mahendra et al., 2011). An added risk factor is that large parts of the coastal zone (Cuddalore) are low-lying with gentle slope resulting large inundation, thus increasing the vulnerability of the region. The southern parts of the Cuddalore district near Chidambaram town in the vicinity of the Kolladam (Coleroon) river indicate larger areas under threat due to multiple hazards, because of lower mean elevation (Mahendra et al., 2011). The Pichavaram mangrove wetland is located between these two rivers (Vellar and Coleroon), and it has been classified as three Reserve Forest (RF), viz., Killai RF, Pichavaram RF and Pichavaram Extension Area (Selvam et al., 2004). The Killai and Pichavaram mangrove wetlands were declared as Reserve Forests (RFs) in 1893 with a total area of 1266 ha. Later, in 1897, an area of 92 ha was included in the RF as Extension area. Thus, the total area of the Pichavaram mangrove wetland is about 1358 ha (Selvam et al., 2002). The study area is covered by alluvium in the western part and fluvial marine, and beach sands in the eastern part and agriculture land in the northern part. The vegetated land of this study area is classified as agricultural land, mangroves and tidal swamps and the non-vegetated area consists of mud flats, beach spits and sand bars along lagoon estuaries. The Pichavaram mangrove area occurs on 51 islets, ranging in size from 10 m^2 to 2 km^2, separated by intricate waterways that connect the Vellar and Coleroon estuaries (Kathiresan, 2000). The social communities that live in this coastal region and directly depend on these resources belong to 20 hamlets of five major revenue villages (small administrative region in India, a village with defined borders. One revenue village may contain many hamlets) (Fig. 2).

3. Materials and methods

3.1. LULC and hamlet mapping approach

3.1.1. Data source

IRS P6 LISS IV with 5.8 m resolution data of 09th May 2009 was procured on 28th February 2011 from NRSC, Department of Space, Government of India and 1:50,000 toposheet No. 58 M/15 from Survey of India.

3.1.2. Preparation of study area boundary

Study area boundaries were extracted from the topographic maps obtained from Survey of India (Toposheet No. 58 M 15), in the scale of 1:50,000 by manual digitizing methods.

3.1.3. Image processing

In the preprocessing phase, the data sets were cut to include only the area of interest (11°30′14.69 N, 79°46′ 38.14 E; 11°21′41.40 N, 79°49′ 51.24 E), i.e. Vellar–Coleroon estuarine region in the east coast of Tamil Nadu, India. Since the digital data do not

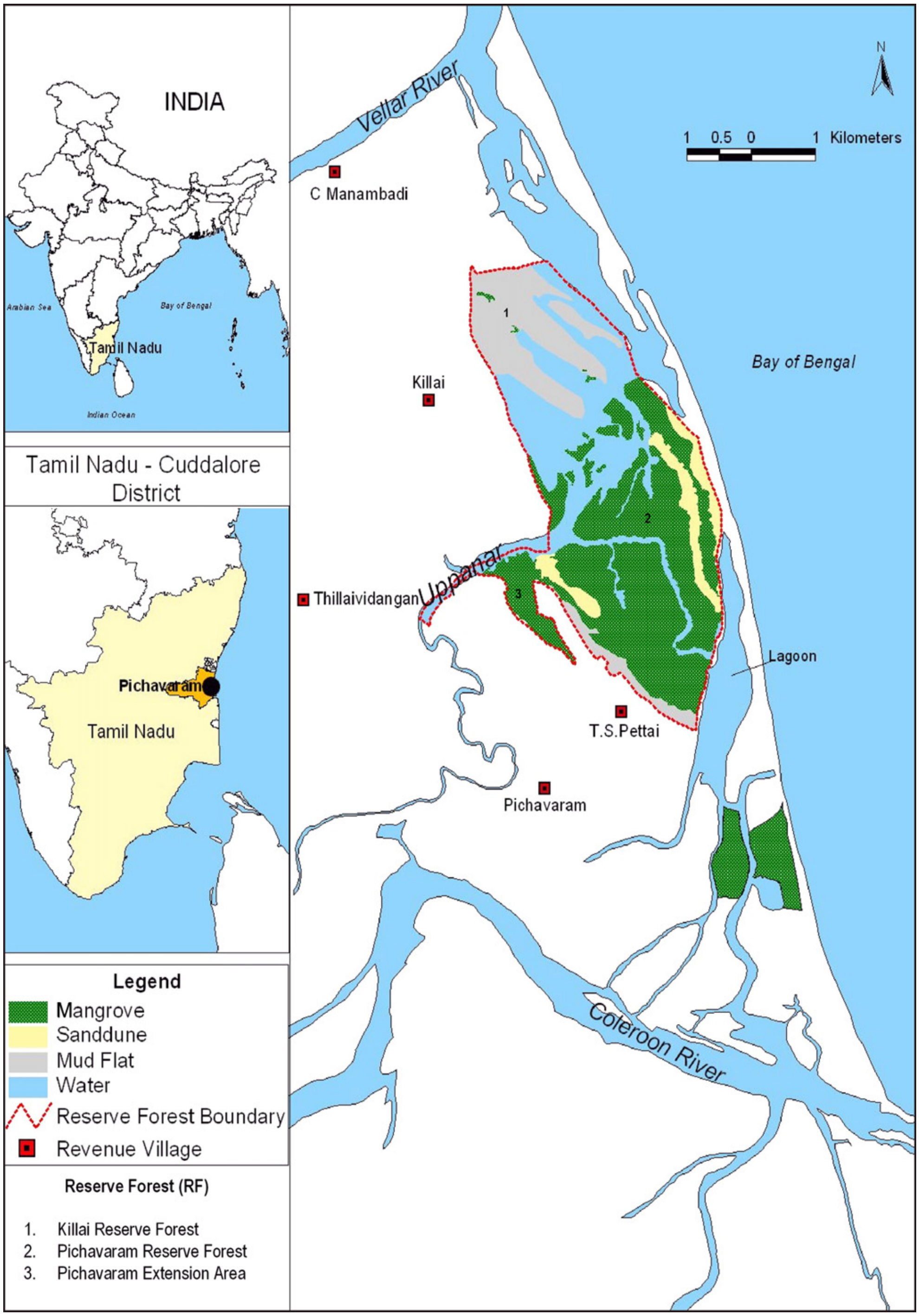

Fig. 1. Study area map.

have the real earth coordinates, they were geometrically corrected using a reference image by taking common feature (Kumar et al., 2012) and by using ERDAS imagine version 9 digital image-processing software. Thus, the satellite image was rectified for geometric errors using 1:50,000 scale survey of India toposheet as a base, in cartographic projection (UTM Zone 44N, WGS84).

3.1.4. Classification (supervised image classification and visual interpretation)

Supervised signature extraction with the maximum likelihood algorithm was employed to classify the image, because this classification algorithm produces consistently good results for most habitat types (Donoghue and Mironnet, 2002; Ardil and Wolff, 2009). Training site data were collected by on-screen selection of polygonal training data method (Weng, 2002) based on extensive field knowledge. To increase the size of the sample to be used in the classification accuracy assessment, the layer with the field checked sites was overlaid on the corrected satellite images and homogeneous polygons with similar spectral reflectance, when viewed in several band combinations, were drawn those sites and the layer of polygons created using this process was later used for checking the accuracy of the classified map (Ardil and Wolff, 2009). After ground

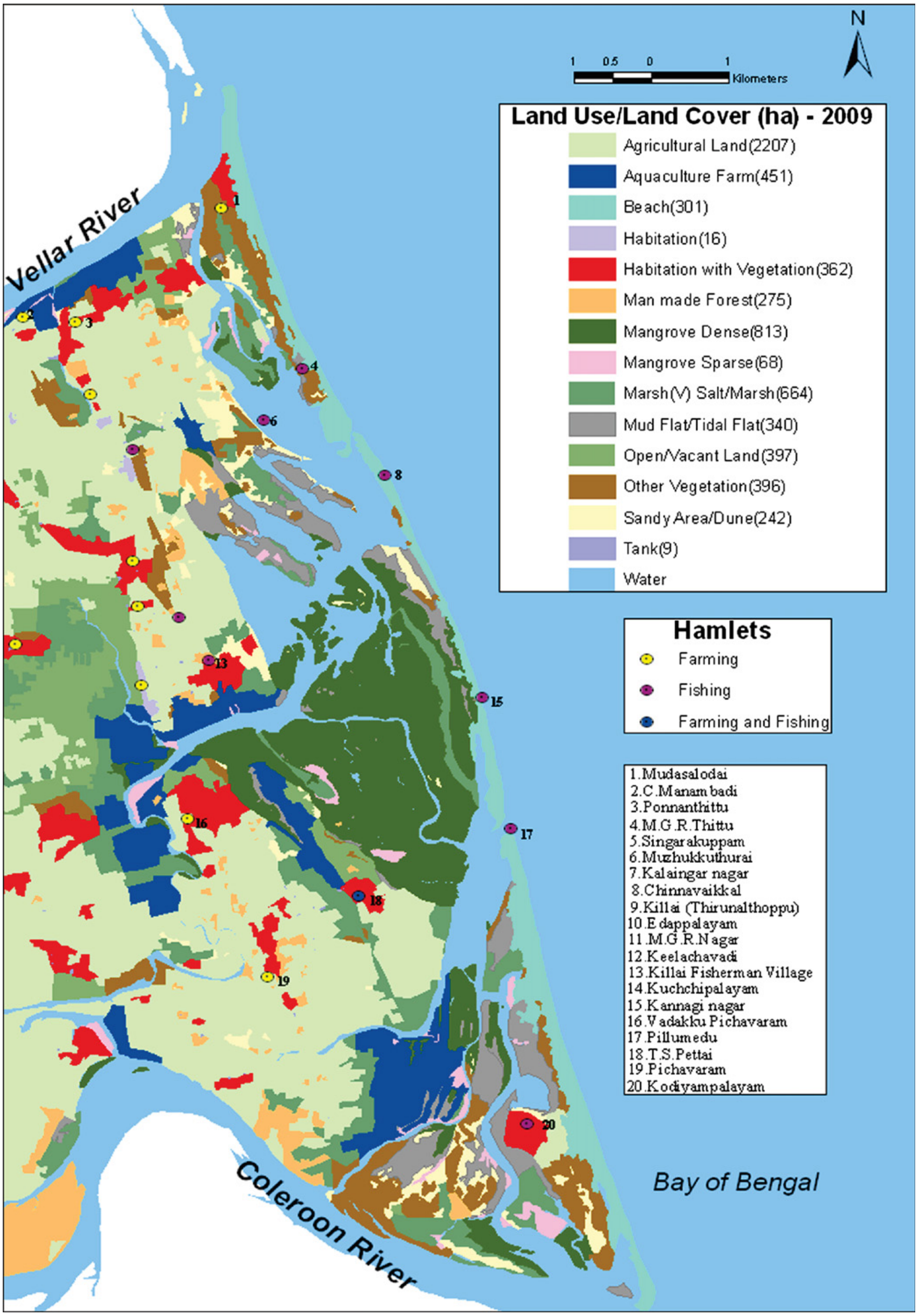

Fig. 2. LULC and hamlets location map of the study area.

truth verification, 2009 LULC was prepared by using the visual interpretation method. ERDAS imagine version 9 is used for image processing and analysis, and Arc GIS version 9.3 was used for GIS analysis.

3.1.5. Accuracy assessment

Accuracy assessment of the LULC map of Vellar–Coleroon estuarine region of Tamil Nadu Coast was done based on ground truth points recorded during the field survey. An error matrix was used in this study to calculate overall classification accuracy. Quantifying and documenting the accuracy of maps and spatial data are important components of any mapping process (Muller et al., 1998).

3.1.6. Post-classification analysis

The classified images were transferred to the GIS facilities to produce the final LULC map. Analysis and quantification of LULC included in the GIS database, and they were tabulated. The characterization of land cover is made from cumulative measurements of area by cover based on the data source available for the study area (2009).

3.1.7. Hamlet locations

Hamlets of social communities who depend on these coastal natural resources are identified based on secondary sources (Selvam et al., 2002). The revenue village map and hamlets geographical locations based on latitude and longitude values are superimposed over 2009 LULC map using Arc GIS 9.3.

3.2. Computation of inundation zone to predicted SLR

3.2.1. Data source

Arc GIS 9.3 is used to superimpose the inundation zones with the 2009 LULC resource map of the study area along with hamlets location for the projected SLR of 0.5 m and 1 m. For this purpose, an application was then developed using publicly available SRTM 90 m digital elevation data sets for the Indian subcontinent. The absolute vertical accuracy of the SRTM DEM is about 15 m, and the relative accuracy to the coastline is less than 1 m (Demirkesen et al., 2008).

3.2.2. Generation of Digital Elevation Model (DEM)

Elevation is one of the most important parameters that determines the vulnerability of coastal lands to inundation from flooding events and SLR (Gesch et al., 2009). Coastal inundation impact assessments require the use of DEMs to identify low-lying lands with low or no slopes that are at risk (Committee on Floodplain Mapping Technologies, 2007; Gesch, 2012). DEM of the Vellar-Coleroon estuarine region of Tamil Nadu coast was derived from the SRTM elevation data using ENVI image-processing software following topographic method.

3.2.3. Computing and identification of inundation zones

The zones of the inundation were obtained from the SRTM 90 m elevation data by computing the value 0.5 m and 1 m for the SLR scenarios using a spatial analyst method by following the methodology of Rodriguez (2010). Further areas of inundation were identified by overlaying the inundation zones with 2009 LULC resource map along with the hamlet location of the study area.

4. Results

4.1. LULC

The coastal natural resource based on LULC of 2009 satellite image of the study area has been classified following ISRO classification of coastal resources. Thus, the total study area of 6541 ha has been classified into 14 categories as agricultural land, aquaculture farm, beach, habitation, habitation with vegetation, man-made forest, mangrove dense, mangrove sparse, marsh/salt marsh, mud flat/tidal flat, open/vacant land, other vegetation, sandy area/dune and tanks, respectively (Fig. 2). The agricultural land covers an area of about 2207 ha, mangrove dense covers an area of about 813 ha and aquaculture farm covers an area of about 451 ha, which are the three major coastal natural resources of this study area (Table 1).

4.2. Areas of inundation

Accurate delineation of inundation areas is a challenging task because the shoreline and surrounding topography are modified constantly by various coastal processes (Zhang, 2011). Further, the inundation vulnerability of a particular section of coastlines to SLR over time scales from hours to centuries depends not only the environmental factors of elevation, geomorphology, historic shoreline change rate, coastal slope, wave height, tidal range, and rate of SLR but also the capacity of society to adopt preventive and mitigative measures to accommodate to dynamic conditions (Pilkey and Cooper, 2004; Demirkesen et al., 2008). In this study, the results of the quantitative estimation of the inundation area of coastal natural resources and its dependent social communities of the study site are included in this analysis. Study area with low elevation coastal zone which is prone to SLR is illustrated by using SRTM based DEM models (Fig. 3). The Metadata of SRTM provides elevation accuracies of −6 to 15 m (Fig. 4). The detailed quantification on area of inundation to predicted impact, i.e. Area of inundation to projected SLR scenarios of 0.5 m and 1 m of the study area are given in Table 1. Out of the total study area of 6541 ha, about 1570 ha will be inundated to 0.5 m SLR and for 1 m SLR, about 2407 ha will be inundated. Three major coastal natural resources of the study, viz., agriculture, mangroves, the aquaculture farms and its dependent social communities are at high-risk of inundation due to rising sea.

Table 1
Inundation area of coastal natural resources in hectares (ha) to 0.5 m and 1 m SLR.

Coastal natural resources based on LULC map 2009 of the study area	Total area in ha	Area of inundation (ha) to 0.5 m SLR	Area of inundation (ha) to 1 m SLR
Agriculture land	2207	401	801
Aquaculture farm	451	134	188
Beach	301	49	53
Habitation	16	1	7
Habitation with vegetation	362	33	59
Man-made forest	275	23	72
Mangrove dense	813	265	373
Mangrove sparse	68	20	23
Marsh(v)/salt marsh	664	247	304
Mud flat/tidal flat	340	120	137
Open/vacant land	397	129	200
Other vegetation	396	71	107
Sandy area/dune	242	75	80
Tank	9	2	3
Total	**6541**	**1570**	**2407**

4.2.1. Agriculture

Groundnut and paddy are the major agricultural crops cultivated in this study area (Selvam et al., 2002). The agricultural land of about 401 ha and 801 ha will be under severe threat of inundation to 0.5 m and 1 m SLR. However, the impacts of SLR on agriculture arise not only from direct loss of arable land to inundation, but also to the increased potential for erosion and increased coastal and riverine flooding (IPCC, 1990). The agricultural lands of this study area may also face the threat not only due to inundation but also through erosion and riverine flooding at Vellar and Coleroon riverine region. In addition, salt water intrusion due to SLR may also pose a serious threat to agricultural land. Salinity intrusion due to SLR will decrease agricultural production by unavailability of fresh water and soil degradation. It also decreases the terminative energy and the germination rate of some plants (Rashid et al., 2004; Ashraf et al., 2002). For this study site, Devi Sivasankari (1995); Kathiresan (2000) predicted that salinity will increase by 5% in the year 2020, based on salinity data for 20 years (1971–1990) of Pichavaram region, using time-series analysis. This higher salinity may reduce availability of nutrients (Kathiresan et al., 1996) to cultivable lands and may reduce the yield.

4.2.2. Mangroves

Dense mangrove area of about 265 ha and 373 ha will be under severe threat of inundation to 0.5 m and 1 m SLR. *Rhizophora* and

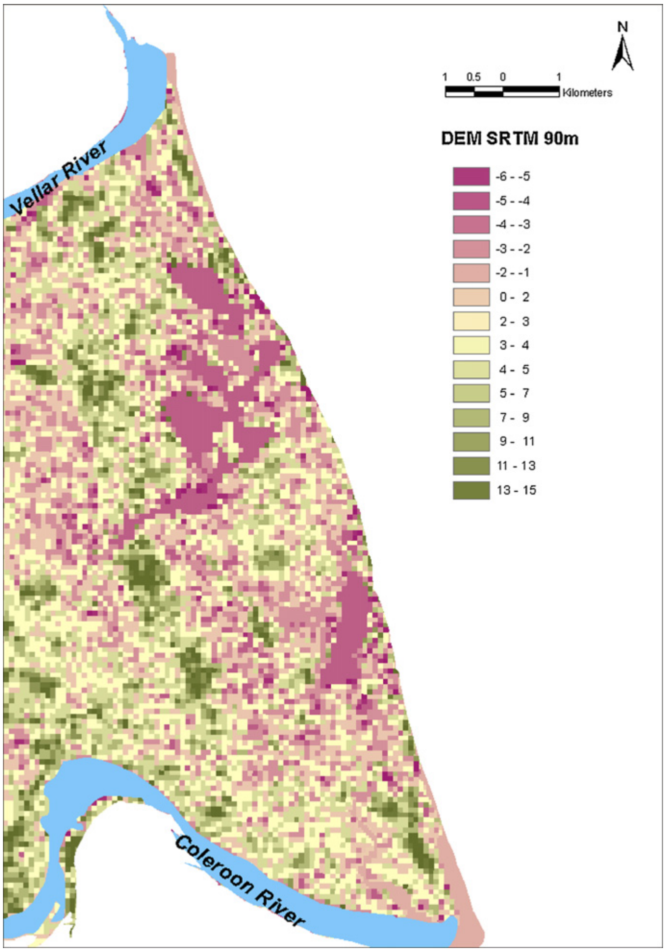

Fig. 3. SRTM 90 m DEM of the study area.

Avicennia species are the two major mangrove species of the study area. Pneumatophores or aerial roots of these mangrove species may find difficult to breathe in rising sea level, and its survival is threatened. On the other hand, sedimentation profile plays a major role in the response of mangrove ecosystem to SLR. Mangrove systems do not keep pace with the changing sea level when the rate of change in elevation of the mangrove sediment surface is exceeded by the rate of change in relative sea level (Gilman et al., 2008). The geomorphology of the Pichavaram mangrove area is covered by floodplain, sedimentary plain and beach sand (Cho et al., 2004). The study area deltaic region is formed by rapid deposition of a stream borne sediments into a still body of water. The river brings sand, silt and other materials which are deposited (Planning Commission, 2008) and alluvium is dominant in the western part, whereas fluvial marine and beach sands dominate in eastern parts (Prasad and Ramanathan, 2008). However, the understandings of sedimentation process and response of mangroves in this study area to changes in sea level are inadequate and demands urgent research.

4.2.3. Aquaculture farm

Brackish water aquaculture is a pattern followed in this region, and prawn is the major species cultivated in the aquaculture farms mostly following the semi-intensive method of farming. According to the 1996 remote-sensing data, brackish water aquaculture is being practiced in about 685 ha in the area spreading from Vellar estuary in the north to Coleroon estuary in the south (Selvam et al., 2002). This study reveals that about 134 ha and 188 ha from the total of 451 ha of aquaculture farms will be under the threat of inundation to 0.5 m and 1 m SLR. SLR associated with salt water intrusion coupled with rising temperature may threaten the aquaculture farming species. Finfish and shellfish (prawns and crabs) form an important renewable aquatic resource for the local population of this study area. Apart from fish, prawns and crabs, oysters are also found in large beds. The survival of these aquaculture-based organisms is uncertain to SLR and associated salt water intrusion. More research is required in this context to identify and introduce

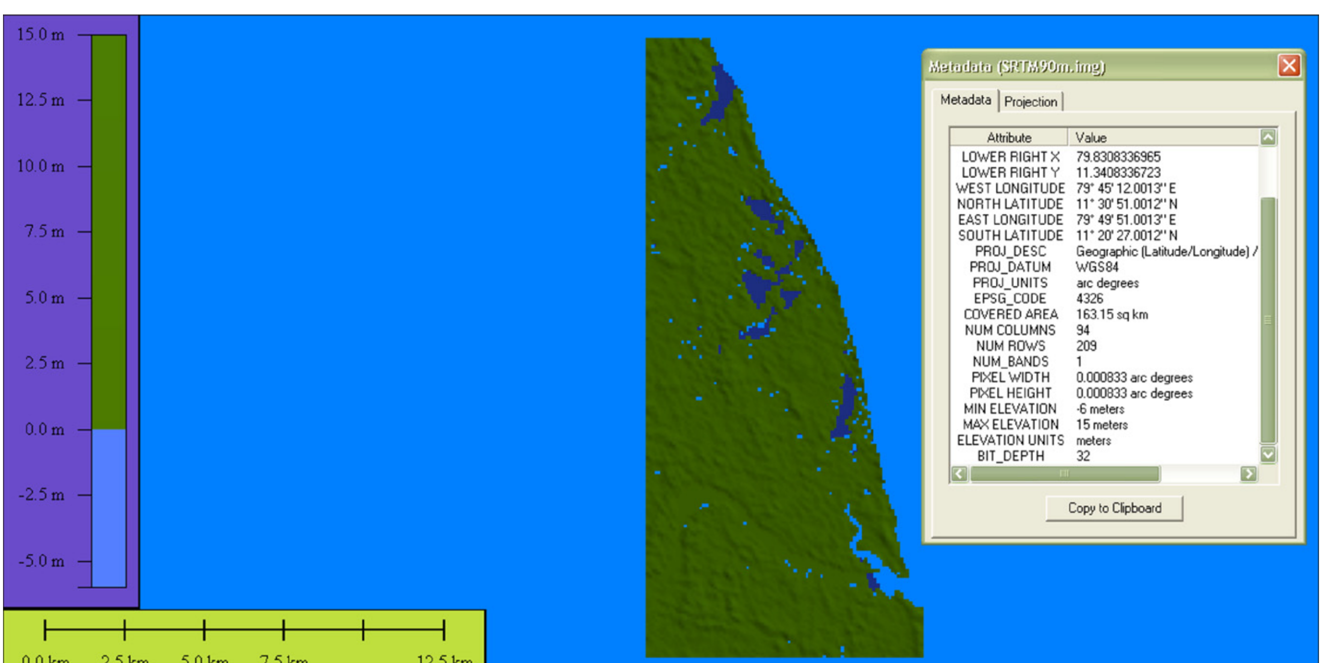

Fig. 4. Metadata of SRTM 90 m DEM.

salt tolerant species in the aquaculture farm on the study site. The area of inundation of all other coastal natural resources in the study area to 0.5 m and 1 m SLR is shown in Figs. 5 and 6, respectively.

4.2.4. Hamlets

The social communities that live in this coastal region and directly depend on these resources belong to 20 hamlets of five major revenue villages namely C. Manambadi, Killai Town Panchayat, Pichavaram, Thandavarayan Solan Pettai (T.S. Pettai) and Thillaividangan. The total area of these five major revenue villages is about 4031 ha. The area of inundation to 0.5 m SLR is about 905 ha and for 1 m SLR it is about 1326 ha. The area of inundation of each major revenue village to 0.5 m and 1 m SLR is given in Table 2. The 20 hamlets in and around these five major revenue villages are classified as fishing hamlets and farming hamlets. Among the 20 hamlets, nine are fishing hamlets; 10 are farming hamlets, and 1 hamlet is a combination of fishing and farming (Fig. 2). Based on the visual interpretation method, the impact of 0.5 m and 1 m SLR on the geographical location (lat/long) of hamlets are identified (Figs. 5 and 6). The hamlets located at low elevation from the MSL, and at

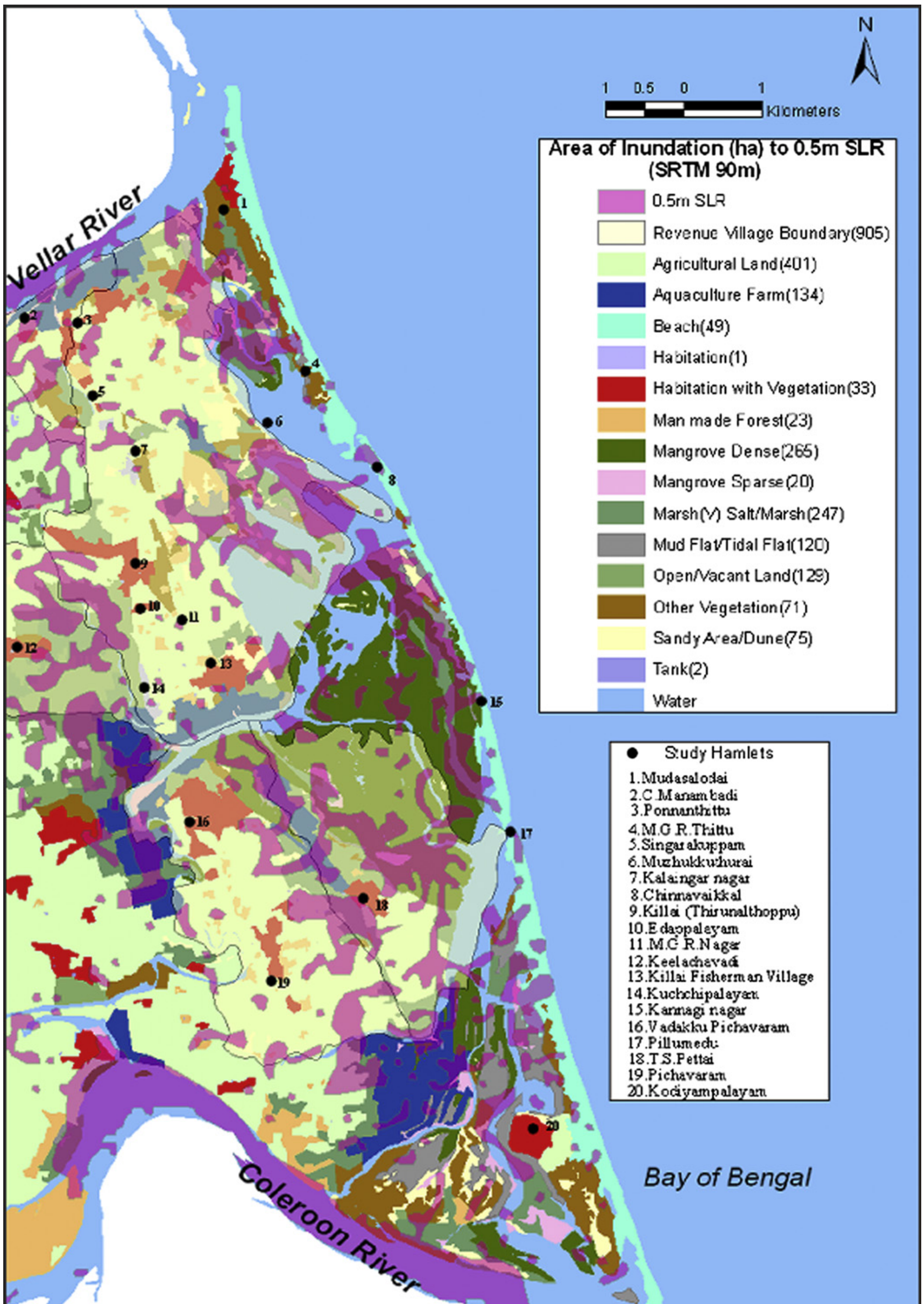

Fig. 5. Area of inundation to 0.5 m SLR of the study.

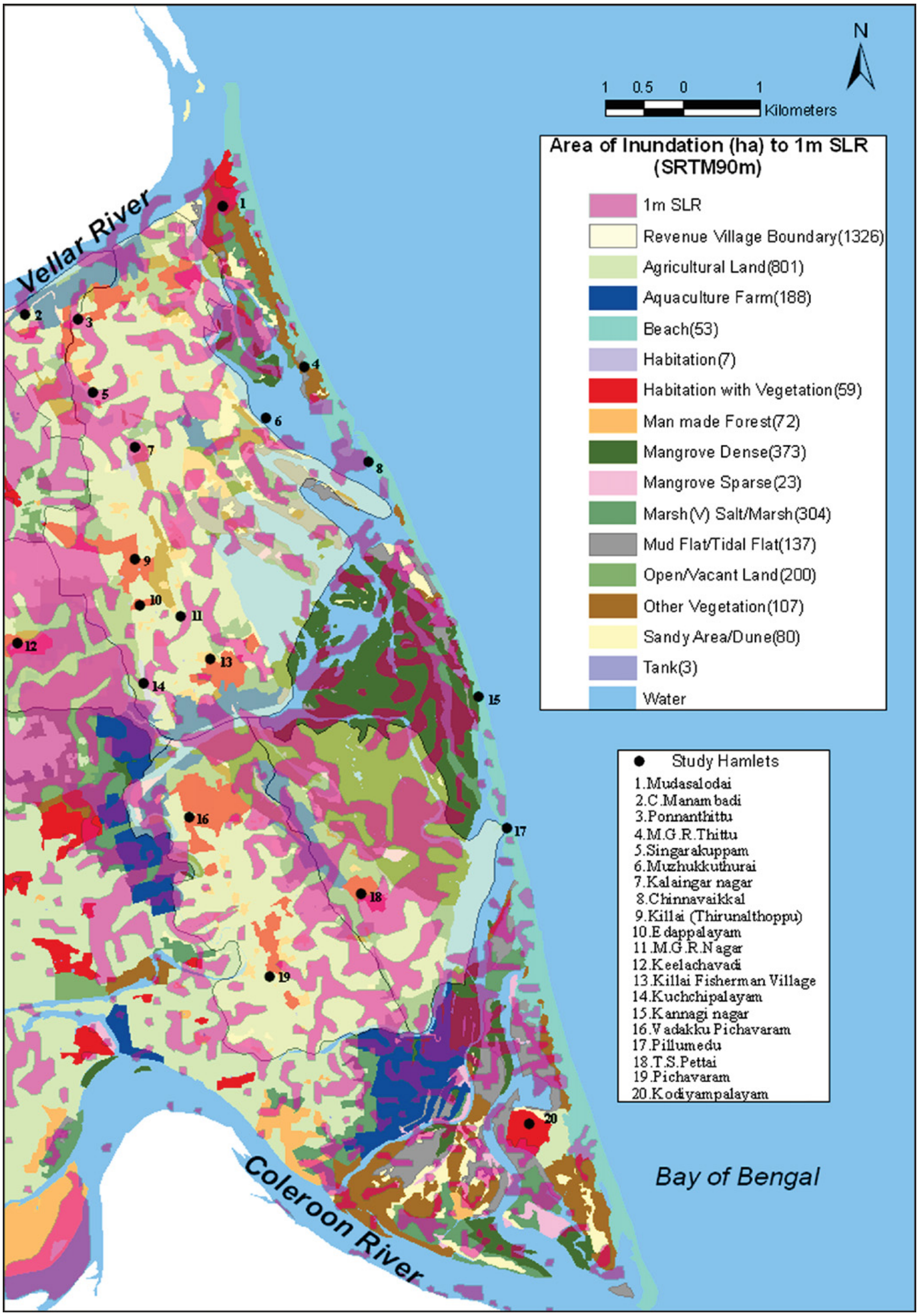

Fig. 6. Area of inundation to 1 m SLR of the study area.

high exposure to SLR are at risk and identified as vulnerable hamlets to 0.5 m SLR and 1 m SLR (Table 3). The total population of these hamlets who are vulnerable to both 0.5 m and 1 m SLR is approximately 9891 (Table 3). Thus, the fishing and farming communities of these hamlets who depend on the coastal natural resources are at high-risk and vulnerable to 0.5 m and 1 m SLR both for their livelihood and life security. European Commission (2008) reported that SLR may threaten the habitat of millions of people as 40% of Asia's population (almost 2 billion) lives within 60 km from the coastline. Arable land might be reduced, and people may have to be relocated, increasing pressure on some resources in neighboring areas. Thus, the impacts of SLR on coastal population in terms of displacement or forced migration as a result of inundation will depend on rate as well as magnitude of change (Hanh and Furukawa, 2007).

5. Discussion

SLR and climate change will not occur in vacuum, and these responses need to be placed within an ICZM framework (Integrated Coastal Zone Management) (Bijlsma et al., 1996) and also

Table 2
Inundation area of five major coastal revenue villages in (ha) 0.5 m and 1 m SLR.

Name of the five major revenue villages	Total area (ha) of each revenue villages	Area of inundation (ha) to 0.5 m SLR	Area of inundation (ha) to 1 m SLR
C. Manambadi	179	60	65
Killai	1608	340	478
Thillaividangan	768	99	203
T.S. Pettai	684	232	300
Pichavaram	792	174	280
Total	**4031**	**905**	**1326**

understanding climate change in the coastal zone is a fundamental component to ICZM. Climate change will alter the physical, socio-economic and environmental characteristics of the coastal zone. Adaptive coastal management programs must consider the potential impacts of climate change and how these may be addressed to ensure system sustainability; however, the impacts will vary based on physical exposure and the capacity of the local population (MMF, 2010).

In this case study, the rise of projected sea level (0.5 m and 1 m) has a greater impact on three major coastal resources of the study area (Vellar–Coleroon estuarine region of Tamil Nadu coast) namely agriculture, mangroves and aquaculture farms and five major revenue villages. Bindoff et al. (2007) states that, in the coastal belt, climate change-induced adverse impacts such as the SLR and increase in frequency and intensity of tropical cyclones and storm surges, pose a major challenge for countries in developing and implementing appropriate, affordable, and cost-effective adaptation measures. It is important to recognize that climate-change adaptation presents a fundamental challenge to managing the coastal resources and should be mainstreamed into coastal management and development at all levels. Mainstreaming means integrating climate concerns and adaptation responses into relevant policies, plans, program and projects at the national, subnational and local scales (USAID, 2009). However, adaptation options may vary based on the timing of the management response (prior to or after a climate event has occurred) and the type of action (e.g., physical, technological, institutional) (US EPA, 2009). It may also vary across geographical regions and demographic groups (Scheraga and Grambsch, 1998). Based on timing (future SLR projection), geographical location (impact and vulnerability) and need (urgency), adaptation measures could be short-term and long-term. IPCC (2001) identified different types of adaptations namely anticipatory adaptation, planned adaptation, autonomous adaptation, private adaptation, public adaptation, reactive adaptation. In this case study, a combination of planned and anticipatory adaptation is recommended to integrate with ICZM (Fig. 7) as proactive measures to combat the predicted impact of SLR at the study area. IPCC (2001) defines planned adaptation as a result of deliberate policy decisions, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state. Anticipatory adaptation aimed at reducing a system's vulnerability by either minimizing risk or maximizing adaptive capacity (Klein, 2001). In other words, most adaptive management is associated with developing the resilience of systems, thereby reducing the sensitivity and increasing the adaptive capacity of management systems (Rebbeck et al., 2007). To frame planned-anticipatory adaptation for productive coastal system like this, the following dual approach is recommended, one is the ecosystem-based adaptation and other is a community-based adaptation to predicted impact of SLR. However, adaptation measures on these two approaches mainly fall within three categories for coastal natural resources and its dependent communities, namely, to protect (hard structures, soft structures, walls of wood, stone or afforestation), to retreat (establishing set-back zones, relocating threatened buildings, phasing out development in exposed areas, creating an upland buffer, rolling easements) and to accommodate (early warning and evacuation systems; hazard insurance; new agricultural practices, such as using salt-resistant crops, new building regulations, improved drainage, desalination systems) (MMF, 2010). Thus, a key component of climate adaptation involves building resilience, where resilience is the capacity of a system to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes: a resilient system can withstand shocks and rebuild itself when necessary (Ziervogel et al., 2008). The ecosystem and community-based adaptation discussed below are only a few recommendations of major concern. However, region specific and issue specific detailed adaptation

Table 3
Coastal hamlets of revenue villages at high-risk and vulnerable to 0.5 m and 1 m SLR.

Hamlet type	Hamlets at high-risk and vulnerable to 0.5 m SLR	Hamlets at high-risk and vulnerable to 1 m SLR	Hamlets population in approximate (Selvam et al., 2002)
Fishing hamlets	Chinnavaikkal	Chinnavaikkal	200
		Kalaingar Nagar	272
	Kannagi Nagar	Kannagi Nagar	50
	MGR Nagar	MGR Nagar	494
	Pillumedu	Pillumedu	150
Farming hamlets	C. Manambadi	C. Manambadi	450
		Keelachavadi	934
		Kuchipalayam	550
		Mudasalodai	3000
		Ponnathittu	1747
		Singarakuppam	920
Fishing and farming hamlets	T.S. Pettai	T.S. Pettai	1124
Total			**9891**

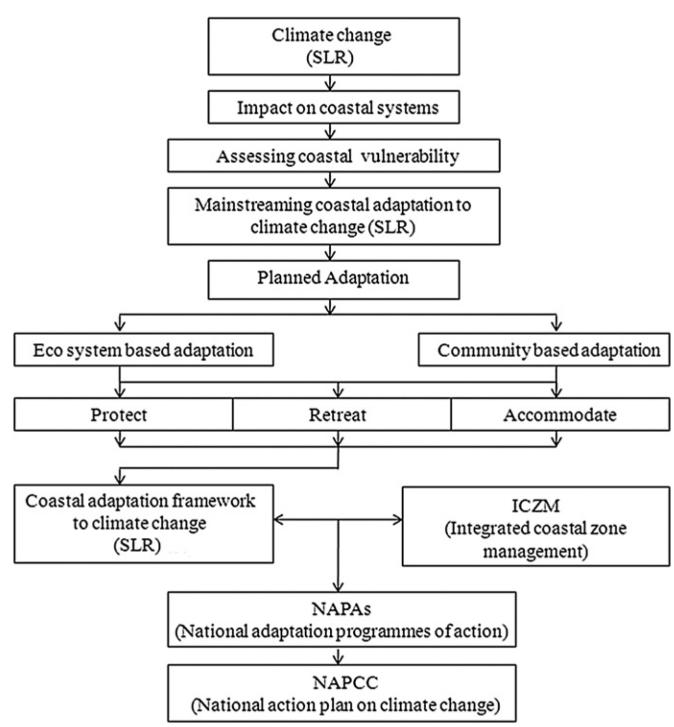

Fig. 7. Framework on mainstreaming coastal adaptation to SLR.

framework for each sector (in this case, three major coastal natural resources and its dependent communities) based on country's (India's) National Adaptation Programs of Action (NAPA) and National Action Plan on Climate Change (NAPCC) needs to be developed.

5.1. Ecosystem-based adaptation

Ecosystem-based adaptation identifies and implements a range of strategies for the management, conservation and restoration of ecosystems to ensure that they continue to provide the services that enable people to adapt to the impacts of climate change. The main objective of ecosystem-based adaptation is to boost the resilience and lessen the vulnerability of ecosystem and its dependent social communities in the view of climate change. An outline for ecosystem-based adaptation in this case study for three major coastal natural resources namely agriculture, mangroves and aquaculture of the study area should consider following key requisites.

5.1.1. Agriculture

Successful local-level adaptations of agriculture require multiple pathways of well-planned and interrelated short-term and long-term measures (Baas and Ramasamy, 2008). This includes development of salt tolerant agricultural crops, development of farm risks insurance, and the adjustment of cropping patterns (Meodiarta and Stalker, 2007; Ministry of Environment, 2010; Forster et al., 2011) by developing and implementing dynamic cropping calendars (Forster et al., 2011) and improving water efficiency.

5.1.2. Mangroves

Mangroves may adapt to changes in sea level by growing upward in place or by expanding landward or seaward. Mangroves produce peat from decaying litter fall and root growth and by trapping sediment in the water. The process of building peat helps mangroves keep up with SLR (Mcleod and Salm, 2006). Mangroves can expand their range despite SLR if the rate of sediment accretion is sufficient to keep up with SLR. However, the ability of different mangrove species to migrate landward or seaward is also determined by local conditions, such as infrastructure (e.g. roads, agriculture fields, dikes, urbanization, seawalls, etc.), topography (Mcleod and Salm, 2006) and site specific planning. Site planning for some sections of shoreline containing mangroves, such as areas that are not highly developed, may facilitate long-term retreats with the relative SLR (Dixon and Sherman, 1990; Mullane and Suzuki, 1997; Gilman, 2002; Gilman et al., 2008).

5.1.3. Aquaculture farm

Practicing alternative aquaculture farming by introducing salt tolerant strains may be a viable adaptation option for aquaculture farms to respond to SLR. In addition, site specific zoning of aquaculture activities will be a significant long-term adaptation measure to SLR and also integrating aquaculture with other farming practices may reduce risk associated with economic loss and livelihood insecurities, which are dependent on aquaculture alone. Thus, the ecosystem approach to aquaculture aims to integrate aquaculture within the wider ecosystem in such a way it promotes sustainability of interlinked social-ecological systems (Soto et al., 2008).

5.2. Community-based adaptation

Community-based adaptation address explicitly the needs of marginalized groups that are most vulnerable to the types of climatic and socioeconomic changes that are likely under perturbed climates (Baas and Ramasamy, 2007). Community-based adaptation draws on participatory approaches and innovative participatory methods to help communities analyze the causes and effects of climate change, to integrate scientific and community knowledge of climate change, and to plan adaptation measures (Reid et al., 2009). Thus, identifying appropriate adaptation options should then follow, building on information about existing community capacity, knowledge and practices used to cope with climate hazards (Huq, 2008). Therefore, through an understanding of how people might cope and adapt to predicted climate-change effects, meaningful measures can be taken to reduce their vulnerability. An outline for community-based adaptation in this case study for three major coastal natural resource dependent communities namely farming communities (agriculture), fishing communities (mangroves), fishing and farming communities (aquaculture farms) of the study area should consider following key requisites:

5.2.1. Farming communities (agriculture)

Suggestions on how to adapt to climate change in the short-term and long-term perspective, taking into account potential climate variability and extremes (SLR) for agricultural cropping are recommended. For short-term adaptation practice, minimize high input costs on high-risk areas (areas which are at high-risk to 0.5 m and 1 m SLR in this case study). A key to successful long-term adaptation in coastal agriculture in the face of accelerated SLR would be diverse livelihoods. Livelihood diversity helps ensure that, if one economic option temporarily closes, people can resort to other options for making a living. Poverty reduction strategies that help diversify livelihoods and improve poor people's access to natural resources also help build adaptive capacity for climate change (World Fish Centre, 2009). Comprehensive risk insurance should be provided with the focus on SLR and coastal agriculture. Both small farmers and women farmers should be educated and encouraged to choose these insurance mechanisms as preparatory measures to SLR. For a long-term adaptation response to SLR, develop training to build capacity on specialist adaptation issues such as relocation or migration considering availability of space, economic, social and ethnic tension to avoid the competition of resources and conflicts.

5.2.2. Fishing communities (mangroves)

Responses to the direct impacts of extreme events in fisheries infrastructure and communities are believed to be more effective if they are anticipatory as part of long-term integrated coastal and disaster risk management planning (Nicholls, 2007; FAO, 2008; Mustafa and Sharmin, 2010). Examples of adaptation in fisheries to climate change are dominated by diversification or flexible livelihoods (Allison et al., 2008) and migration in response to climate-mediated fluctuations in yield (Daw et al., 2008). A common alternative livelihood considered for fishers is aquaculture (Pomeroy et al., 2006). Evidence exists that fishers would consider aquaculture as an alternative source of food and Income (Pomeroy, 2004; Pomeroy et al., 2006). Decrease in the marginalization and vulnerability of small-scale fishers is thought to be an anticipatory adaptation to a range of threats, as well as facilitating sustainable management (FAO, 2007; Daw et al., 2008). Working towards equitable and sustainable fisheries, which has been a goal of fisheries management, may be seen as advancing the adaptive capacity of fishing communities (Daw et al., 2008) which may also include communities that depend on mangroves for inland fishing.

5.2.3. Farming and fishing communities (aquaculture)

Integrating aquaculture with other practices, including agro-aquaculture, multi-trophic aquaculture and culture-based fisheries, this could include fisheries and agricultural farming and assist coastal communities in general and regarded as one of the viable livelihood adaptation strategies. Integrated aquaculture has been proposed as a means to develop environmentally sound aquaculture practices and resource management through a balanced ecosystem approach to avoid pronounced shifts in coastal processes (Chopin et al., 2001; Troell et al., 2003; Neori et al., 2007; Buschmann et al., 2008; Xu et al., 2011). Insurance against damage to aquaculture farms an adaptive measure that will help limit bankruptcies in aquaculture businesses as a result of losses caused by climatic events (SLR) is to encourage aquaculture participants to take insurance against damage to stock and property from extreme climatic events (De Silva and Soto, 2009).

6. Limitations of the study

This study urges the need of more accurate information on the exact area of inundation of the coastal area along with real time elevation from MSL to frame suitable coastal adaptation strategies. This could be achieved by using high-resolution satellite images with more accuracy on elevation data and/or even measurement of real time exact elevation measurement of each geographical point by using a DGPS survey process. And also cadastral level hamlet boundary map along with availability of recent census data 2011 on population will help to identify the exact number of population of social communities who are vulnerable to different SLR scenarios. Very importantly, projection of SLR on various scenarios at the regional and local level is needed, and this will enhance to perform accurate impact and vulnerability assessment to frame suitable adaptation strategies. In addition, guidelines for the climate-change adaptation framework for various sectors (in this case, coastal sector) under NAPA of NAPCC is needed, to prepare sectoral, issue and region/area-specific adaptation framework. However, unavailability of these data and guidelines should not impede the overviews on the projection of the predicted impact of SLR on coastal natural resources and its dependent social communities and initiatives on adaptation actions, particularly in a developing country like India with a coastline of about 7500 km.

7. Conclusions

The magnitude of sea-level change impacts will vary from place-to-place depending on topography, geology, natural land movements and human activities (Kebede et al., 2010). The potential impacts are uneven, and are likely to affect the most vulnerable, due to multiple stresses and their lower ability to prepare, adapt and respond (Kebede et al., 2010). Because of the availability of fewer resources and their lower social, technological and financial ability for adaptation, developing countries, particularly those with low-lying coastal areas with high population density are most vulnerable (Nicholls et al., 2007; UNFCCC, 2007). In this study, the extent of inundation of the coastal natural resources and its dependent social communities was identified using SRTM 90 m DEM. Agriculture, mangroves and aquaculture are the three major resources which are at high threat to SLR. Out of 20 hamlets of social communities that depend on these resources, nearly, five fishing hamlets and six farming hamlets and one fishing and farming hamlet may be at high-risk to 0.5 m and 1 m SLR. The results of this study throw a light on urgency to respond to accelerating SLR. Even if GHG concentrations are stabilized at relatively low levels, the SLR is expected to continue for many centuries (Church et al., 2001; Nicholls and Lowe, 2004; Sahin and Mohamed, 2009). Therefore, to reduce vulnerability and to enhance resilience to projected scenarios of SLR, mainstreaming adaptation is considered as one of the appropriate responses as a coastal management option. Management actions can ameliorate or exacerbate a system's vulnerability to climate change and consideration of climate change impacts and appropriate adaptation options can help to ensure that managers' actions reduce the risk, improve resiliency, and ameliorate rather than exacerbate the vulnerability of their coastal ecosystems (US EPA, 2009). An attempt on outlining adaptation options in this study area suggests two different but integrated approaches. One is to address adaptation options of coastal natural resources (ecosystem-based adaptation) to SLR, and the other is capacity building at the community level (community-based adaptation) that depends on these resources. These adaptation options primarily aim to preserve coastal natural resources and its dependent social communities to anticipated impact of SLR in the coastal region on which development is intended or already present. However, a detailed guideline for developing an adaptation framework is needed to address all coastal natural resources and its dependent communities to climate change induced SLR. There is an urgent need for preparedness and taking suitable and effective adaptation measures together with the local community in response to the expected influence of climate change, and to find ways to ensure coastal sustainability and human security (Khan et al., 2012).

An effort, in particular, is desired in the perspective of SLR to assist coastal communities in these hamlets that depend on the coastal natural resources and to facilitate a community-wide adaptation process to increase their resilience to SLR and inundation. Thus, adaptive coastal management must consider the potential impacts of climate change and how these may be addressed to ensure system sustainability. In addition, there is a cautious need to harmonize various sectoral development options in the pursuit of sustainable development of coastal zones. Long-term thinking, as encouraged by the consideration of climate change (SLR), is therefore, a key component of ICZM and can be economically feasible (Tol et al., 1996).

Acknowledgements

The authors are grateful to All India Council for Technical Education (AICTE), New-Delhi, Government of India for funding this research work under NDF (National Doctoral Fellowship) Schemes 2009–2010 (Ref. No: 1-10/RID/NDF-4/2009-10 dated 26.02.2010).

References

AIMS, 2000. Environment Profile of Cuddalore District: Final Report. Directorate of Environment, GTN, AIMS Research, Chennai, Tamil Nadu, India, 35 pp.

Allison, E.H., Beveridge, M.C.M., Van Brakel, M., 2008. Climate change, small-scale fisheries and smallholder aquaculture. In: Culberg, M. (Ed.), Fish, Trade and Development. Stockholm, Royal Swedish Academy of Agriculture and Forestry, Sweden.

Ardil, E.R., Wolff, M., 2009. Land use and land cover change affecting habitat distribution in the Segara Anakan lagoon, Java, Indonesia. Regional Environmental Change 9 (4), 235–243.

Ashraf, M.Y., Sarwar, G., Ashraf, M., Afaf, R., Sattar, A., 2002. Salinity induced changes in α-amylase activity during germination and early cotton seedling growth. Biologia Plantarum 45 (4), 589–591.

Baas, S., Ramasamy, S., 2007. Community Based Adaptation in Action, Summary Report Project Phase I, Improved Adaptive Capacity to Climate Change for Sustainable Livelihoods in the Agriculture Sector, Comprehensive Disaster Management Programme. CDMP, Food and Agriculture Organization of the United Nations. ftp://ftp.fao.org/docrep/fao/010/ai505e/ai505e00.pdf (accessed 21.05.12).

Baas, S., Ramasamy, S., 2008. Community Based Adaptation in Action: A Case Study from Bangladesh. Project Summary Report (Phase I), Improved Adaptive Capacity to Climate Change for Sustainable Livelihoods in the Agriculture Sector. Food and Agriculture Organization of the United Nations/Department of Agricultural Extension, Rome/Dhaka, Bangladesh. ftp://ftp.fao.org/docrep/fao/010/i0481e/i0481e.pdf, pp. 27–56 (accessed 21.05.12).

Bijlsma, L., Ehler, C.N., Klein, R.J.T., Kulshrestha, S.M., McLean, R.F., Mimura, N., Nicholls, R.J., Nurse, L.A., Perez Nieto, H., Stakhiv, E.Z., Turner, R.K., Warrick, R.A.,

1996. Coastal zones and small islands. In: Watson, R.T., Zinyowera, M.C., Moss, R.H. (Eds.), Impacts, Adaptations and Mitigation of Climate Change: Scientific and Technical Analyses. Cambridge University Press, Cambridge, pp. 289–324.
Bijlsma, L., 1997. Climate change and management of coastal resources. Climate Research 9 (1–2), 47–56.
Bindoff, N., Willebrand, J., Artale, V., Cazenave, A., Gregory, J., Gulev, S., Hanawa, K., LeQuéré, C., 2007. Observations: oceanic climate change and sea level. Climate change 2007: the physical science basis. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 385–432.
Boesch, F.D., 2002. Summary of Climate Change Assessments: Implications for Estuarine Biocomplexity. Biocomplexity in Responses of Estuarine Ecosystems to Climate Variability and Change. Planning for Science in the 21st Century. Estuarine Research Foundation, University of Maryland Centre for Environmental Science, Maryland, pp. 3–5.
Buschmann, A.H., Varela, D.A., Hernández-González, M.C., Huovinen, P., 2008. Opportunities and challenges for the development of an integrated seaweed based aquaculture activity in Chile: determining the physiological capabilities of Macrocystis and Gracilaria as biofilters. Journal of Applied Phycology 20 (5), 571–577.
CCFID, 2012. Cyclone Thane: Impact Assessment Report. Community Collective Society for Integrated Development (CCFID), Seetharamnagar, Cuddalore, Tamil Nadu, India, p. 9.
Cho, H.Y., Lakshumanan, C., Natesan, U., 2004. Coastal Wetland and Shoreline Change Mapping of Pichavaram, South East Coast of India Using Satellite Data. Geospatial Application Papers, Map Asia Conference, Beijing, China. http://www.gisdevelopment.net/application/nrm/coastal/mnm/ma04081.htm (accessed 15.05.12).
Chopin, T., Buschmann, A.H., Halling, C., Troell, M., Kautsky, N., Neori, A., Kraemer, G.P., Zertuche-González, J.A., Yarish, C., Neefus, C., 2001. Integrating seaweeds into marine aquaculture systems: a key toward sustainability. Journal of Phycology 37 (6), 975–986.
Church, J.A., Gregory, J.M., Huybrechts, P., Kulm, M., Lambeck, K., Nuham, M.T., Qin, D., Woodsworth, P.L., 2001. Changes in sea level. In: Hought, J.T., Ding, Y., Griggs, D.J., Noguer, M., Van der linden, P.J., Xiaosu, D. (Eds.), Climate Change 2001: The Scientific Basis. Cambridge University Press, Cambridge, pp. 639–693.
Committee on Floodplain Mapping Technologies, 2007. Elevation Data for Floodplain Mapping. National Research Council, The National Academies Press, Washington, D.C, p. 151.
Daw, T., Adger, W.N., Brown, K., Badjeck, M.C., 2008. Climate Change and Capture Fisheries. University of East Anglia, Norwich and WorldFish Center, Penang, p. 136. http://library.enaca.org/emerging_issues/daw_et_al.pdf (accessed 21.05.12).
Demirkesen, A.C., Evrendilek, F., Berberoglu, S., 2008. Quantifying coastal inundation vulnerability of Turkey to sea-level rise. Environmental Monitoring and Assessment 138 (1–3), 101–106.
De Silva, S.S., Soto, D., 2009. Climate change and aquaculture: potential impacts, adaptation and mitigation. Technical Paper No. 530. In: Cochrane, K., Young, D.C., Soto, D., Bahri, T. (Eds.), Climate Change Implications for Fisheries and Aquaculture: Overview of Current Scientific Knowledge. FAO Fisheries and Aquaculture, Rome, pp. 151–212.
Devi Sivasankari, B., 1995. A Futuristic Study of Salinity Variations in the Pichavaram Mangrove Channels From the Period 1995 to 2020. M.Sc. dissertation, Annamalai University, Parangipettai, India, p. 18.
Dixon, J.A., Sherman, P.B., 1990. Economics of Protected Areas. A New Look at Benefits and Costs. Island Press, Washington DC, USA.
Donoghue, D.N.M., Mironnet, N., 2002. Development of an integrated geographical information system prototype for coastal habitat monitoring. Computational Geosciences 28 (1), 129–141.
European Commission, 2008. Climate change and international security. Paper from the high representative and the European Commission to the European Council. http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/reports/99387.pdf (accessed 05.01.12).
FAO, 2007. Reducing Fisher Folk's Vulnerability Leads to Responsible Fisheries: Policies to Support Livelihoods and Resource Management. New Directions in Fisheries – a Series of Policy Briefs on Development Issues, pp. 1–9. FAO, Rome. ftp://ftp.fao.org/docrep/fao/012/a0228e/a0228e00.pdf (accessed 13.01.12).
FAO, 2008. Climate Change for Fisheries and Aquaculture, Technical Background Document from the Expert Consultation Held on 7th to 9th April 2008. ftp://ftp.fao.org/docrep/fao/meeting/013/ai787e.pdf (accessed 21.05.12).
Forster, H., Sterzel, T., Pape, C.A., Moneo-Lain, M., Niemeyer, I., Boer, R., Kropp, J.P., 2011. Sea-level rise in Indonesia: on adaptation priorities in the agricultural sector. Regional Environmental Change 11 (4), 893–904.
Gesch, D.B., Gutierrez, B.T., Gill, S.K., 2009. Coastal elevations, in coastal sensitivity to sea-level rise: a focus on the Mid-Atlantic region. In: Titus, J.G., Anderson, K.E., Cahoon, D.R., Gesch, D.B., Gill, S.K., Gutierrez, B.T., Thieler, E.R., Williams, S.J. (Eds.), A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. U.S. Environmental Protection Agency, Washington DC, pp. 25–42.
Gesch, D.B., 2012. Elevation uncertainty in coastal inundation hazard assessments. In: Cheval, S. (Ed.), Natural Disasters. In-Tech Publishers, p. 156. http://dx.doi.org/10.5772/1373.
Gilman, E.L., 2002. Guidelines for coastal and marine site-planning and examples of planning and management intervention tools. Ocean and Coastal Management 45 (6–7), 377–404.
Gilman, E., 2004. Assessing and managing shoreline response to projected relative sea level rise and climate change. In: Prepared for the UNESCO World Heritage Central Pacific Project Planning Workshop, Kiritimati Island, Republic of Kiribati.
Gilman, E., Ellison, J., Coleman, R., 2007. Assessment of mangrove response to projected relative sea-level rise and recent historical reconstruction of shoreline position. Environmental Monitoring and Assessment 124 (1–3), 105–130.
Gilman, E.L., Ellison, J., Duke, N.C., Field, C., 2008. Threats to mangroves from climate change and adaptation options. Aquatic Botany 89 (2), 235–250.
Hanh, P.T.T., Furukawa, M., 2007. Impact of sea level rise on coastal zone of Vietnam. University of the Ryukyus's Bulletin of the College of Science 84, 45–59.
Huq, S., July 2008. Community based adaptation. Tiempo (86). http://www.tiempocyberclimate.org/portal/archive/pdf/tiempo68low.pdf (accessed 17.01.12).
IPCC, 1990. Climate change: the impact assessment. Chapter 6, world ocean and coastal zones. In: McG Tegart, W.J., Sheldon, G.W., Griffiths, D.C. (Eds.), Report Prepared for Intergovernmental Panel on Climate Change by Working Group II to the First Assessment Report of the Intergovernmental Panel on Climate Change (FAR-IPCC). Australian Government Publishing Service, Camberra, Australia, p. 294.
IPCC, 2001. Climate Change 2001. The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (TAR-IPCC). Cambridge University Press, NY, p. 881.
IPCC, 2007. Global climate projections. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 996.
Kathiresan, K., Rajendran, N., Thangadurai, G., 1996. Growth of mangrove seedlings in intertidal area of Vellar estuary southeast coast of India. Indian Journal of Marine Science 25 (3), 240–243.
Kathiresan, K., 2000. A review of studies on Pichavaram mangrove, Southeast India. Hydrobiologia 430 (1–3), 185–186.
Kebede, A.S., Brown, S., Nicholls, R.J., 2010. Synthesis Report: The Implications of Climate Change and Sea-level Rise in Tanzania – the Coastal Zones. University of Southampton School of Civil Engineering and the Environment and Tyndall Centre for Climate Change Research, Southampton, UK, p. 32.
Kennedy, V.S., Twilley, R.R., Kleypas, J.A., Cowan, J.H., Hare, S.R., 2002. Coastal and Marine Ecosystems: Potential Effects on U.S. Resources and Global Climate Change. Pew Center on Global Climate Change, Arlington, p. 52.
Khan, A.S., Ramachandran, A., Usha, N., Arul Aram, I., Selvam, V., 2012. Rising sea and threatened mangroves: a case study on stakeholders' engagement in climate change communication and non-formal education. International Journal of Sustainable Development and World Ecology. http://dx.doi.org/10.1080/13504509.2011.650230.
Klein, R.J.T., 2001. Adaptation to Climate Change in German Official Development Assistance: An Inventory of Activities and Opportunities with a Special Focus in Africa. Deutsche Gesellschaft fur Technische Zusammenarbeit, Eschborn, Germany, p. 42.
Kumar, T.S., Mahendra, R.S., Nayak, S., Radhakrishnan, K., Sahu, K.C., 2012. Identification of hot spots and well managed areas of Pichavaram mangrove using Landsat™ and Resourcesat—1 LISS IV: an example of coastal resource conservation along Tamil Nadu Coast, India. Journal of Coastal Conservation 16 (1), 1–12.
Mahendra, R.S., Mohanty, P.C., Bisoyi, H., Kumar, T.S., Nayak, S., 2011. Assessment and management of coastal multi-hazard vulnerability along the Cuddalore, Villupuram, East coast of India using geospatial techniques. Ocean and Coastal Management 54 (4), 302–311.
Mcleod, E., Salm, R.V., 2006. Managing mangroves for resilience to climate change. In: Resilience Science Group Working Paper Series II. International Union for Conservation of Nature, Gland, Switzerland, p. 63.
Meodiarta, R., Stalker, P., 2007. The Other Half of Climate Change. Why Indonesia Must Adapt to Protect Its Poorest People. Technical report. United Nations Development Program, Indonesia, Jakarta.
Ministry of Environment, 2010. Indonesia Second National Communication.
MMF, 2010. Climate Proof: A Reference Tool to Coastal Climate Change in the Context of Mangroves for the Future. A Pre-publication Version Approved by the Mangroves for Future (MFF), Bangkok, Thailand, p. 68.
Muniyandi, K., 1986. Studies on Mangroves of Pichavaram (Southeast Coast of India). Ph.D. thesis, Annamalai University, Parangipettai, India, 215 pp.
Mullane, R., Suzuki, D., 1997. Beach Management Plan for Maui. University of Hawaii Sea Grant Extension Service and County of Maui Planning Department, Maui, HI, USA.
Muller, S.V., Walker, D.A., Nelson, F.E., Auerbach, N.A., Bockheim, J.G., Guyer, S., Sherba, D., 1998. Accuracy assessment of a land-cover map of the Kuparuk river basin, Alaska: considerations for remote regions. Photogrammetric Engineering & Remote Sensing 64 (6), 619–628.
Murthy, M.V.R., Usha, T., Pari, Y., Reddy, N.T., 2011. Tsunami vulnerability assessment of Cuddalore using numerical model and GIS. Marine Geodesy 34 (1), 16–28.
Mustafa, M.G., Sharmin, 2010. Climate Change Implications for Fisheries and Aquaculture in Bangladesh: A Review. Institute of Water and Flood Management (IWFM), Bangladesh University of Engineering and Technology (BUET).

http://teacher.buet.ac.bd/akmsaifulislam/climaterisk/student/Group-11.pdf (accessed 21.05.12).

Neori, A., Troell, M., Chopin, T., Yarish, C., Critchley, A., Buschmann, A.H., 2007. The need for a balanced ecosystem approach to blue revolution aquaculture. Environment 49 (3), 36–43.

Nicholls, R.J., Leatherman, S.P., 1996. Adapting to sea-level rise: relative sea level trends to 2100 for the USA. Coastal Management 24 (4), 301–324.

Nicholls, R.J., Lowe, J.A., 2004. Benefits of mitigation of climate change for coastal areas. Global Environmental Change 14 (3), 229–244.

Nicholls, R.J., Wong, P.P., Burkett, V.R., Codignotto, J.O., Hay, J.E., McLean, R.F., Ragoonaden, S., Woodroffe, C.D., 2007. Coastal systems and low-lying areas. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., Linden, P.J., Hanson, C.E. (Eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Inter governmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 315–356.

Pilkey, O.H., Cooper, J.A.G., 2004. Society and sea level rise. Science 303 (5665), 1781–1782.

Planning Commission, 2008. Report on Visit to Pichavaram in Tamil Nadu: Awetland Included under National Wetland Conservation and Management Programme of the Ministry of Environment and Forests. Government of India, New Delhi, p. 13.

Pomeroy, R.S., 2004. Socioeconomic Dimensions of Aquaculture as a Solution to Destructive Fishing. Technical report FTR4. Community Conservation Network, Honolulu, Hawaii.

Pomeroy, R.S., Ratner, B.D., Hall, S.J., Pimoljinda, J., Vivekanandan, V., 2006. Coping with disaster: rehabilitating coastal livelihoods and communities. Marine Policy 30 (6), 786–793.

Prasad, B.K., Ramanathan, A.L., 2008. Sedimentary nutrient dynamics in a tropical estuarine mangrove ecosystem. Estuarine, Coastal and Shelf Science 80 (1), 60–66.

Ragoonaden, S., 2006. Sea level activities and changes on the islands of the Western Indian Ocean. Western Indian Ocean Journal of Marine Science 5 (2), 179–194.

Rahmstorf, S., April 2010. A new view on sea level rise. Nature Reports Climate Change (4). http://dx.doi.org/10.1038/climate.2010.29. http://www.nature.com/climate/2010/1004/full/climate.2010.29.html?-session=user_pref:42F948C2164af3635AUmUp340782 (accessed 22.05.12).

Rajkumar, M., Perumal, P., Prabu, A.V., Perumal, N.V., Rajasekar, K.T., 2009. Phytoplankton diversity in Pichavaram mangrove waters from south-east coast of India. Journal of Environmental Biology 30 (4), 489–498.

Rashid, M.M., Hoque, A.K.F., Iftekhar, M.S., 2004. Salt tolerances of some multipurpose tree species as determined by seed germination. Journal of Biological Sciences 4 (3), 288–292.

Rebbeck, M., Dwyer, E., Bartetzko, M., Williams, Amy, 2007. Climate change mitigation and adaptation in agriculture. In: A Guide to Climate Change and Adaptation in Agriculture in South Australia. Primary Industries and Regions South Australia (PIRSA), Adelaide, South Australia. http://www.pir.sa.gov.au/pirsa/nrm/a_guide_to_climate_change_and_adaption_in_ agricul ture_in_south_australia/chapter_five (accessed 15.05.12).

Reid, H., Alam, M., Berger, R., Cannon, T., Huq, S., Milligan, A., 2009. Community-based adaptation to climate change: an overview. In: Theme Section: Community-based Adaptation to Climate Change, Participatory Learning and Action 60. International Institute for Environment and Development, Russell Press, Nottingham, UK, p. 210. http://pubs.iied.org/pdfs/14573IIED.pdf (accessed 21.05.12).

Rodriguez, A., 2010. Mexican Gulf of Mexico regional introduction and sea level rise analysis of the Carmen Island, Campeche, Mexico Region. http://www.geo.utexas.edu/courses/371c/project/2010S/Projects/Rodriguez.pdf (accessed 22.11.11).

Sahin, O., Mohamed, S., 2009. Decision dilemmas for adaptation to sea level rise: how to, when to? In: Proceedings of the 2009 IEEE IEEM, School of Engineering, Griffith University, Gold Coast, Queensland, Australia, pp. 1622–1626.

Scheraga, J.D., Grambsch, A.E., 1998. Risks, opportunities, and adaptation to climate change. Climate Research 11 (1), 85–95.

Selvam, V., Gnanappazham, L., Navamuniyammal, M., Ravichandran, K.K., Karunagaram, V.M., 2002. Atlas of Mangrove Wetlands of India. M.S. Swaminathan Research Foundation, Chennai, India, pp. 12–58.

Selvam, V., Eganathan, P., Karunagaran, V.M., Ravishankar, T., Ramasubramanian, R., 2004. Mangrove Plants of Tamil Nadu. M.S. Swaminathan Research Foundation, Chennai, India, p. 56.

Soto, D., Aguilar-Manjarrez, J., Brugère, C., Angel, D., Bailey, C., Black, K., Edwards, P., Costa Pierce, B., Chopin, T., Deudero, S., Freeman, S., Hambrey, J., Hishamunda, N., Knowler, D., Silver, W., Marba, N., Mathe, S., Norambuena, R., Simard, F., Tett, P., Troell, M., Wainberg, A., 2008. Applying an ecosystem-based approach to aquaculture: principles, scales and some management measures. In: Soto, D., Aguilar-Manjarrez, J., Hishamunda, N. (Eds.), Building an Ecosystem Approach to Aquaculture. FAO/Universitat de les Illes Balears Expert Workshop, 7–11th May 2007, Spain, Mallorca. FAO Fisheries Proceedings. No. 14. FAO, Rome, pp. 15–35.

The working group on sea level rise and wetland system, 1997. Conserving coastal wetlands despite sea level rise. Eos, Transaction, American Geophysical Union 78 (25), 257–262.

Tol, R.S.J., Klein, R.J.T., Jansen, H.M.A., Verburggen, H., 1996. Some economic considerations on the importance of proactive integrated coastal zone management. Ocean and Coastal Management 32 (1), 39–55.

Troell, M., Halling, C., Neori, A., Chopin, T., Buschmann, A.H., Kautsky, N., Yarish, C., 2003. Integrated mariculture: asking the right questions. Aquaculture 226 (1–4), 69–90.

UNFCCC, 2007. Investment and Financial Flows to Address Climate Change. United Nations Framework Convention on Climate Change Secretariat, Bonn, Germany.

USAID, 2009. Adapting to Coastal Climate Change: A Guidebook for Development Planners. U.S. Agency for International Development, Washington, DC, USA. p. 162.

U.S. EPA, 2009. Synthesis of Adaptation Options for Coastal Areas. Climate Ready Estuaries Program, Environmental Protection Agency, Washington, DC, U.S.A. (EPA 430-F-08-024).

Weng, Q., 2002. Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modeling. Journal of Environmental Management 64 (3), 273–284.

World Coast Conference, 1993. Preparing to Meet the Coastal Challenges of the 21st Century. Conference Report of Ministry of Transport, Public Works and Water Management. National Institute for Coastal and Marine Management, The Hague, The Netherlands.

World Fish Centre, 2009. Climate Change and Fisheries: Vulnerability and Adaptation in Cambodia. http://www.thefishsite.com/articles/805/climate-change-vulnerability-and-adaption-in-cambodia (accessed 28.05.12).

Xu, S., Chen, z., Li, C., Huange, X., Li, S., 2011. Assessing the carrying capacity of tilapia in an intertidal mangrove-based polyculture system of Pearl River Delta, China. Ecological Modelling 222 (3), 846–856.

Zhang, K., 2011. Analysis of non-linear inundation from sea-level rise using LIDAR data: a case study for South Florida. Climatic Change 106 (4), 537–565.

Ziervogel, G., Cartwright, A., Tas, A., Adejuwon, J., Zermoglio, F., Shale, M., Smith, B., 2008. Climate Change and African Agriculture: An Overview. Climate Change and Adaptation in African Agriculture. Stockholm Environmental Institute (SEI), Stockholm, Sweden, p. 53.