Chapter 2

Constructing Local Sea Level Rise Scenarios for Assessing Possible Impacts and Adaptation Needs: Insights from Coasts of India

Dhanya Praveen, Andimuthu Ramachandran and Kandasami Palanivelu

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.74325

Abstract

Rising seas are one of the crucial impacts of global warming. Rise in the mean sea level may impact coastal communities under an increasingly warming climate. The coastal zones are highly resourceful and dynamic. The coastal zones are facing many natural hazards such as erosion, storm surge, tsunami, coastal flooding and sea level rise. It is projected to have a three-time expansion of density of population in the coastal areas, and 50% of the world's population will be occupied within the vicinity of 100 km of coastal areas. India has a very long coastline of 7500 km and covers 16.7% of the world's population and has a very high population growth rate which itself make India highly sensitive to these environmental challenge. Projections of mean global sea level rise (GSLR) provide insufficient information to plan adaptive responses; local decisions require local projections that accommodate different risk tolerances and time frames and that can be linked to storm surge projections. Therefore, in this chapter, the main endeavor is to identify and compare coastal vulnerability to projected future sea level rise. In order to project the sea level rise at local level, a climate- and sea level rise simulator model output based on IPCC AR5 (Special Report on Emission Scenarios) has been employed under different scenarios. The results reveal that sea level for Visakhapatnam, Chennai, Cochin and Mumbai may increase by 1.16, 1.19, 1.34, 1.24 m, respectively, by 2100 under the high-emission business as usual carbon pollution scenario under IPCC AR5 Representative Concentration Pathway. The sea level of west coast tends to rise slightly more than the east coastal areas of India. These estimates have great potential for the coastal regulatory authority and other decision-makers to take precautions with regard to inundations of low-lying areas and to conserve India's eco-sensitive coastal resources.

Keywords: sea level rise, climate change, RCP, coast, India, LSLR, adaptation, IPCC AR5, coastal inundation

1. Introduction

The Earth's climate has changed throughout history; however, the current warming trend is of particular connotation because most of it is very likely human-induced and proceeding at a rate that is unprecedented in the past 1300 years [1]. Over the period 1951–2012, global mean surface temperature increased approximately by 0.12°C per decade [2, 3]. The considerable coastal threats include shoreline erosion and inundation of coastal areas. Various global models and forecasts are warning of the loss of critical habitats along the coast due to this global issue. India's Coastal Regulation Zone (CRZ) act of 1991 was revised and reissued in 2011 to incorporate such threats. It has seriously taken into consideration the impact of future sea level changes with more of a management approach rather than a regulatory approach. Additionally, the Disaster Management (DM) act of 2005 and DM policy of 2009 stress that developing contemporary forecasting and early warning systems are prerogative of every State in India. These form part of ensuring efficient response and relief to the vulnerable sections of the society. It is reported that global sea level rose about 17 cm (6.7 inches) in the twentieth century. The rate in the last decade, however, is nearly double than that of the last century [4]. It has also recently been reported by Kopp that global sea levels have risen faster from the late twentieth century than in any of the previous 27 centuries [5]. It is certain that the mean sea level would continue to rise all over the globe in the years to come [2]. Gitay et al. [6] projected that 20% of the coastal wetlands could be lost due to sea level rise by the end of this century. Natural and cultural ecosystems along the coasts are highly susceptible to the consequences of sea level rise and resultant impacts [7–9]). According the IPCC fourth assessment report, SLR would be in the range of 18–59 cm from 1990 to 2090 [10].

Church and White revealed that there is a considerable variability in the rate of rise in sea level during the twentieth century, but there has been statistically significant acceleration of 0.009 ± 0.003 and 0.009 ± 0.004 mm year^{-2} since 1880 and 1900 [11].

Understanding the local changes with respect to climate and sea level rise warrants better adaptation and future management especially for the vulnerable low-lying coastal areas in the developing countries [11, 12]. Although it is highly exigent, downscaling high-resolution data at the local scale using the regional climate and sea level rise simulation models are the best available tools that provide huge potential for further impact assessments and adaptation planning [13].

2. Methodology and results

Projections on sea level rise are highly important especially from the point of view of Asia, as plenty of natural resources and ecosystems are already vulnerable to climate variations [14]. Noteworthy progress has been made during the last decade in estimating and understanding historical sea level rise. However, much work remains to be done in the future. Of particular importance is the maintenance and continuation of the observing network such as the permanent service for mean sea level (PSMSL) archive. Thus, the objective of this chapter is also to provide hands-on information to facilitate coastal manager and adaptation planners to frame location-specific and time-based adaptation strategies to sea level rise. The state of Andhra Pradesh has long coastline of 930 km. A climate simulator model based sea level rise data based on IPCC Assessment Report 5 (Special Report on Emission Scenarios-AR5) has been used to project the sea level rise at local level under different scenarios. The global SLR data were downloaded separately for the selected study areas such as Mumbai, Visakhapatnam, Chennai and Cochin were processed (Source: https://tidesandcurrents.noaa.gov/sltrends/& http://www.psmsl.org/data) to understand the mean changes by the end of twenty-first century [15]. The sea level rise projection is employed based on GHG emission trajectories as per the below-mentioned Representative Concentration Pathways (RCPs) of IPCC AR5 (**Table 1**). Box and whisker plots were used to make visual regional comparisons of projected sea level rise.

India owns 6100 km of mainland coastline and coastline of 1197 Indian islands constituting a total coastal length of 7516.6 km touching 13 States and Union Territories (UTs) (**Figure 1**). The eastern coastal area lies between the Eastern Ghats and the Bay of Bengal and extends from the Ganges delta to Kanyakumari. Chilika Lake and the Pulicat Lake (lagoon) are the important geographical features of east coast. The western coastal strip encompasses from the Gulf of Cambay (Gulf of Khambhat) in the north to Cape Comorin (Kanyakumari) in the south. It is divided into three parts: (1) the Konkan Coast, (2) the Karnataka Coast and (3) the Kerala Coast.

It is obvious from the results that the study area may experience sea level rise in future. The state of Andhra Pradesh, located at south-east coastal areas of India, has long coastline of 930 km. The outcomes from the climate simulator model based on IPCC AR5 (Special Report on Emission Scenarios) emission trajectories projects rise in sea level at local level under different scenarios.. The results reveal that sea level may increase by 1.16 m under the high-emission carbon pollution scenario Representative Concentration Pathway 8.5. Under moderately strong emission reduction scenario, that is, RCP 4.5, the sea level is projected to be 0.89 m above MSL. It can be noted that with aggressive cuts in the carbon pollution, we can further limit the undesirable rise in sea level to be around 0.77 m as per RCP 2.6 (**Figure 2**).

The state of Tamil Nadu has the second largest coastline of India with 1076 km. It is a part of Coromandel Coast of Bay of Bengal and Indian Ocean. In the northernmost part of the coast, Chennai is located, which is not only the capital of the state but it is an important commercial and industrial centre in the country, with Kanyakumari forming the southern tip where the Indian Ocean, Bay of Bengal and Arabian Sea meets. Pulicat Lake, which has a rich and fragile

Name	Radiative forcing	CO_2 equiv (p.p.m)
RCP 8.5	8.5 wm^2 in 2100	1370
RCP 4.5	4.5 Wm^2 post in 2100	650
RCP2.6 (RCP3PD)	3 Wm^2 before 2100, declining to 2.6 Wm^2 by 2100	490

Table 1. Radiative forcing as per representative concentration pathways (RCPs) of IPCC AR5.

Figure 1. Locations of the study area.

ecosystem, is the second largest brackish water lake in India and is located in the northern part of the coast. A climate simulator model based on IPCC AR4 (Special Report on Emission Scenarios) has been used to project the sea level rise at local level under different scenarios. The results from the simulation reveal that sea level of Chennai coasts may rise 1.19 m under the high-emission carbon pollution scenario Representative Concentration Pathway 8.5. Under moderately strong emission reduction scenario under RCP 4.5, the sea level is projected to be 0.92 m above MSL. It can be noted that under RCP 2.6 with aggressive cuts in the carbon pollution, we can further reduce/limit the undesirable rise in sea level to be around 0.79 m for Chennai (**Figure 3**).

http://dx.doi.org/10.5772/intechopen.74325

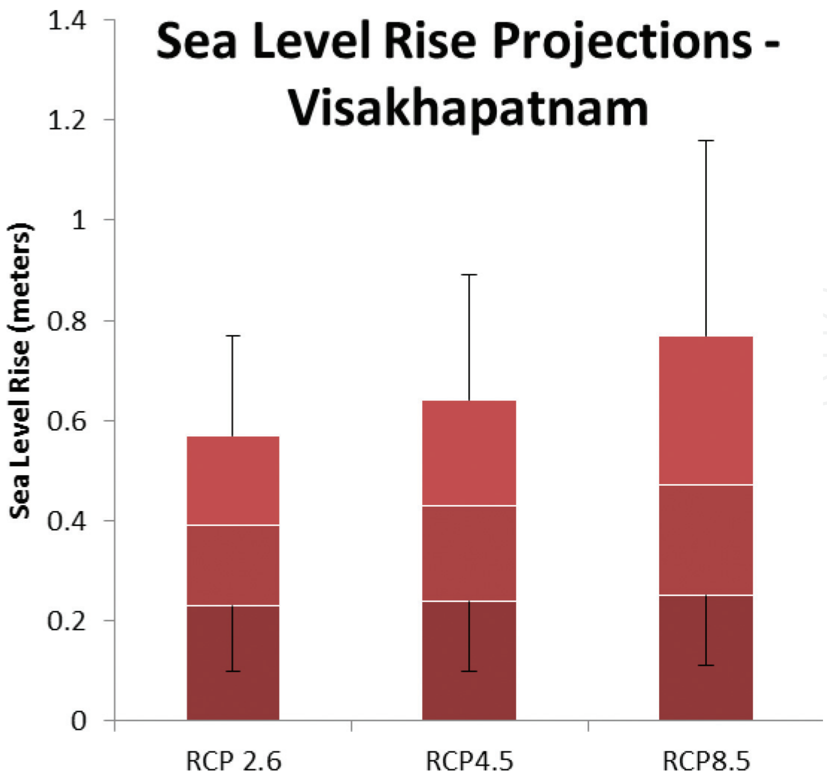

Figure 2. Sea level changes till the end of twenty-first century for Visakhapatnam, Andhra Pradesh coast.

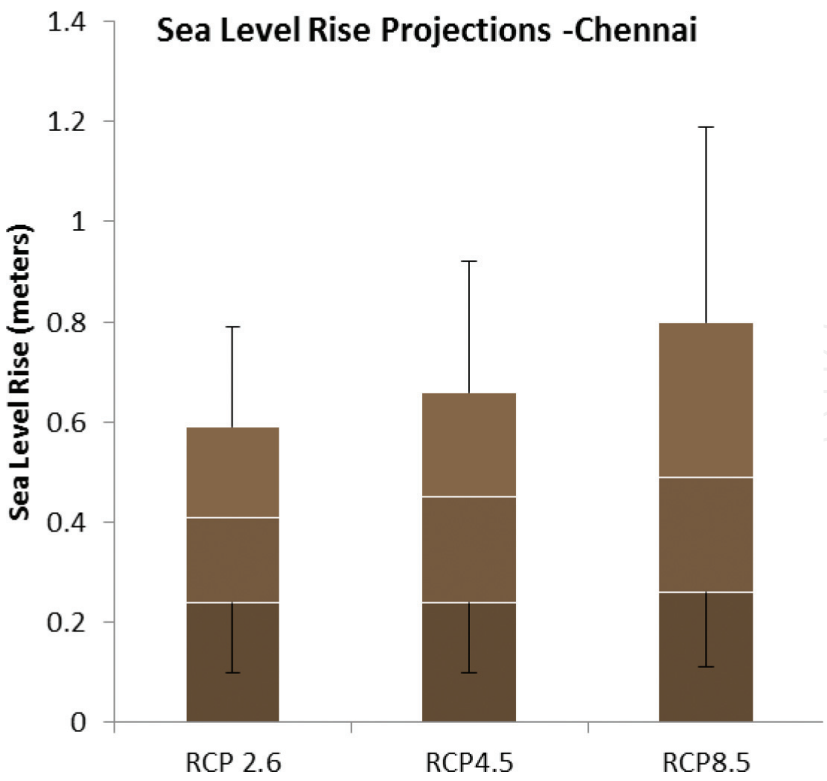

Figure 3. Sea level changes till the end of twenty-first century for Chennai, Tamil Nadu coast.

The state of Kerala has long coastline of 569.7 km. The usage of the climate simulator model helped in projecting sea level rise at local level under different emission pathways. The results reveal that sea level of Cochin coasts may rise 1.34 m under the high-emission carbon pollution

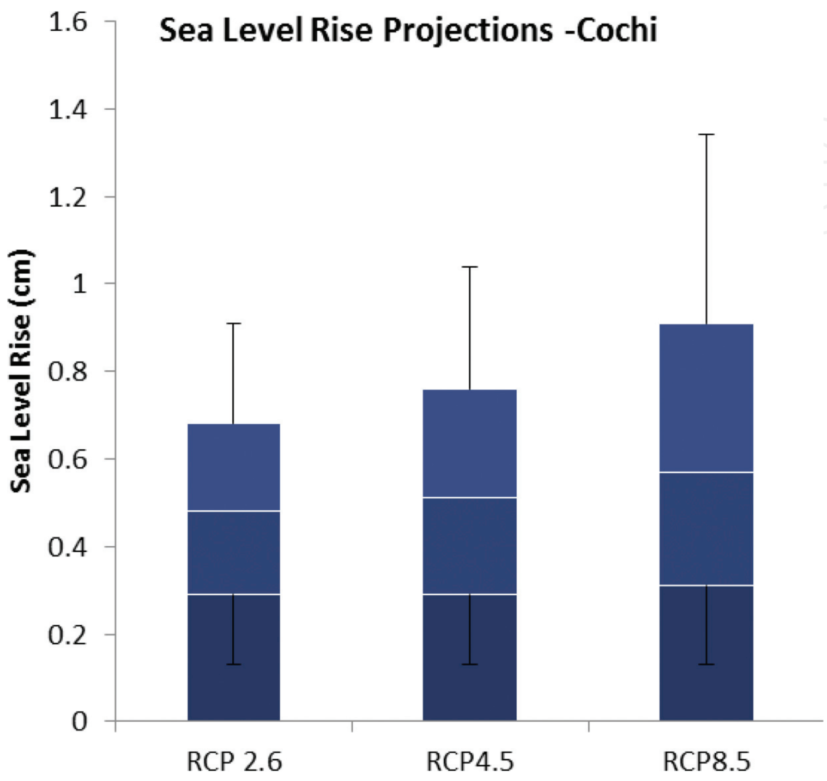

Figure 4. Sea level changes till the end of twenty-first century for cochin, Kerala coast.

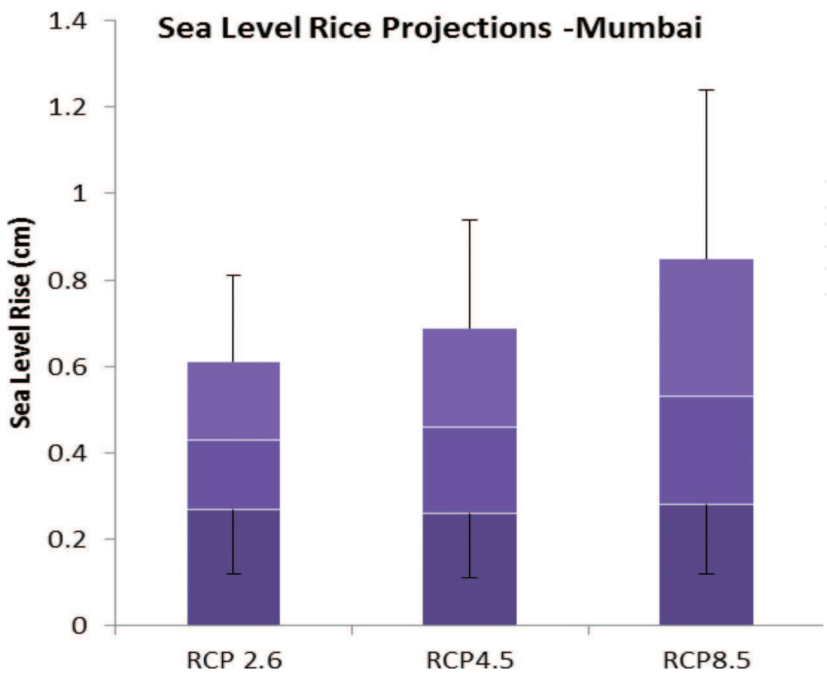

Figure 5. Sea level changes till the end of twenty-first century for Mumbai, Maharashtra coast.

http://dx.doi.org/10.5772/intechopen.74325

scenario Representative Concentration Pathway 8.5. Under moderately strong emission reduction scenario under RCP 4.5, the sea level is projected to be 1.04 m above MSL. It can be noted that under RCP 2.6 with aggressive cuts in the carbon pollution, we can further reduce/limit the undesirable rise in sea level to be around 0.91 m for Cochin (**Figure 4**). It shows the highest rate of sea level rise among all other three locations chosen for study. As a next step forward, inundation impact study needs to be conducted as Cochin has a group of islands that form part of the city like Vypin which is not only a fishing harbor but an industrial hub, which may be under high risk.

The coastline of the state of Maharashtra is 652.6 km long. The climate simulator model has been employed to predict the sea level rise at local level for Mumbai coast under different scenarios. The results reveal that under the high-emission carbon pollution scenario Representative Concentration Pathway 8.5 is 1.24 m. Under moderately strong emission reduction scenario under RCP 4.5, the sea level is projected to be 0.94 m above MSL. It can be noted that under RCP 2.6 with aggressive cuts in the carbon pollution, we can further reduce/limit the undesirable rise in sea level to be around 0.81 m (**Figure 5**).

3. Discussions and conclusions

The CRZ 2011 notification has been a new addition to the list of policies using bottom-up approach as a good governance tool. A modelling study carried out by (Aggarwal & Lal SLR rise of 30–80 cm had been projected for Indian coast over the twenty-first century [16]. All these study areas Mumbai, Chennai, Cochin and Visakhapatnam are not only thickly populated but also intensively used zone with significant harbour activities such as travel and trade. These coastal tracts do possess historical heritage sites as well.

Natesan and Parthasarathy observed in their study that about 13 km2 of the land area would be inundated permanently due to SLR in Kanyakumari [17]. Khan et al. carried out sea level rise simulation study using SimCLIM for the coasts of Tamil Nadu, South India [18]. Researchers reported that studies involving SLR projections are highly useful to find susceptible areas to SLR and to minimize its potential impacts on coastal area [19–21]. Rising ocean heat content (and hence ocean thermal expansion) is an important element of climate change and sea level rise [22–24, 11]. Sea levels are rising now and are expected to continue rising for centuries, even if greenhouse gas emissions are curbed and their atmospheric concentrations are stabilized. In this case, ecosystem- and community-based adaptation is the need of the hour. As mentioned by Adger et al., it is the citizen's responsibility to identify three mechanisms: altering (human) exposure to climate change-induced sea levels, reducing sensitivity (sometimes called 'climate proofing') and increasing the resilience of the coastal eco systems [25]. Coastal agriculture is also going to be hit. Apart from several biotic and abiotic factors, salt water intrusions into coastal wetlands would also negatively affect the growth and yield of cultivated plant species, especially in potential arable land in our coastal states, where food production is already considered a critical issue. Even though India has strengthened its potential in coastal management, disaster management and several community-based field projects to enhance the participation of stakeholders, and much work needs to be done in the future [26].

Accurate sea level predictions are vital for planning coastal infrastructure development within the buffer zone in low-lying coastal areas anticipating predicted sea level rises of almost a meter by 2100. Hybrid approaches consisting of empirical and semi-empirical models and process-based models have also been undertaken to reduce uncertainties in the projections [27]. Projecting accurately the population growth per locations, especially in a rapidly growing Asian coastal city, adds to additional uncertainty [28]. Forecasting sea level rise does not just depend on how much sea water rises, but also how land levels change due to tectonics, natural compaction of soft soils as well as human influences [29]. Hence it is the responsibility of the research team to communicate and sensitize about integrated coastal zone management for minimizing the impacts of future sea level rise to all the stakeholders.

Site-to-site differences in LSL projections may be attributed to varying non-climatic background uplift or subsidence, oceanographic effects and spatially variable responses of the geoid and the lithosphere to shrinking land ice. Thus, the objective of this chapter is to provide sea level projections to facilitate coastal manager and adaptation planners to frame location-specific and time-based adaptation strategies to sea level rise. This chapter also recommends Chennai Metropolis, Greater Visakhapatnam Smart City Corporation, Mumbai Corporation and Cochin development Corporation to conceptualize the future sea level rise scenario while preparing the city developmental plans to incorporate adaptation and enhanced disaster risk reduction. Metro City Development Corporation may include this matter while preparing plans for developing smart city master plans to deal with enhanced disaster risk reduction proactively. Futuristic coastal zone land use planning, construction of dykes, afforestation programmes using bamboo, mangrove, bamboo fencing, adapting coastal agriculture to salt tolerant species, strengthening the existing coastal regulation zone (CRZ) policies, and so on would help in conserving critical ecosystem services and infrastructure.

Author details

Dhanya Praveen*, Andimuthu Ramachandran and Kandasami Palanivelu

*Address all correspondence to: dhanyapraveen.cc@gmail.com

Centre for Climate Change and Adaptation Research, Anna University, Chennai, India

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