A paper presented at the 18th International Conference on Sustainable Development,
Montclair State University, New Jersey, USA, 13-14 December 2023.

Assessing the Shoreline Dynamics Integrating Sea-Level Data and Geo-Spatial Technology: Lessons from Kerala State, India

Rajeev R [1], Adinarayanane Ramamurthy [2]
[1]Assistant Professor and PhD Research Scholar
[2] Dean (Planning & Development) and Associate Professor,
Department of Planning, School of Planning and Architecture Vijayawada,
Ministry of Education, Government of India.

OIDA International Journal of Sustainable Development, Ontario International Development Agency, Canada.
ISSN 1923-6654 (print) ISSN 1923-6662 (online) www.oidaijsd.com
Also available at https://www.ssrn.com/index.cfm/en/oida-intl-journal-sustainable-dev/

Abstract: Global sea-level rise has been estimated to accelerate and to reach 1–2 m by 2100. The rise in ocean level and the consequent coastal flooding present noteworthy dangers to urban settlements situated in coastal regions. Despite the efforts made to implement mitigation strategies, there is uncertainty regarding the effectiveness of these actions in reducing the exposure of cities and the risks associated with climate change-related events. Numerous studies on this subject have explored the vulnerability of sea level change and related climatic impacts at various spatial scales. The broad spatial scales required to assess the impacts of climate change necessitate collaboration and coordination among managers, planners, and policymakers from different jurisdictions, agencies, and management units. Globally, the coastal regulations try to address the above challenges in this ever-changing environment by maintaining adequate setbacks from the High Tide Line (HTL) and setting guidelines for coastal planning and governance. However, studies indicate that these regulations are often violated; more development is attracted towards the coast and this exceeds the inherent development capacity of the coast.

Keeping the aforesaid knowledge in mind, the southern state of Kerala in India has been chosen for further detailed investigation on shoreline changes, climate change and CRZ regulations. The authors have tried to conceptualize the Sea-level Rise and related impacts, generated the spatial interaction model for Composite Coastal Vulnerability and Coastal Risk associated with Sea Level Rise under the Coastal Regulation Zone (CRZ). The qualitative "Coastal Vulnerability Index (CVI)", the factor indicating Composite Coastal Vulnerability, is based on quantitative estimates to characterize the physical setting – including Geomorphology (G), Mean Elevation (ME), Shoreline Change (SLC), Bathymetry/ coastal slope (B), relative Sea-Level Change/ Rise (SLR), Significant Wave Height (SWH), and Mean Spring Tide Range (MSTR) – coupled with predominant land use/ human activities (LU), and coastal population (P). A linear regression model was drawn along with sea-level and shoreline change data to understand the impact of sea-level. Additionally, through hotspot analysis areas of high concern have been identified and coastal development in these coastal stretches has been studied to understand the adherence to the CRZ regulations and violations. For this study, secondary data has been used to construct and analyse regional level (state-level) details; further primary survey which includes interviews with stakeholders and expert opinions were undertaken.

Based on the positive relationship between rising sea-level, shoreline change and CRZ, this study finally suggests that using satellite imagery, sea-level data and statistical and spatial techniques, the changing nature of shorelines along with sea-level rise and CRZ violations can be reliably understood. The study also reveals that the planning framework for coastal management requires a system of classification and evaluation that embraces wide areas of environmental sensitivity, or areas of concern, as well as the smaller areas of concentrated ecological value and particular essentiality to the ecosystem, the vital areas - broadly designated as areas for "preservation", "conservation" and "utilization" according to their varying ecological sensitivities. The study concludes with recommendations to the decision-maker to include climate concerns into spatial planning of coasts for deriving the most appropriate spatial development strategies to maintain the balanced and sustainable development of the coastal region in India.

Keywords: Climate Change; Coastal Vulnerability; CRZ; Geo-spatial Technology; Sea Level Rise.

Introduction

Climate Change and subsequent sea level changes along the coastal areas is of great interest to researchers and policy makers because of its potential impact on human habitation. Studies estimate a likely increase in sea level in the range of 0.3m to 1.2m by 2100 and few even higher. The impact of sea level rise is not just limited to the seacoast. Based on the development pattern around the world, it has been projected that Asia is likely to witness maximum increase in built-up areas by 2030, a major percentage along the low lying coastal stretches. Under the Environment (Protection) Act of 1986, the Ministry of Environment and Forests (MoEF), Government of India, issued the Coastal Regulation Zone (CRZ) Notification in 1991 with the goal of preventing the depletion and degradation of coastal resources and managing development activities along the coastline; which according to the requirements and need of the people based on deliberations with various stakeholders, was amended as Coastal Regulation Zone Notification 2011 (CRZ Notfn. 2011) and further modified in the year 2019. This notification regulates all developmental activities on the coastal stretches in India within 500m of HTL on the landward side and within the territorial limits into the sea, as classified under the CRZ Regulations. The Kerala State's coastal stretches have been identified separately in the CRZ Notification 2011 as an area requiring special consideration due to the state's distinctive backwater and backwater island coastal systems and space constraints. As estimated by the Intergovernmental Panel for Climate Change (IPCC, 2007) estuaries, backwaters and the land adjoining are equally or more vulnerable to the changes in sea-level.

Unless advanced planning to address the effects of climate change becomes an ongoing and integral part of the planning process, the country risks finding itself in extremely dire situations. Hence this makes it necessary that we evaluate the CRZ regulations that concern the coast with respect to the probable sea-level rise (based on estimates) that may happen in the future. For this study, considering the geographical vulnerability and ecological significance, the coastline of Kerala is taken for critical analysis of CRZ Regulations w.r.t. coastal vulnerability and climate change impacts.

Review of Existing Coastal Regulations in India

The importance of the coastal zone and the protection of its resources have been recognized by almost all the nations of the world. International institutions like the UN (UNEP) and the World Bank have been giving high priority in supporting programmes and projects formulated world over to sustain the coastal ecosystems. Interests surrounding this environment are many like natural resources exploitation, tourism, industries, and avenue for dumping of waste. (United Nations, 2002) This multi-user environment has naturally attracted conflicts in different forms. Such diversity calls for a holistic and sustainable approach to research, planning and management. The planning framework for coastal management requires a system of classification and evaluation that embraces wide areas of environmental sensitivity, or areas of concern, as well as the smaller areas of concentrated ecological value and particular essentiality to the ecosystem, the vital areas - broadly designated as areas for “preservation”, “conservation” and “utilization” according to their varying ecological sensitivities.

Given India's densely populated 7500-kilometer-long coastline, ensuring coastal stability becomes critical. Like in several coastal countries, many coastal zones in India have fragile ecosystems and these continue to degrade (loss of habitats and species diversity, water pollution, eutrophication, and landscape deterioration). Thus, owing to the threat faced by the beaches of India, the Government of India issued in 1991 under the Environment Protection Act and Rules of 1986, the Coastal Regulation Zone Notification 1991.

Table 1 : Coastal Setback Zones (Distance from HTL) adopted by different Countries/States

Continents	Countries	Setback Zone
Asia	India	500 m
	Indonesia	50/400 m*
	Philippines (Mangrove Green Belt)	20 m
	Sri Lanka	300 m
Europe	Denmark	1000 - 3000 m
	France	100 m
	Greece	500 m
	Norway	100 m
	Spain	100 - 200 m
	Sweden	100 m
	USSR-Coast of Black Sea	3000 m
Oceania	New Zealand	22 m
North America	Hawaii	13 m
	Mexico	20 m
	Oregon	Permanent Vegetation line (variable)
South America	Brazil	33 m
	Columbia	50 m
	Costa Rica (Public Zone)	50 m
	Costa Rica (Restricted Zone)	50 - 200 m
	Chile	80 m
	Ecuador	8 m
	Uruguay	250 m
	Venezuela	50 m

Source : (MSSReport, 2005)

The CRZ notification designated the land between the "Low Tide Line" (LTL) and the "High Tide Line" (HTL) and the coastal stretches of seas, bays, estuaries, creeks, rivers, and backwaters that are affected by tidal action up to 500 metres from the HTL as the Coastal Regulation Zones (CRZs). Developmental activities were restricted, and the notification in turn would govern the use of land within 500 metres of the coast and 100 metres along tidally influenced water bodies. Between 1991 and 2009, there were about 25 amendments made to this notification as various state governments and other stakeholders complained that they were having trouble putting its provisions into practise. Eventually this notification was allowed to lapse and the Ministry brought out a fresh notification in September 2010, which after much discussions and deliberations, was finally issued as Coastal Regulation Zone Notification 2011 (CRZ Notfn. 2011) on January 6, 2011. As of 2022, the coastal states of India are still in the slow-process of mapping its coast and demarcating the Coastal Regulation Zone. Post CRZ Notification 2011, there was continued resistance from various stakeholder communities representing industries and tourism etc. claiming for further relaxation of the CRZ norms; resulting in the CRZ Notification 2019.

India has also already implemented a number of voluntary measures with its own funds in support of a sustainable development strategy which includes Coastal Ocean Monitoring and Prediction Systems (COMAPS), Land Ocean Interactions in the Coastal Zone (LOICZ), Integrated Coastal and Marine Area Management (ICMAM), and Society of Integrated Coastal Management (SICOM) (Planning Commission, 2012).

Methodology

Coast is a dynamic environmental region which is continuously modified by the constant action of water and wind on land. Considering the eco-system services and development significance of this environmental region; this common resource is often degraded. In addition to the natural and man-made modification of the coast, the changing climate also affects this region. Globally, the coastal regulations try to address the above challenges in this ever-changing environment by maintaining adequate setbacks from the High Tide Line (HTL). However, studies indicate that these regulations are often violated; more development is attracted towards the coast and this exceeds the inherent development capacity of the coast. This study tries to critically evaluate and present evidence that the coast is not homogenous; and hence requires the preparation of integrated coastal management plans based on the existing coastal regulations which considers the concern of climate change as well. First, the composite coastal vulnerability (which includes physical and social vulnerability) is ascertained and further which the coastal risk is computed. In parallel, the CRZ Regulation is critically evaluated to ascertain the inclusion of Sea-level rise and other climate concerns in the provisions. Thirdly, based on the coastal risk and threat to SLR, specific strategies are proposed to improve the coastal regulations and include climate concerns into spatial planning. For this study, secondary data has been used to construct and analyse regional level (state-level) details; further primary survey which includes interviews with stakeholders, and expert opinion were undertaken. Through this study the author attempts to promote sustainable and climate resilient coastal development in Kerala by understanding the coastal development capacity and re-visiting the coastal regulations from the climate perspective.

Vulnerability of Kerala Coast to Sea-level Rise

Sea Level Rise (SLR) is one of the apparent and widespread consequences of the climate change that will affect the Western Coast of India. By 2100, the IPCC projects a maximum SLR of 100 cm. Since it doesn't account for upcoming dynamical changes in ice flow, such as some crucial ice sheet processes that quicken the movement of glaciers, especially in the polar ice caps, this estimate is widely acknowledged to be conservative (IPCC 2014). SLR will have a wide-ranging impact on the coastal zone; a graphic depiction of the same is presented at Fig. 1.

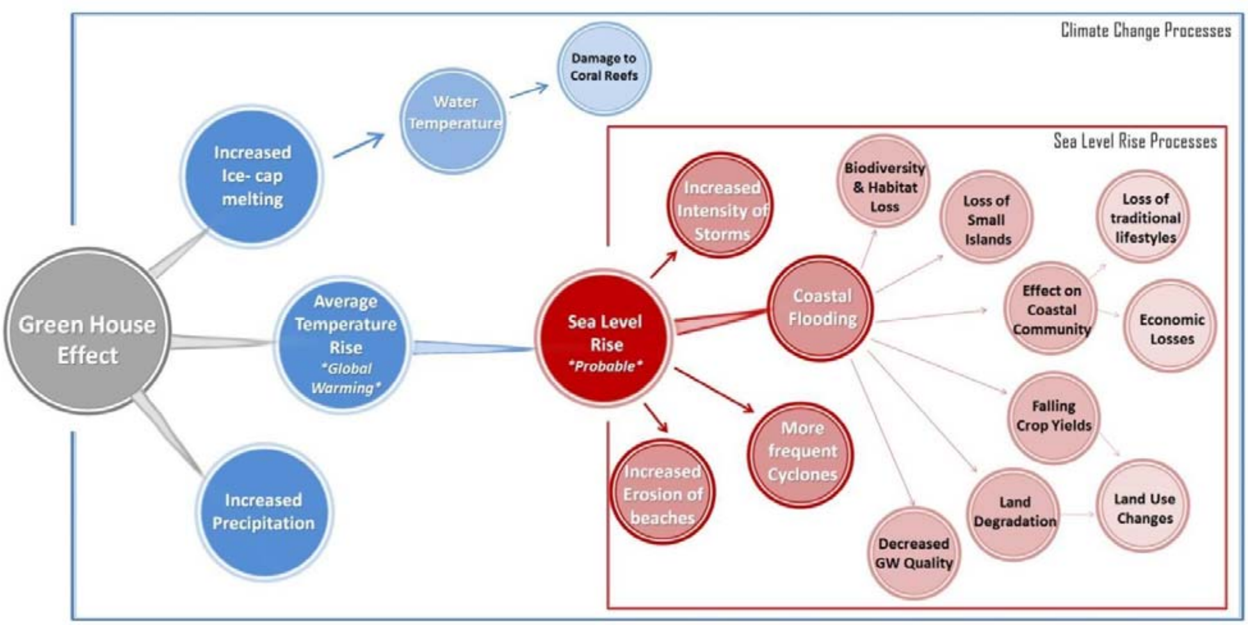


Figure 1: Sea-level Rise and Related impacts

(Source: Compiled by Author from Literature Review)

Over 7,500 kilometres of India's coastline, including the continent and its islands, are occupied by people who live less than 50 kilometres from the ocean. Sea level rise (SLR) will probably force people to move inland or out of their islands and delta regions since the region in which India falls includes small islands, delta regions, and long coastlines. Tens of millions of people will be affected negatively by climate change in one of the world's most densely populated regions. Each of these effects will bring about a number of additional effects that could quickly devastate the Indian coast if they all come into play.

Coastal Morphology

The 590 km of brackish water bodies that make up Kerala's coastline stretch from Manjeswaram in the north to Pozhiyur in the south. Chittari, Kappad, Ponnani, Calicut, Cochin, Alleppey, and Kovalam all have developed sandy beaches. This covers 113 inland fishing villages and 221 coastal fishing villages. (R, A, & R, 2011) (SAC, 2012) Additionally, pocket beaches in the shape of a crescent can be found at Ezhimala, Dharmadom, Tellicherry, Kadur Point, and Ealthur. At the estuaries of Vambanad, Asthamudi, Shiriys, Bypore, and Veli, spits are visible. The growth of spits at some locations during the lean season blocked the opening of small estuaries. On the Keralan coast, there are numerous locations with cliff and rocky coastlines. Near Bekal, Ezhimala, Azhikode and Kadalur point in the north and Vizhinjam, Varkala and Tangasseri in the south are the notable rocky coasts. (SAC, 2012)

The mangrove vegetation in Kerala's coastal region is extremely thin and sparse; it used to cover 70,000 ha, but it is now only 1671 ha. In the state, Valapattanam, Kunghimangalam, Kasargod-Nileswar, Kavvay, and Puthuvypin are the principal mangrove harbouring areas. Kerala's mangrove forests can be divided into four districts: Kannur, Kozhikode, Ernakulam, and Allepey, running from north to south. There are numerous islets and islands off the coast of Kerala. They are mostly inhabited. The islands are known as thuruths locally. Thuruths made by humans are also typical. More islands can be seen in the estuaries of Kakavvayi, Asthamudi, and Vembanad. In comparison to the islands in the Kavvayi estuary, the islands in Kerala's central Vembanad estuary are larger. The major islands are Wellington, Kumbalam, Nettur, Madavana, Cheppanam and Perumbalam. Dharmadam (Green Island / Dharmadam Thuruth), a large an uninhabited marine island, with mangroves and harbouring a variety of marine organisms, is situated in the northern Kerala and is being threatened due to tourism related activities. One of the largest breeding and fishing grounds in the nation is the coast's unique mudbanks. On Kerala's northern coast, at Kolavipalam Beach, nesting grounds for the Olive Ridley turtle, one of the endangered turtle species, are under threat from human activity. There are numerous habitats along the coast of Kerala. (SAC, 2012)

Ashtamudi Lake, Vembanad Lake, and Sasthamkotta Lake are notable wetlands in Kerala. Sasthamkotta Lake is the largest naturally occurring fresh water lake, while Vembanad Backwater Lake is the biggest in the state. Anjengo, Veli, Edava, Kadinakulam, Nadayara, Kayamkulam, Paravoor, Kowai, and Chotwa are some of the other significant backwaters. (SAC, 2012)

In view of these unique coastal systems including backwater and backwater islands along with space limitation present in the coastal stretches of the State of Kerala, it has been considered separately as an area requiring special consideration in the CRZ Notification 2011.

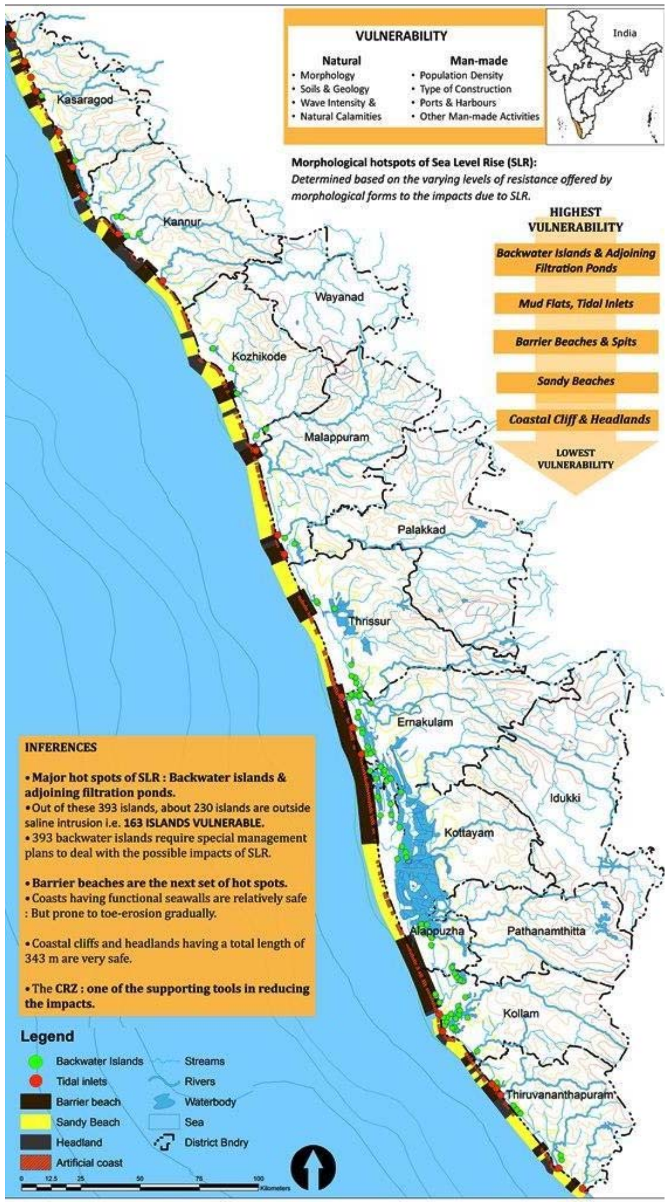


Figure 2: Coastal Morphology of Kerala

(Source: Generated by Author based on analysis of Coastal Vulnerability)

Coastal Vulnerability and Risk

The coastal vulnerability of Kerala have been assessed based on 8 (eight) broad parameters namely geomorphology, shoreline change, bathymetry, mean spring tide range, significant wave height, coastal population and settlements, other vulnerable areas like ESAs, tourist spots, historical areas, areas of natural beauty etc.

The coastal physical vulnerability to the impacts of Sea-Level Rise (SLR) has been ascertained based on the varying level of resistance offered by the coastal geo-morphological forms - namely backwaters and backwater islands; adjoining filtration ponds; tidal inlets; mudflats; spits; barrier beaches; sandy beaches; coastal cliffs and headlands etc. in the descending order of coastal vulnerability to SLR. The major hot spots of SLR on the Kerala coast are the backwater islands and adjoining filtration ponds. The 393 backwater islands require special management plans to deal with the possible impacts of SLR. Sandy beaches, especially barrier beaches are the next set of hot spots. Coasts having functional seawalls are relatively safe. Coastal cliffs and headlands having a total length of 29.02 km are very safe from the impacts of SLR.

Table 2: Coastal Vulnerability and Risk Matrix

	Parameters	Low	Moderate	High
VULNERABILITY	**Geomorphology**	Rocky, Embayed or Indented Coast	Sandy Beach, High Dunes, Vegetated coast	Estuaries, Backwaters & Backwater Islands, Mudflats, Mangroves, Barriers/Spits
	Shoreline Change (m/yr)	Accretion (>1m)	Nil	Erosion (>1m)
	Bathymetry (Off-shore continental shelf)	Very less steep slope (> 1:600m)	Moderately steep slope (b/w 1:300 - 1:600m)	Steep slopes(< 1:300m)
	Mean Spring Tide Range (m)	< 2m	2-4m	> 4m
	Significant Wave Height (m)	< 0.6m	0.6 - 1m	> 1m
	Elevation from MSL in meters	> 1.2m	0.6 - 1.2m	< 0.6m
	Coastal Population	Nil	If any settlements exist	
	Other Areas of Concern		Tourist spots, Historical areas, Area of natural beauty	Ecologically Sensitive Areas (ESAs)
	SCORE	**1**	**2**	**3**
	Areas of High Concern		**Areas having cumulative score of 19 -24**	
	Areas of Moderate Concern		**Areas having cumulative score of 11-18**	
	Areas of Low Concern		**Areas having cumulative score of 6-10**	

(Source : Generated by Author, based on Delphi Technique employed by Author during interviews)

In addition, the inner-continental shelf and the near-shore bathymetry show considerable variation along its length. There is a decreasing tendency of steepness values from Thiruvananthapuram in south towards north of Kerala. (CZM, 1995) South Kerala is having a steeper slope which when combined with wave intensity and height results in strong and powerful swells and rough waves along the southern coast, especially along the Thangassery to Poovar stretch. This again puts the coastal stretches at higher risk.

The Kerala coast is considered to be erosion prone. A temporary or permanent holdback of the shoreline threatens human activity, which makes coastal erosion a danger. Along the Kerala coast, eroding areas (sum of high + medium + low erosion+artificial coast) account for 63.02%.

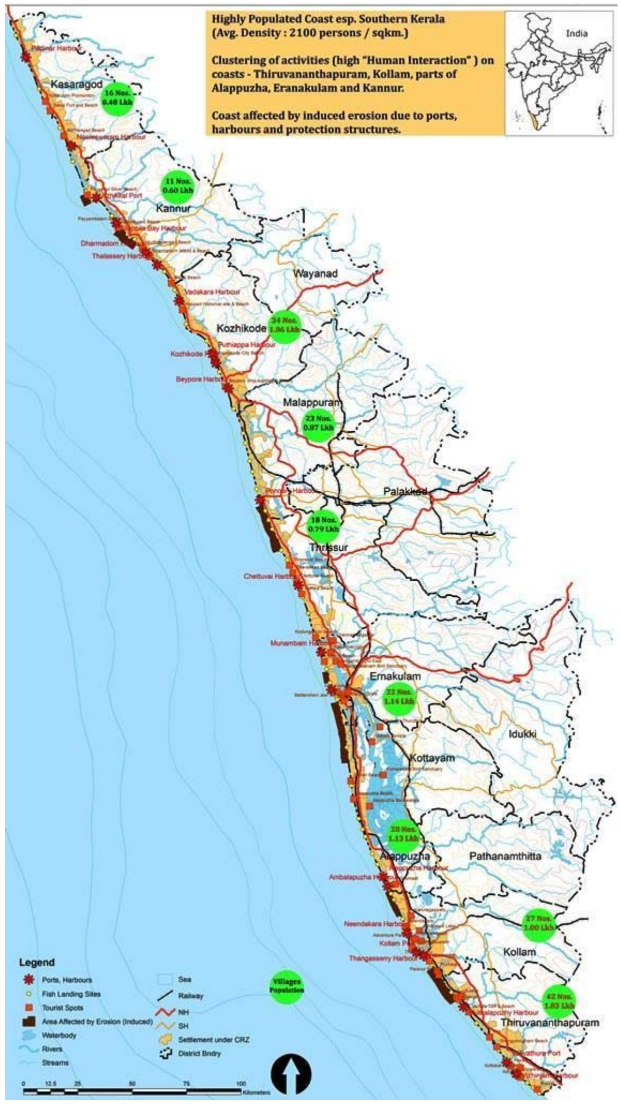


Figure 3: Anthropogenic Activities along Kerala Coast

(Source : Generated by Author)

Considering the development pattern in Kerala, a major share of the population in Kerala is at the risk of adverse impacts of climate change especially due to sea level rise and resultant coastal flooding and saline intrusion. The prominent activities along the coast of Kerala include tourism and ancillary hotel and resort industry, fishing industries and supporting infrastructure and ports, harbours and fish landing centres. From the population and activity distribution it is evident that southern Kerala is at a larger risk due to various coastal processes i.e. the districts of Ernakulam, Alappuzha, Kollam and Thiruvananthapuram.

Moreover, the modelling studies of probable Sea-level Rise carried out by the author indicates that the area affected by SLR is far greater than the area inundated by SLR which is greater than the area categorized under CRZ.

Figure 4: Composite Vulnerability and Coastal Risk to SLR

(Source : Generated by Author)

Changing Coast of Kochi, Kerala

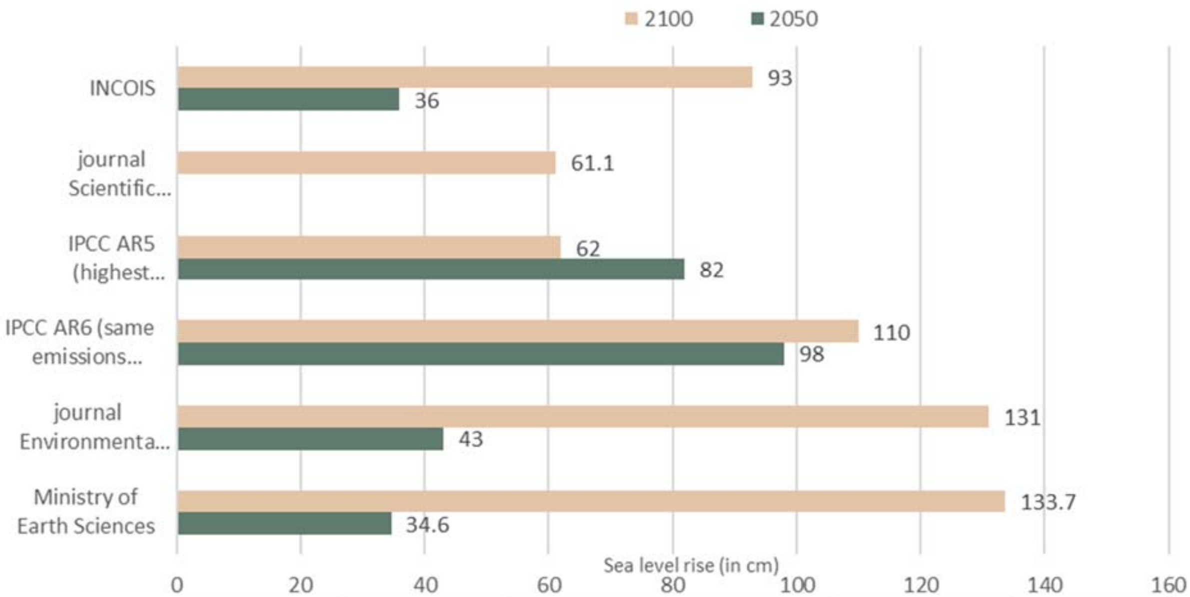
Sea Level Rise Scenario Building in Kochi

As discussed, Sea Level Rise poses a significant threat to buildings and infrastructure located in coastal areas. If sea levels were to rise by 1 meter in Kochi based on literature available, the consequences would be devastating. The low-lying areas of the city, including Fort Kochi, Mattanchery, and parts of Ernakulam, would be submerged, causing massive flooding and displacement of people. In such a scenario, buildings located in low-lying coastal areas would be particularly vulnerable to flooding and storm surges. The worst-case scenario for sea level rise would be a rapid and significant increase in sea levels, which could cause widespread flooding and damage to buildings and infrastructure.The rise in sea level would also have a significant impact on the local economy, particularly the fishing industry. The livelihoods of many fishers who depend on the sea for their income would be at risk due to the loss of fishing grounds and damage to fishing infrastructure.

Furthermore, the increased frequency and intensity of coastal flooding and storm surges would lead to a rise in water-borne diseases, damage to crops, and loss of habitat for wildlife.It is therefore essential to consider the worst-case scenario in the future and take measures to mitigate the effects of climate change and reduce greenhouse gas emissions to prevent such a scenario from becoming a reality.

However, it is important to note that this is not a certainty and that the actual sea level rise in Kochi may be lower or higher than this projection. This projection is based on different literature review on sea level rise in Kochi, and there is still uncertainty surrounding the exact extent and timing of sea level rise. Nonetheless, it is crucial to prepare for the worst-case scenario and take action to adapt to the potential impacts of sea level rise**.**

Based on literature review, the following are based on few studies conducted on the potential impacts of sea level rise on Kochi, and considered in this study:



	Ministry of Earth Sciences	journal Environmental Research Letters 2018	IPCC AR6 (same emissions scenario)	IPCC AR5 (highest emissions scenario)	journal Scientific Reports in 2020	INCOIS
2100	133.7	131	110	62	61.1	93
2050	34.6	43	98	82		36

Figure 5: SLR Scenarios – 2050 and 2100

(Source: Compiled by Author)

A. The intergovernmental panel on climate change (IPCC) has provided sea level rise projections in their fifth assessment which considers the highest emission scenario to have an increase in sea level rise of 62 cm by 2100 and 82 m by 2050.

B. Under the sixth assessment report by the IPCC considering the same emission scenario in the future an increase of 110cm of sea level rise by 2100 and 98 cm by 2050 is predicted.

C. The study conducted by Indian national centre for ocean information services (INCOIS) predicts an increase of 93cm by 2100 and 36cm by 2050.

D. Journal scientific reports published in 2020 identifies an increase in sea level rise of 61.1 cm.

E. Ministry of earth science have predicted the highest increase in sea level rise of 133.7 cm by 2100 and 34.6cm by 2050.

F. An increase of 131 cm by 2100 and 43 cm by 2050 is predicted by the research conducted to analyze the potential impacts of sea level rise on the Indian coastline by the journal environment research letter in 2018.

Through this study it can be observed that the highest increase in sea level rise is 98 cm by 2050 as predicted by IPCC AR6 and 133.7 cm by 2100 given by the ministry of earth sciences.A study by the National Institute of Oceanography (NIO) estimates that a 1- meter sea level rise would inundate about 3% of the Kochi metropolitan area, affecting more than 50,000 people. Similarly, the areas that would be inundated can be identified and use as a tool for understanding the potential consequences of sea level rise for adapting to the impacts of climate change, and building resilience in vulnerable coastal communities by the policy makers.

Shoreline Change Assessment in Kochi

Shoreline change assessment is to understand the dynamic interface between land and water along a coast or shoreline as these are the regions that changes erratically in response to one or more factors, like morphological or geological factors in nature (including erosion, sedimentation), climatic (viz. sea level rise), as well as the effects of natural and human-induced changes on coastal ecosystems and communities. (Kaliraj, 2013). Shoreline change assessment can aid in ensuring the long-term sustainability of these critical and rapidly changing environments by helping to understand the intricate relationships that exist between natural and human systems in coastal zones.

From several studies it can be noted that the end point Technique combined with satellite imagery can give accurate and reliable results for shoreline change computation and analysis (Sebat, 2018). Linear regression method for calculating the shoreline change is high recommended by experts as this it have the potential to use more than two shoreline and is determined by fitting a least-square regression line to all shoreline points for a particular transects which provide a precise calculation of the rate of change (Burningham, 2017).

Digital Shoreline Analysis System (DSAS) extension tool an essential component of the U.S. Geological Survey's Coastal Change Hazards project provides a robust suite of regression rates in a consistent and simply repeatable method to execute on large volumes of data collection at various scales (Emily A. Himmelstoss, 2021). This software too has been used in the study despite of few limitations with regards to the accuracy of the baseline shoreline which is dependent on the quality of the input data, and errors can occur due to the presence of vegetation or other features that can affect shoreline detection. This analysis allows to quantify the historical and temporal shoreline changes over time with a high degree of accuracy. This is important because shoreline change can have significant impacts on coastal ecosystems, communities, and infrastructure.

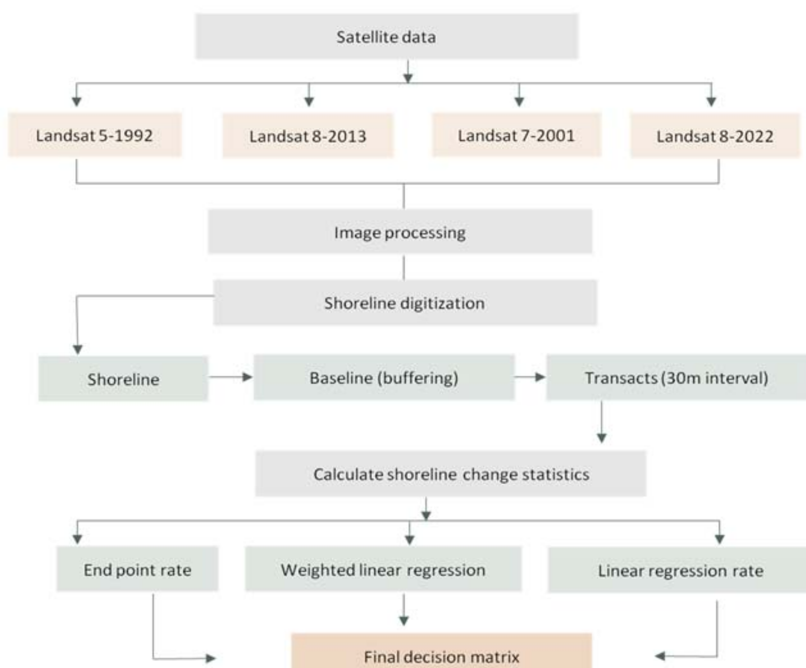


Figure 6: Digital Shoreline Analysis System (DSAS) Methodology

(Source : Generated by Author based on Literature)

The shoreline of Kochi is characterized by a series of sandy beaches, rocky cliffs, and tidal flats. The coastal environment is influenced by a range of natural processes, such as waves, tides, currents, and sediment transport.

From the analysis the following calculation were developed

I. NET SHORE MOVEMENT- the distance between the oldest and the youngest shorelines for each transect
   1. Maximum negative distance: -865.29 m (81%)
   2. Maximum positive distance: 655.1 m (19%)

II. END POINT RATE (m/yr.)- NSM/ (time between oldest and most recent shoreline)
   1. Average rate: -0.91 m/year
   2. Maximum value erosion: -28.85
   3. Maximum value accretion: 21.84

III. LINEAR REGRESSION RATE- rate-of-change statistic can be determined by fitting a least-squares regression line to all shoreline points
   1. Total number of transects: 1695
   2. Average rate: -0.9 m/year

Figure 7: Shoreline Change for Kochi coast – DSAS Output

(Source : Generated by Author)

In conclusion, the average of all erosional rates is computed to be at the rate of -1.33 m/year and average of all accretional rates at the rate of 0.97 m/year. From the study conducted for the assessment of shoreline change for Kochi coast it can be observed that most of the coastal tract is vulnerable to coastal erosion, which is mainly dominant in the areas of Pallipuram, Edavanakkad, Nayarambalam, Fort Kochi and Chellanam and accretion more active in the areas of Kuzhupilly, Njarackal, Elamkunnapuzha, South Chellanam.

It can be observed from the site visit that the areas experiencing coastal erosion like Edavanakkad, Nayarambalam are still left unaddressed that have resulted in frequent erosion with change of weather and other conditions. The highest level of erosion is shown at Fort Kochi where the Vembanad lake (RAMSAR site) opens to the Arabian Sea and has water traffic in addition to the harbor and port. High accretions are seen at Elamkunnapuzha and minor levels were analyzed in Kuzhupilly and Southern Chellanam that is seen as an effect of the South west monsoon.

Thus based on the study at State level (Kerala - macro-region) and Regional level (meso-region), it can be concluded that ‘coast’ is not a single homogenous environmental region; but composed of separate heterogeneous units. The results obtained from this study indicates the need for specific regulations that guide the development of high-risk areas which can promote sustainable use and protection of coastal resources. Hence, separate management plans are required for each of the different sets of social and morphological units to deal with climate sensitivity concerns (viz. Sea Level Rise). Coastal regulations (CRZ) and the supporting management plan made specific for individual stretches (viz. sediment cells etc.) would be one of the supporting tools in reducing the impacts, optimal utilization of coastal resources and enhancing the coastal protection.

Challenges in Planning Process

The institutional and ancillary legal arrangement for the effective management and conservation of the coastal environment at the national, state and district level in India is mandated by the Environment (Protection) Act 1986 - an ‘umbrella’ legislation that has been setup foreseeing its role in addressing the environmental concerns, including that along the fragile but rich coasts of India.

The Coastal Regulation Zone (CRZ) Notification was enacted with the goal of regulating development activities along the coast with the understanding that the shore and coastal ecosystems are important ecological entities. During the 27-odd years of existence of CRZ 1991 and post CRZ Notification 2011 till CRZ Notification 2019, the two main problems with the CRZ have been its dilution through repeated amendments, and the lack of implementation of several of its provisions. This 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 Kerala coast; this concern is still not subsiding. This far exceeds the carrying capacity of the coastal region, which gets never ascertained in the planning process in India.

Coastal zone is a zone of involvement of multi-stakeholders; however there is lack of clear devolution of specific powers and functions in the implementation of the CRZ Notification. Moreover the slow progress in preparation of Integrated Coastal Zone Management Plan (ICZMP) for the coastal states is also hampering the coastal protection and regulation process. The biggest obstacle to fostering a sustainable coastal zone management strategy is the absence of interdepartmental and centre-state coordination; in this multi-stakeholder coastal region. Thus, the ICZMP process in India should clearly detail the vision and sensitive development strategy provided through an institutional framework recommended as well, which can prevent turning these invaluable natural resources into biological and economic wastelands. In addition, participatory planning at the grassroot level of coastal villages need to be ensured in the plan making process.

Also, the CRZ Notification which is enacted to regulate coastal activities and development, is largely left out in the spatial plans - urban and regional planning process outlined in through the URDPFI and the town planning legislations.

Conclusion and Way Forward

Coastal Zones are dynamic multi-stakeholder environments, with overlapping of multiple natural, administrative, and institutional boundaries. This complex system which includes the changing coast, climate and regulations requires careful planning and management. Firstly, Coastal plans preparation need to be detailed and completed at the lowest unit level of implementation. These Coastal plans further need to be streamlined into the respective Spatial Development Plans; and enforcement mechanisms for coastal development regulations need to be clearly defined and shared with the respective local self-governments as well.

Secondly, under prevailing development conditions along the coast of India, 'Carrying Capacity' is one such tool which if operationalized in the coastal development process, can help in strategizing for the optimal use of coastal resources while minimizing adverse ecological impacts of development in this zone.

Thirdly, all this entails setting up a task force under the nodal department of Planning and Convergence which should include experts in the various fields and public representatives for effective plan preparation; and separate cells at the local level with State officials (respective departments), coastal communities and NGOs for enforcement and monitoring the coastline. This would then enhance economic, social, cultural and ecological prosperity and lead to larger regional development. In addition to CRZ Notification, other initiatives of the Government of India viz. National Action Plan on Climate Change (NAPCC) - a prominent climate initiative addressing climate change etc. which fails to explicitly discuss specifically on aspects of SLR and associated impacts also need to be strengthened in parallel. The way-forward is to bring about climate-resilient sustainable development of the coast through careful planning and supporting legislation by strategizing according to the changing development needs, understanding the development capacity of the coastal region and protecting natural resources in a balanced manner.

References

1. Baba, M., Kurien, N., & Joseph, P. S. (1988). Deep water wave climate off Cochin and Thiruvananthapuram. Ocen Waves and Beach Processes, CESS.
2. Baba, M., Muralikrishan, M. & Sreekala, S.P. (1998) Shoreline changes of Kerala coast using remote sensing data and aerial photographs. Indian Jour Mar. Sci., V.27, pp.144-148.
3. Basak, P. (1995) Water Atlas of Kerala, Central for Water Resources and Development Management, pp. 16-20.
4. Clark, J. R. (1972). Coastal Ecosystem Management. USA: Wiley-Interscience, USA.
5. Coastal Regulation Zone Notification (1991), MoEF
6. Coastal Zone Management Plan of Kerala, 1995, Dept. of Science Technology and Environment, Government of Kerala, pp77.
7. Federal Coastal Zone Management Act (P.L.92-583). (1972).
8. Jayappa, K.S. & Vijaya Kumar, G.T. (2006) Beach Morphological Studies in India – A Review, Journal Geological Society of India, V.68, 2006, pp.874-884.
9. Ketchum, B. H. (1972). The water's edge: critical problems of the coastal zone. Coastal Zone Workshop (pp. 22 May-3 June 1972). Woods Hole, Massachusetts: Cambridge: MIT Press.
10. KSCSTE, (2007) State of Enviroment Report- Land Environment Wetlands of Kerala & Enviroment Health, V. 1, pp.25.
11. Kumar, N. A., & K, George. (November 1997). KERALA - The Land Of Development Paradoxes. Centre for Socio-economic & Environmental Studies.
12. Kurien, N. P., Baba, M., & Hemeed, S. T. (1985). Prediction of near-shore wave heights using a wave refraction programme. Coastal Engineering, 9(4), 347-356.
13. La Roe, E. T. (1974). Environmental Considerations for Water Management District No.6 of Collier County. In Rookery Bay Land-use Studies, Study No. 8. Washington, D.C.: The Conservation Foundation.
14. MoEF. (1995). Coastal Zone Management Plan, Kerala.
15. MoEF. (2011). Coastal Regulation Zone Notification.
16. MoEF. (2013). Shoreline Change Assessment Report for Kerala Coast.
17. Nair, M.M. (1987) Coastal Geomorphology of Kerala, Journal Geological Society of India, V.29, pp.450-458.
18. National Institute of Oceanography (NIO). (2013). Indian Tide Tables.
19. Odum, E. P. (1971). Fundamentals of Ecology. Phladelphia: W.B. Saunders Co.
20. Pritchard, D. W. (1967). "What is an estuary? Physical Viewpoint.". In E. G.E. Lauff, Estuaries (Vol. No. 83). Washington D.C.: American Association for the Advancement of Science.
21. Ramesh, R., Vel, A. S., & Purvaja, R. (2011). Shorelie Change Assessment for Kerala Coast. NCSCM.
22. Space Application Centre (2012). Coastal Zones of India. Ahmedabad.
23. Stang, P. R. (1975). Inland boundaries of a state's coastal zone. Boundaries of the Coastal Zone, OCZM, National Oceanic and Atmospheric Administration, Washington, D.C.
24. Suchindan, G.K., Samsuddin, M. & Thrivikranji, K.P. (1987) Coastal Geomorphology and Beach Erosion and Accretion in the Northern Kerala Coast, Journal Geological Society of India, V.29, pp.379-389.

25. Swaminathan, M. S., (2005). Report of The Expert Committee on Coastal Regulation Zone Notification, 1991. New Delhi: MoEF.
26. TCPO, D. o., & GoK. (March 2012). State Urbanization Report Kerala. GoK.
27. The Hindu. (2011, June 17). 63 per cent of Kerala coast faces erosion. The Hindu.
28. Burningham, H. a. J. F., 2017. Understanding coastal change using shoreline trend analysis supported by cluster-based segmentation. *Geomorphology 282: 131–149.*
29. Cendrero, A., 1989. Mapping and evaluation of coastal areas for planning.. *Ocean and Shoreline Management 12 (5–6): 427–462.*
30. Emily A. Himmelstoss, R. E. H. M. G. K. a., 2021. Digital Shoreline Analysis System (DSAS) Version 5.1.
31. Kaliraj, S. N. C. a. N. M., 2013. Evaluation of coastal erosion and accretion processes along the south-west coast of Kanyakumari, Tamil Nadu using geospatial techniques.. *Arabian Journal of Geosciences 8 (1): 239–253.*
32. Lillesand, T. M. R. W. K. a. J. W. C., 2015. Remote Sensing and Image Interpretation.
33. Sebat, M. a. J. S., 2018. Estimate the rate of shoreline change using the statistical analysis technique (Epr).. *Business & It Viii (1): Pp.59–65.*