2

REVIEW OF LITERATURE

2.1 General

An attempt has been made in this chapter to review the various research works so far accomplished in the field of rise in sea level rise vis-à-vis changes in global climate at various parts of the world. Although an exhaustive review is beyond the scope of this study, some of the most important and interesting literatures studied for preparation of this thesis are presented in the following sections not only for convenience of future reference but also to provide a better insight into the problem. It is intended for easy understanding by the agencies, engineers and others.

2.2 Historical Look at the Problem of Sea Level Rise

Earth's climate in couple of millions of years earlier was dominated by the glacial period sequences. It included long cool periods (glacial) where giant ice sheets have developed at the polar regions. After water disappeared due to evaporation from the oceans, formation of ice sheets substantially lowered water level globally. In interglacial periods of short and warm intervals, the ice sheets fragmented and water level at sea has risen with glacial meltwater drained backto the oceans.

From coldest glacial period (18,000 years before) levels in the sea were 120 meters below present, which has almost risen at a rate of 6 mm/year and reached as high as 120 m (NOAA Paleoclimatology Report). Although all the particulars aren't completely understandable, the reason regarding these changes in the glaciers are minor changes in the orbit of the Earth. While circling around Sun, small decrease/increase took place in the sunlight's amount which reaches the surface of the planet. After the Holocene Climatic Optimum (HCO) roughly 9,000 to 5,000 years before present (*Encyclopedia Britannica, Inc.*), for the present interglacial, 4-5000 years back, all the exposed ice frost had vanished and the heating from orbital movement of earth in due course ceased to termination.

Volume of the ocean worldwide remained more or less same till the economic Revolution and water level begun to rise again by 19th Century (*Church & White,2006*) [1]. Excepting some short-term decelerations, the global averaged water level has experienced long-term acceleration (*Merrifield 2009*) [2]. Within the gigantic ice blocks at Antarctica and

Greenland holds about 60-70 m level of water equivalent worldwide (*National Snow and Ice Data Centre*). With worldwide warming underway, the question arises as to how much level in rise of water, we are expecting to notice by the end of this century (and beyond), and just how briskly or quickly such rise can happen. The disintegrating process of ice blocks are recognized inaccurately, and knowledges of future melting of ice is in its early stages till now. Estimates of future rise sea level are in an outsized range. There are forecasts that rise in sea level by 2100 may vary from 1m to 2 m (*Horton et.al. Climate and Atmospheric Science, May 2020*).

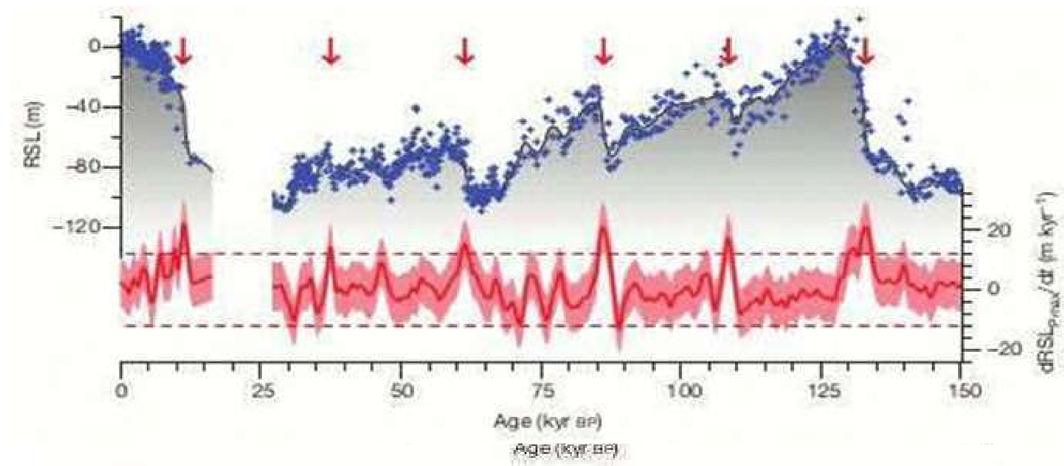


Figure 2.1: Sea level reconstruction from past 150,000 years till present time [6]

In the above figure, relative level of sea is presented in grey-shaded (RSL in blue). The down arrows in red indicate apexes of rise in sea level (12 mm/year) surpassing 1.2 m per century. Break is shown due to absence of foraminifera (basis of reconstruction) in excessively salty seawater during last ice age [3].

2.3 Ice Volume and Polar Temperature

For a period spanning over the last 1.50,000 years records level of water at sea, has been observed [3]. It was particularly found that rates of rise in water level touched a minimum of 1.2 m per century, during major global ice volume loss all in the said period. It was surfaced that disintegration of main ice blocks (as indicated by rise of water level at sea) happened much faster due to warming at polar region [3].

Miniscule sized shelled planktic marine creatures which glide within the water column or the benthic ones which stay at the seafloor are known as Foraminifera. Reconstruction of the ocean level are understood by watching these forams. Forams utilize dissolved minerals to create their shells within the encircling seawater and these mineral in their shells expresses about the environment at that period when they lived.

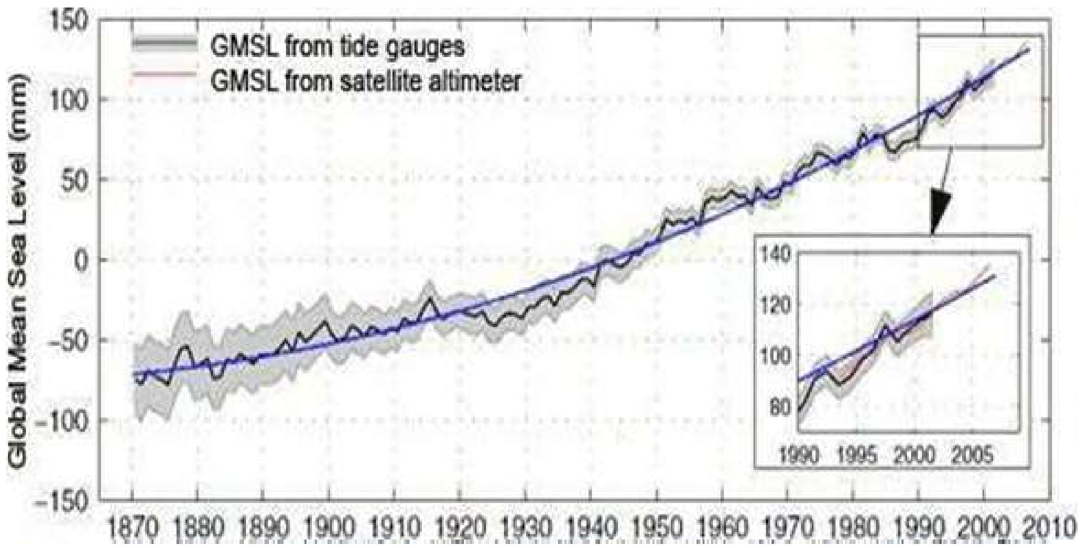


Figure 2.2: Global mean sea level (1870-2006) (Church 2008) [4]

The ratios of Oxygen-18 element within the forams' shells from sediments in Red Sea is counted as an indication for measurement of relative rise (i.e., local) of sea level in that Sea [5]. For Red Sea continuously reconstructed data of relative level at sea [6], when compared, did not accurately match with independent ice-core data, [3].

2.4 Chronological Record of Sea Level

The Strait of Gibraltar is a one narrow natural opening which connects the Eastern Mediterranean to the remainder of the oceans is like a basin. Enormously sluggish change of seawater within any waterbody sink indicates very long time of dwelling of seawater locally. This timing of dwelling was utilized for generating the history of water level within Sea. Shortening or prolongation of dwelling time of local seawater is connected with the raising or lowering of water level and also relates with the rate of evaporation there. Changes in ratios of the oxygen-18 elements in the fossils of foram were found as closely related to water level variations. Grant (2014) effectively considered these oxygen-18 isotope elements as recorders of local water level based on this circumstance [6]. Accordingly, at Mediterranean Sea, a date wise water level history was gathered based on water level variations, utilizing back up data of oxygen-18 isotopes stored in speleothems (cave mineral deposits) [6]. For complicated weather patterns in the Mediterranean, it was earlier opined that the history of water level at sea in the Mediterranean was not sufficiently accurate [8]. The lesson from Mediterranean chronology was transferred to the history of level at Red Sea. Because of the basin seclusion effect, oxygen isotope signal similarity was observed as sufficiently accurate, for both the water level records.

2.5 Sea Level Rise Closely Follows Polar Warming

The reconstructed water level being available accurately, the scientists compared the present water level variations with those at the time of warming in polar region by extracting frozen ice cores from ice sheets at Antarctic and Greenland. It has been observed that during reconstruction the level at Sea has rapidly risen 6 times, with least rate of 1.2 m per 100 years, which is 4 times the present rate of rise in sea level (Figure 2.1). A more noteworthy finding is that humans have been heating the environment for more than a few centuries. This is understood from the responses in the rise of water level and the short-time lag thereby, between heating of the ice blocks at the poles and resulting breakdown of the ice sheets. Disintegration occurs within 100 years (very quickly) at Greenland whereas at Antarctica large ice disintegrations occur within 400–700 years (*National Snow and Ice Data Center*).

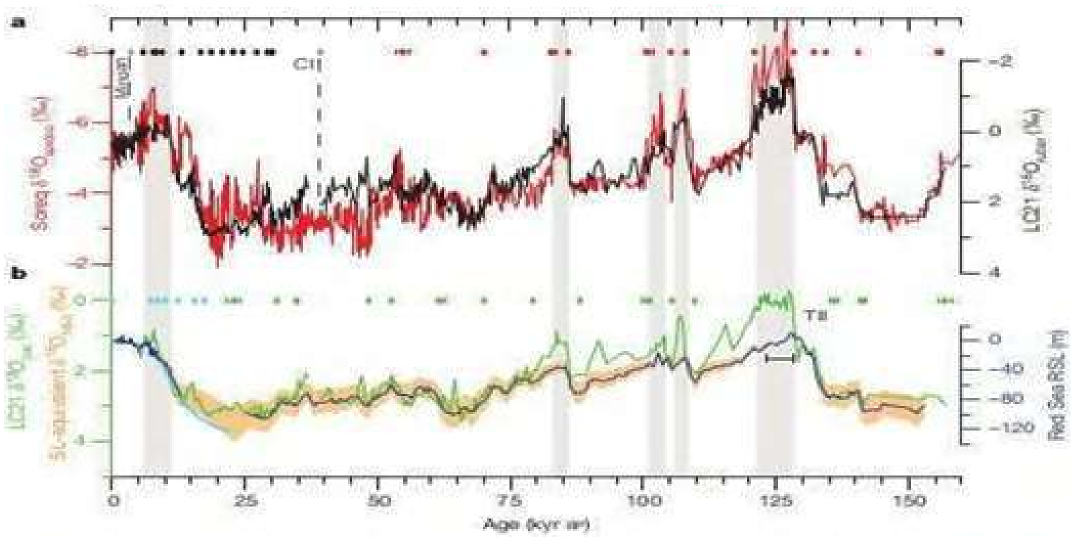


Figure 2.3a - Oxygen-18 isotope signals – red line (Soreq Cave) and black line (Mediterranean).

Figure 2.3b- Oxygen-18 isotope record – green line (Mediterranean) and blue line (Highest probability). The coloured dots and grey-shaded columns (Paleo data used to validate the reconstructions [6]

2.6 Learning from (Sea Level) History

During the orbitally driven warming (in glacial periods) the ices at lower elevations being nearer to the equator (than in inter–glacial period) were far more vulnerable to thawing and eventually the ice sheets fragmented slowly. When ice has greater vulnerability, collapse of Ice sheet can happen more quickly. Although in geological terms the heating happened almost sudden comparing with the present situation it is inferred that today the ices are far less vulnerable. As a matter of fact, in the past 300 million years, the Earth has never faced such a rapid rise carbon dioxide in atmosphere [7].

From glacial to interglacial because of the altered characteristics of the climate state at present scenario a direct comparison of atmospheric carbon dioxide became difficult. Present estimates for rise in water level and the rates of rise seen during reconstruction both are ballpark figure. For several centuries now heating has been underway and because of polar warming ice blocks at Greenland and the Antarctic are undergoing melting in a high-speed manner. Water level history for the past 150,000 years suggests much enhanced rates of rise in water level are expected afterwards (climate.gov).

2.7 Scientific Approach to Study the Problem of Sea Level Rise

Scientists have been studying various aspects of changes in climate, and resulting escalation in sea level due to global heating from various angles in almost every part of the world at various scales. Results suggest various scenarios across the shorelines. In the following sections, therefore, the works carried out by scientists till date are presented in brief for the sake of reference and for better understanding of the problems and approaches.

Sea level basically can increase by two unalike processes. Firstly, for increase global temperature warm sea water is expanding which causes an increase in water level. The second process is liquification of ice over land and ocean which causes a rise in water level. It has been established that the second mechanism is more responsible than the first one.

Climate Science and its impact on Sea Level Rise being a complex amalgamation of a multiple subjects, an insight into the expected sea level rise warrants knowledge on variety of subjects like Hydraulics, Oceanography, Coastal Engineering, Geological science, Glaciology, Remote sensing, GIS, Altimetry, GHG emissions and other allied subjects. The sea level rise that has taken place so far and the anticipated rise in future for respective parts of the world is again dependent upon population explosion, demography, national economic policies, global scenario and the like.

For the proposed study literature on all the aforesaid subjects have been reviewed starting from the beginning of this millennium till the end of the last decade. Various facts have been noted with references so as to have a fair idea on the concerned topic to find out the direction of research. Summary of literature cited by this author for respective authors till 2020 is presented in Table 2.1.

2.8 Works in the Year 2000

Nakicenovic, N. et al. mentioned (2000) that IPCC in its SRES (special report on emissions scenarios) report established the global and regional

Sl. No.	Year of Publication	Number of Literature Cited
1	2000	3
2	2006	1
3	2008	1
4	2009	1
5	2010	3
6	2011	3
7	2012	6
8	2013	3
9	2014	3
10	2015	4
11	2016	3
12	2017	3
13	2018	3
14	2019	5
15	2020	8
	Total	50

Table 2.1 Summary of literature cited by this author for the present study

emission pathways. As a development from additional thought processes the concept of SRES (2000) has now been revised. Scientific community later preferred modelling change climate based on RCPs (Representative Concentration Pathways) as per IPCC's AR5 (Fifth Assessment Report) taking the imaginable range of the radiative forcing values in 2100 with four trajectories of GHG concentration (not emissions) viz. RCPs 2.6, 4.5, 6.0, and 8.5 respectively [9].

Gerald et. al. (2000) has briefed the advance of CMIP (Climate Model Intercomparison Project), a project to compare simulations climate made with coupled circulation models of ocean/ atmosphere/ cryosphere/ land. CMIP was established for studying the results from AOGCMs/OGCMs coupled (atmosphere- ocean general circulation models) CMIP1 & CMIP2 studied (i) simulating capability of the models designed for climate, and (ii) simulation of climate change model based on an idealized concept of CO2 increase only 1% per year. IPCC AR4 considered the model CMIP3, released in 2010, whereas, IPCC AR5 considered the CMIP5 model, released in 2013. CMIP6, the first model of climate from India developed by ESM of IITM at CCCR in IITM contributed to the IPCC AR6 (Sixth IPCC Assessment Report), released in 2021[10].

Grinsted et al. (2000) estimated likelihood distributions for conjuring up of scenarios of level of sea both for past and future using Monte Carlo inversion of equation parameters. For validation of the high rates of rise in sea level obtained from satellite-based altimeters, they recommended a linear response equation of 4 nos. of parameters for relating global increase in temperatures for past 2000 years with corresponding rises in level of sea. Taking 1980-1999 as the reference period considering the A1B scenario of AR4 IPCC, the level of by 2090-2099 is projected to be about 0.99m to 1.44 m [11].

2.9 Works in the Year 2006

Rupakumar et al. (2006) over most regions in India speculated a major intensification in rainfall during this century. Considering a single RCP scenario, the maximum projection of rainfall was predicted by them and they disclosed that maximum rainfall may produce dissimilar results when investigated with multi-scenario-based multi-models [12].

2.10 Works in the Year 2008

Horton et al. (2008) considered an empirical relationship amongst air temperature at surface of globe and obtained mean level of sea commensurate with the latest IPCC AR4 generation Models of Climate. They emphasized that the range results for rise in sea level is dependent on the chosen scenario for emissions and the assumed Climate related Model. It was stated that the projections for rise in sea level from both IPCC AR4 scenario and the empirical assumption may be incorrect to find rise future sea level if the tendencies of ice melting accelerate [13].

2.11 Works in the Year 2009

Vermeer and Ramstorf (2009) proposed to link variations in global sea-level with mean temperature of globe on a simple relationship amidst a long-time scale varying from periods of 10 years & spans of 100 years and more. Such relationship was tested from a global model related to climate based on synthetic data for earlier millennium and the next century. Following their proposed relationship, the future global temperature scenarios projected a rise in sea-level varying from 75cm upto 190 cm within the years 1990 to 2100, which commensurate with IPCC AR4 [14].

2.12 Works in the Year 2010

El Sioufi, M., et. al. (2010) recognized that predictions about changes in climate is foreseen as the highest contest, our globe is going to face and reiterated that the major parameters associated with change in Climate and abnormal weathers are changes in Temperature and Rainfall [15].

Kumar T. S. et al. (2010) presented the case of 480 km of coastline that was susceptible to fast-tracked destruction hazard along the shoreline [16]. The authors using eight risk variables developed a CVI (coastal vulnerability index) for the state of Orissa. This is one of the primary studies which has been taken up on India's coast. Low, high, and medium vulnerability zones are acknowledged and publicized on a map, taking data from satellites through remote sensing, in situ measurements for long time and results from numerical depictions [16].

Saravanan et al. (2010) documented the record of monthly seasonal and beach profile parameters at 10 beaches within the coast of Tiruchendur and Kanyakumari, Tamilnadu, India and determined the variations in the beach morphology. Changes in beach profile are influenced by features of upsurge, environment, current and nature of soil. The variations at South India 's coasts are dominated by three seasons although southwest and northeast monsoons have more or less equal impact along the south side of east coast. Currents varying from about 0.5 knot from June to August and 0.75 knot between December and January are monsoonal in character. The beaches in this zone experience accretion especially during North Eastern monsoon. Due to the area’s wave climate and coastal configuration the sediment transport is towards the onshore is mainly from cross-shore components [17].

Study on the littoral sediment transport along South Eastern Coast of India by the said authors (2010) re-established that sediment movement in the surf zone, is governed by complex interplay of waves. The nearshore movement of sand is due to waves and currents. The long shore sediment transport from Kanyakumari to Tiruchandur region is affected due to the bay, gulf and the island. Considering fluvial activities as negligible in the region it was inferred that trend in the direction of sediment transport varies as per the coastal configuration [18].

Above studies [17] and [18] fairly document the seasonal variation of near shore littoral drift related to sediment transport in the southern eastern coast of India and suggests for continual cascading effects of sea level rise over due course of time.

2.13 Works in the Year 2011

Ranger et al. (2011) opined that a 2005–like event is likely to recur in 2080s (SRES A2 scenario). The study approached for quantifying city–scale future flood risk at Mumbai following the philosophies of risk modelling related to catastrophes. Flood extent map across the city displayed flood waters in low-lying areas (20% of City's affected area) upto a depth varying from 0.5 to 1.5 m, excepting the possible consequence of rise in sea level in future. It was opined that the effect of these combined risks from storm surges, heat waves, cyclones and SLR warrant substantial revision in urban development for lessening disaster risk. As rise in sea level could harm the drainage system at Mumbai, it was inferred that mitigation measures for rise in sea level and local inundation must be planned [19].

Nicholls et.al. (2011) considering likely rise of Global Sea levels of more than 1m by the top of 21st century, illustrated the impacts of rise in sea level rise with some suggestions for remedial measures [20]. Serious concerns on the impact of the rise (consisting of rise in water level (flooding), erosion of coastline etc.) on important cities like New York, Tokyo, London, Shanghai, Mumbai, and Lagos was expressed [20].

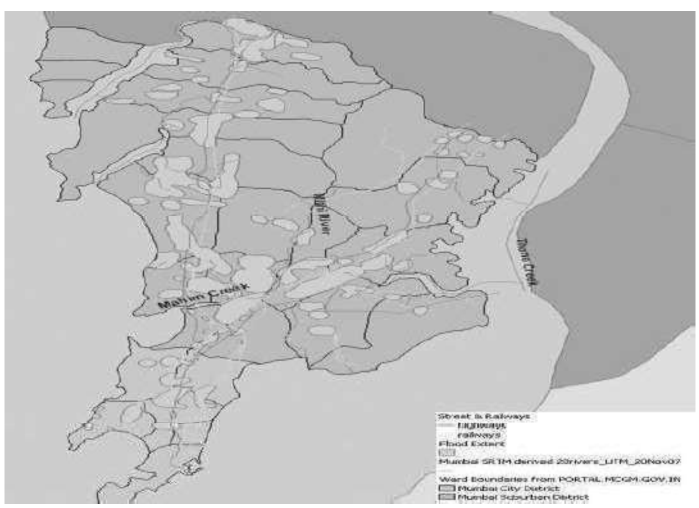


Figure 2.4: Flood extent map for the 2005 event- Climatic Change (2011) 104:141

Cazenave et al. (2011) consulted data obtained from various altimetry and data sets from site and mentioned about the reasons of rise in Sea Level and observed contribution of total land ice in 21st century remains highly uncertain and difficult to be quantified [21].

2.14 Works in the Year 2012

Balica et al. developed (2012) CCFVI (Coastal City Flood Vulnerability Index) for nine cities around the world viz. Rotterdam (the Netherlands), Casablanca (Morocco), Buenos Aires (Argentina), Kolkata (India), Osaka (Japan), Dhaka (Bangladesh), Marseille (France), Manila (Philippines), Shanghai (China) each with different exposure. They portrayed an index (from 0 to 1) demonstrating comparison of the Flood Vulnerability Index (low to high) for ranking of the coastal cities. Total FVI for the selected coastal cities was ranked and the Vulnerability for the cities were shown in a

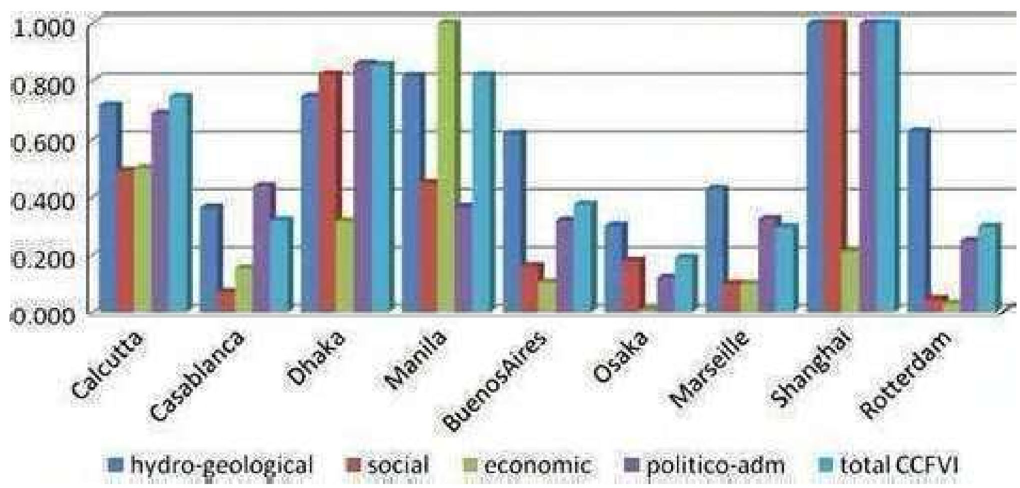


Figure 2.5: Ranking of coastal cities as per FVI for different scenarios [Nat Hazards (2012)]

histogram (Figure 2.5) for all components of FVI. It was inferred that by 2100, the greatest vulnerability to seaside floods is with the cities- Shanghai and Dhaka, trailed by Manila and Calcutta, Rotterdam, Casablanca, Marseille and Buenos Aires, where Osaka city will be least vulnerable to floods [22].

Rahmstorf et al. (2012) applied proportionality constant to future warming scenarios suggested by IPCC, particularly for warming in anthropogenic period assuming a relation (semi-empirical) between rise in level of sea & surface temperature at global level. The rate of rise in sea-level was considered proportionate with the warming magnitude above those than in preindustrial Age. A decent guesstimate of a proportionality constant for sea level rises and temperature is reported to be 3.4 millimeters/year/ °C [23].

Chaturvedi et al. (2012) mentioned about climate projections for IPCC AR5 and emphasized on the importance of impact studies considering extreme predictions & not only based on just the mean climate projections [24].

Coastal vulnerability for Chennai was assessed by Arun Kumar et al. (2012) using remote sensing and GIS data. An indicative scenario in the world given in Figure 2.6. For knowing coastal erosion & the vulnerable inundation areas due to future SLR eight relative risk variables were used with the help of the GIS tools and remote-sensing. In study area, vulnerability to coastal natural hazards was found low at the coast for 11.01 km medium for 16.66 km high for 27.79 km. [25].

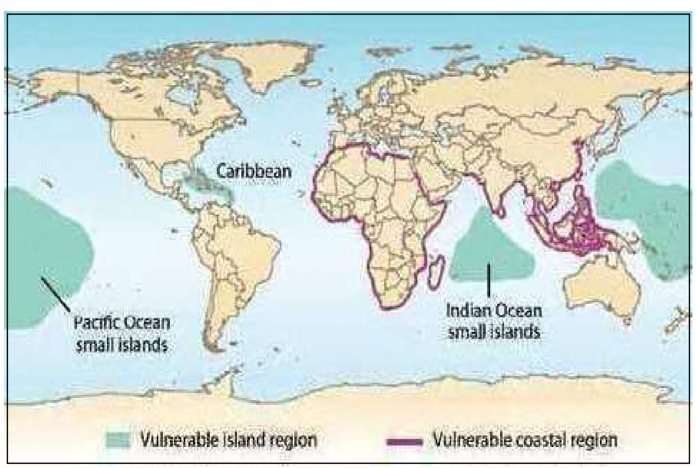


Figure 2.6: Island and coastal regions vulnerable to coastal flooding (Oceanography, June 2011)

Mukhopadhyay et al. (2012) used geo-informatics in Shoreline prediction models to envisage the changes in coastline. It was observed from the obtained results, that the use of GIS technology coupled with remote sensing data is for detecting shoreline changes, which otherwise is a complex process. For delineation of shoreline simple ISODATA binary classification technique was found to be convenient. To demarcate the land water interface, based on observation of the histogram, images from Landsat have been classified. Based on the delineated shoreline, shoreline positions for up to 2015 and 2025) have been predicted. Coastline is Puri district is suffering from erosion and evidences of shifting inside is presented in Figure 2.7 [26].

Radhika S. et al. (2012), considering the effects of changes in climate at three locations, evaluated the significant wave height related to planning of offshore structures [27]. They authors discoursed that evaluating the wave height considering hindcast only may be insufficient. For the next 30 years they projected heights of wave (by downscaling wind status from GCM) and

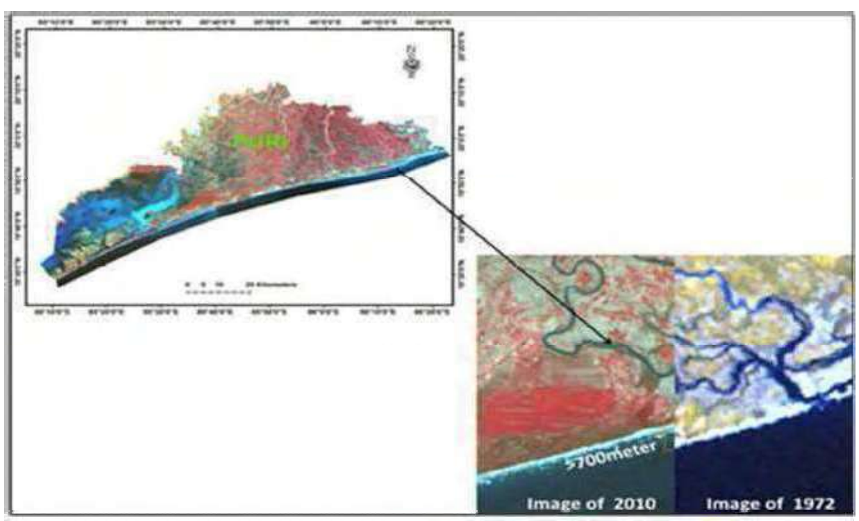


Figure 2.7: Shifting of shoreline inside the coast

fitted that to prevalent distributions (Gumbel or Weibull). Considering 100 years as the period of return, significant wave heights for design purposes were likely when changes in climate was comprehended. [27]

2.15 Works in the Year 2013

Viviek et al. (2013) developed CVI (Coastal Vulnerability Index) for Tamil Nadu using remote sensing and GIS. The CVI was calculated based on six vulnerable ocean related parameters. ArcMap 9.0 software package was used for mapping the coastal vulnerability zones after classifying the results using GIS & remote waves, and tsunamis are likely to aggravate and acceleration in rise of sea-level risks of storm, high estuary and minimum in coast exposed to rock. Due to change in global climate diverted from Sri Lanka (Figure 2. 8). Maximum hazard occurred in mouth of sensing. The southernmost part of India is subjected to wave refraction from waves [28].

Mahapatra et al. (2013) reiterated global warming due to human induced causes will contribute towards Sea Level Rise which will pose threat upon coasts. It was measured that out of total global coastlines about 1.6 million km is under pressure from both anthropogenetic activities and normal processes. They reviewed the available Coastal Vulnerability Assessments and stated that between the years 1750 and 2000 (according to IPPC 2001), the atmospheric concentrations have grown substantially. The salinity gradient along the east coast is higher in comparison to that at west coast. They reviewed the CVI studies at various locations along Indian Coast viz. at Andhra Pradesh, Orissa, Karnataka, Tamil Nadu etc. and emphasized the importance of CVI studies [29].

Anders Levermann et. al. (2013) raised a different opinion that melting ice from Artic Sea does not increase in level of sea as ice is floating on ocean, but sea level rises due to melting of ice on land as well as from the glaciers on Antarctica and Greenland. As per satellite images the level, which has been rising by an average of 3.3 millimeters/year, since 1990, have increased to about 5 millimeters/year in past 5 years. It is said that majority of rise in from melt and about 1/3rd is from warming and expansion of ocean water. They projected a rise upto 2.5 meters by year 2100, for 1°C of earth's temperature rise. [30].

2.16 Works in the Year 2014

Bhaskaran et al. (2014) highlighted the of climate change impact at Indian Ocean, as per altimetry report on significant wave height and wind speed [31]. Using the BRAT (Basic Radar Altimetry Toolbox), the data observed from 8 satellite missions for 21 years from 1992 to 2012 were analyzed. The authors identified the Southern Ocean sector of the Indian Ocean from latitude range 40° S – 55° N have the maximum wind-wave variability. Wind speed about 2m/s and about +0.3 m high significant wave

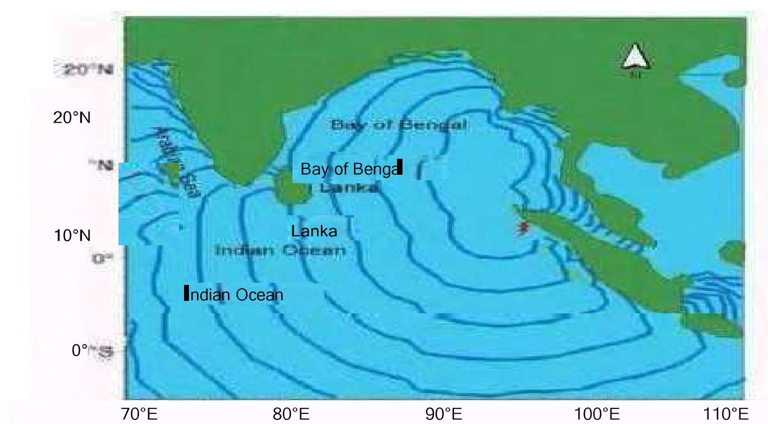


Figure 2.8: ***Waves Diverted & Refracted from Sri Lanka***

height observed in two chosen transects in Bay of Bengal and Arabian sea. It revealed increased wave and intense swell in Southern Ocean can change the wind-waves in the North Indian Ocean but impact of change in climate in the equatorial zone was less.[31].

Chenthamil Selvan et al. (2014) used Remote sensing GIS techniques at coast at Karnataka and relied upon Weighted linear regression (Stochastically method) combined with satellite imagery for analysis of changes in shoreline. After systematically studying the historical information on change of shoreline along the Karnataka coast (Study Area shown in Figure 2.9),70 % of the coastline was found to be either accreting or stable in nature, whereas varying magnitude of erosion was being experienced at the remaining 30% region. Statistical quantitative method Weighted Linear Regression was found robust for long term change analysis whereas for short term changes End Point Rate was adopted. Delineation alongwith Remote Sensing and GIS was acknowledged to be of great help due to cost–effectiveness and less time-consuming for their study to comprehend the behaviour of changes in at Karnataka coast [32].

Trenberth et al. (2014) accounted 90% of the human caused excess heat being absorbed by oceans and the remaining 10% is responsible for ice melting both in terrestrial and sea [49].

Figure 2.9: Coast of Karnataka (Ind. Journal of Mar. Sci., Vol.43, No.7, 2014)

B. Deepika et al. (2014) in a contemporary period investigated the changes in shoreline positions for a period of 98 years in a nearby area of Udupi coast, western India, using satellite images and topographic maps [33]. Four littoral cells transected at uniform intervals was studied (Figure 2.10).

Different statistical methods, namely EPR (End Point Rate), AOR (Adjusted Odds Ratio) and LR (Linear Regression) were used at the transects to assess rate of change in shoreline. The Statistical methods viz., AOR and LR were cross verified with CC & RMSE to estimate the shoreline changes. It was concluded that at Udipi changes in shoreline are affected by coastal currents, waves, seaward relief, river entrance changes and changes in level of sea alongwith human–induced anthropogenetic activities. The study reports that in addition to natural processes, anthropogenic interventions also play a lot in shoreline changes [33].

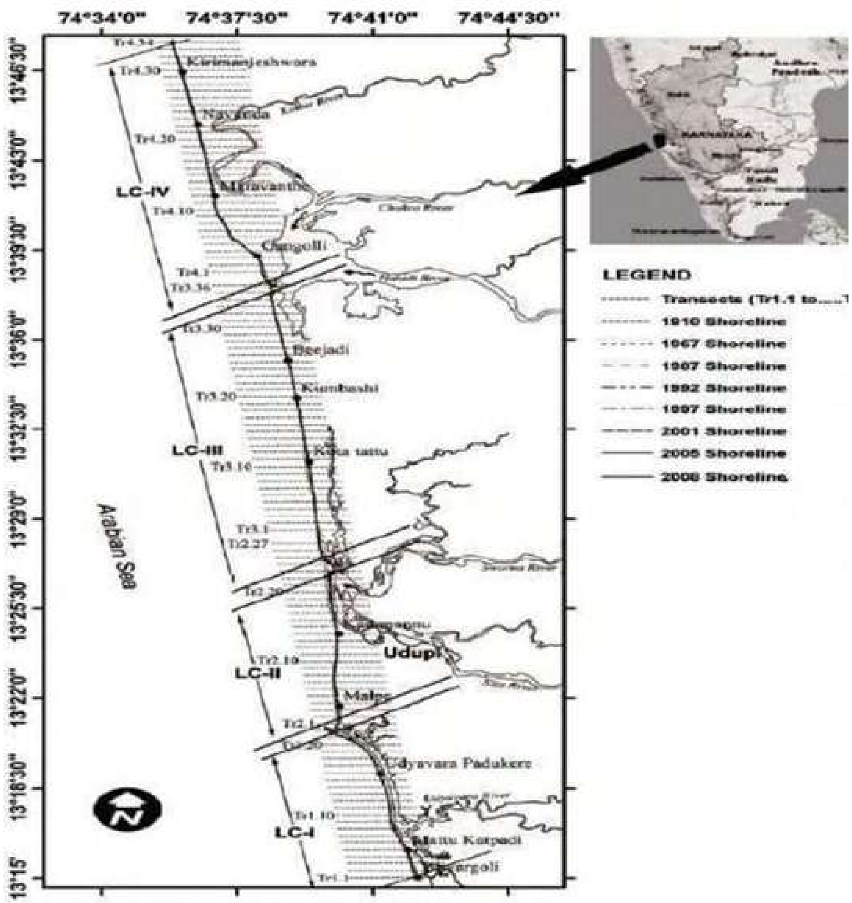


Figure 2.10: Shoreline positions (during 1910–2008), Transects and littoral cells (Int.J. Environ. Sci. Technol. (2014) 11)

2.17 Works in the Year 2015

Singh Pratibha et al. (2015) developed scenario on rise of sea level at

Mumbai using GIS (Geographical Information System) for a study area was about 167 km of the coastline of Arabian Sea. The area inundation map for different SLR scenarios was plotted (Figure 2.11). Changes in Sea Level (1900 to 2011) were obtained from GLOSS (Global Sea level Observing System), Digital Elevation Model (DEM) followed from Shuttle Radar Topographic Mission (SRTM) – NASA). ArcGIS10.1 software was used to determine the Intensity of vulnerability for administrative blocks under Municipal Corporation of Greater Mumbai & were compared for scenarios of rise in Sea Level Rise for 1, 2 & 3m. It was mentioned by the authors that due to rise in sea level at India's coastline till 20th century 34.906 km2 area was inundated, whereas Mumbai coastline has shifted 4.049 m. Mumbai is vulnerable flooding due to heavy rainfall as well as simultaneous high tide and one such worst scenario happened in July 2005, when the city incurred huge loss in terms of damage of housing properties [34].

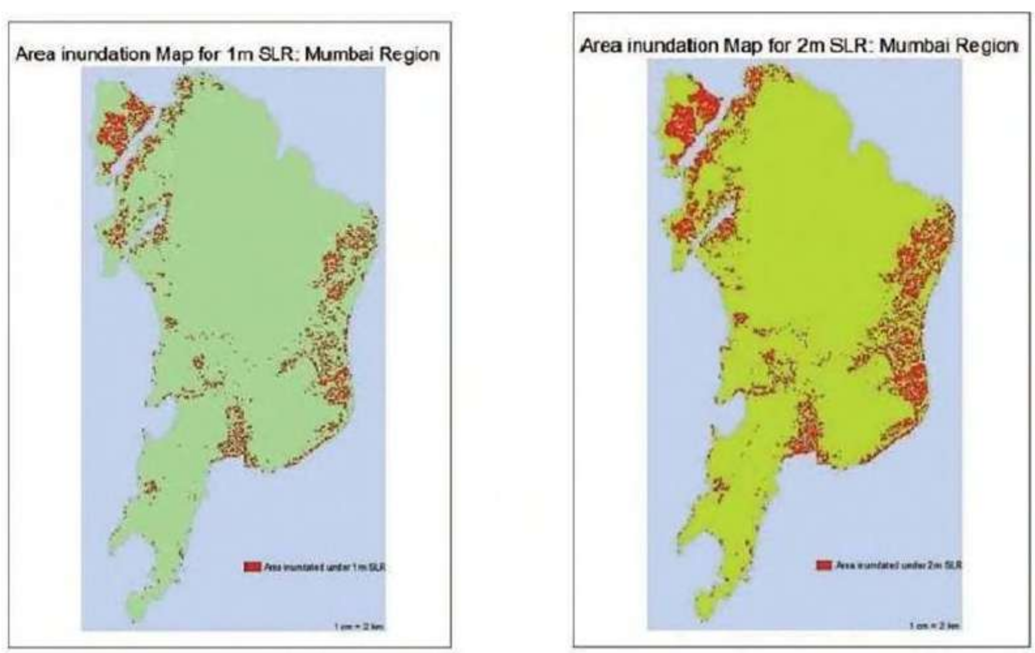


Figure 2.11: Area Inundation Map for 1M & 2M Sea Level Rise

Unnikrishnan et al. (2015) studied data from satellite altimeter and tide-gauge at the locations shown in Figure 2.12

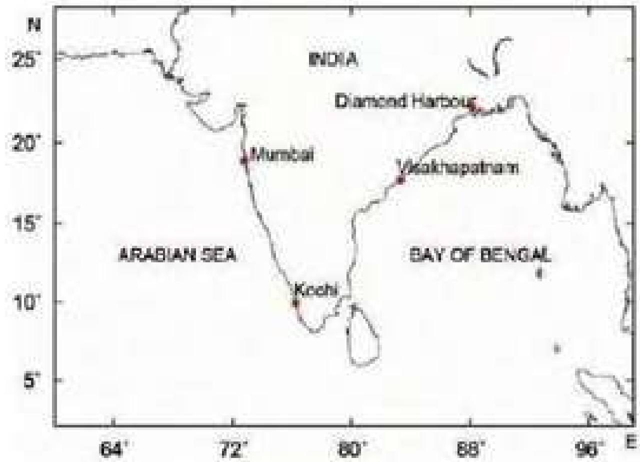


Figure 2.12: Geographical Locations of Tide Gauges [35]

Over the 1993–2012 period, data analysis from Altimeter revealed that the rate of rise of sea level is consistent, and also that the trends of the rise in MSL observed as 3.2 mm/year at north Indian Ocean and 5 mm per year at north and east of Bay of Bengal. Faster rate of rise observed during the last 20 years, than for the whole 20th century. Figure 2.13 shows mean sea levels at the designated stations. However, it was generally felt that a period of two decades only was not adequate to indicate the accuracy of variability of the natural sea level [35].

Misra et al. (2015) presented the LULC (land use/ land cover) changes for a decade at southern Gujarat, India for years 1990, 2001 and 2014 [36]. The study area was between Saurashtra peninsula and mainland Gujrat at the 130 km long, 70 km wide and 30 m deep Gulf of Cambay (Figure 2.14) which dominate features related to and accretion and erosion. Changes in shoreline was analyzed using DSAS tool (decision support analysis system) embedded in ArcGIS 10.1. The accretion or erosion for the periods 1990–2001, 2001–2014, and 1990–2014 are shown in Figure 2.15. It has been highlighted in this paper that immense eroding trend is noticed in some places at the coast of Southern Gujrat under consideration, due to anthropogenic effects. Loss of mudflats was found to a large extent in Hazira industrial belt, which poses a concern to sustainability [36].

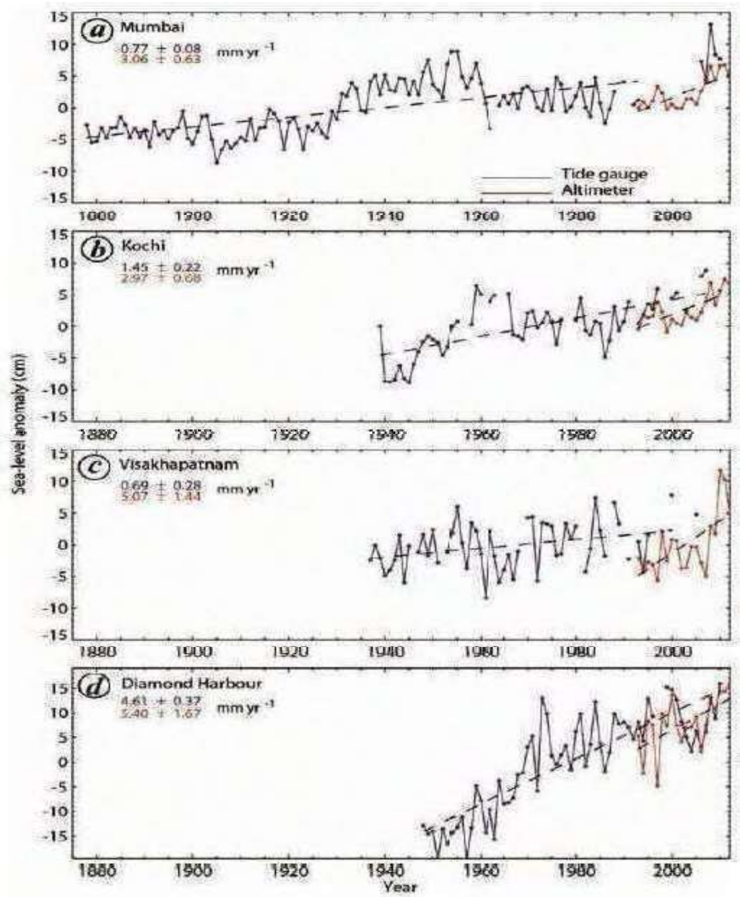


Figure 2.13: Annual mean sea-level anomalies at (a)Mumbai, (b)Kochi, (c)Visakhapatnam and d) Diamond Harbour. Tide-gauge (blue line), altimeter (red line), sea level rise trend (black dashed line) [35]

2.18 Works in the Year 2016

Rajasree B. R. et al. (2016) studied the shoreline changes at western coast of India [Figure 2. 16] and demonstrated that due to the change climate affected by warming of globe, the prediction of shoreline changes along with variation of erosion/ accretion is preferred to be determined based on wind projections in moderate warming and related changes in climate change at global level.

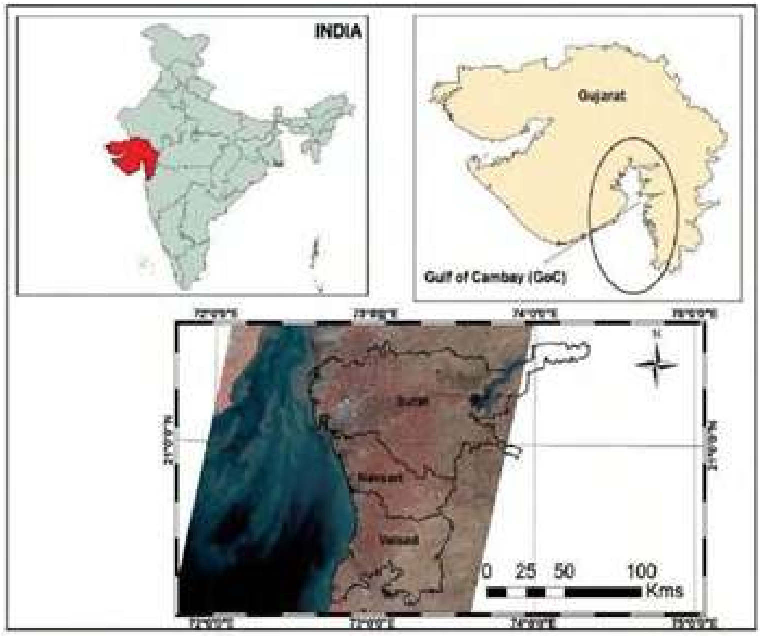


Figure 2.14: Study Area at Surat, Navsari and Valsad
(Environ. Monit. Assess. (2015) 187: 461)

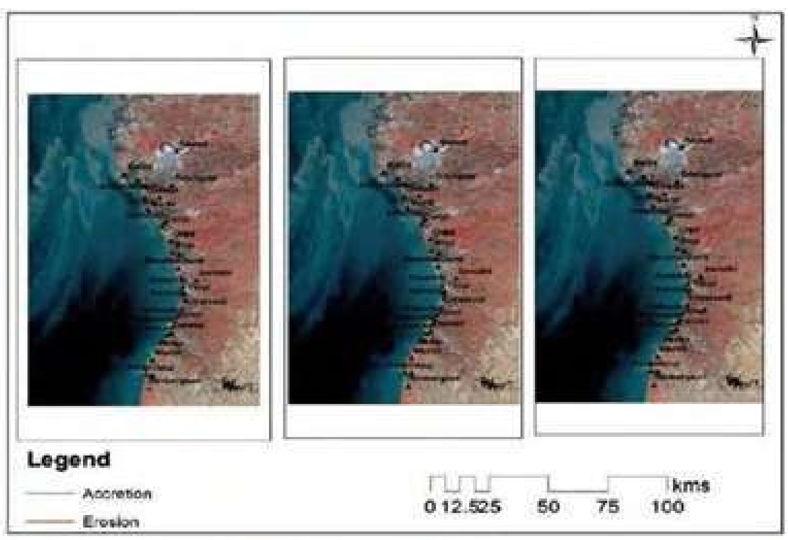


Figure 2.15: Changes in Shoreline from 1990–2001 , 2001-2014 and 1990–2014
[Environ Monit Assess 187: 461 (2015)]

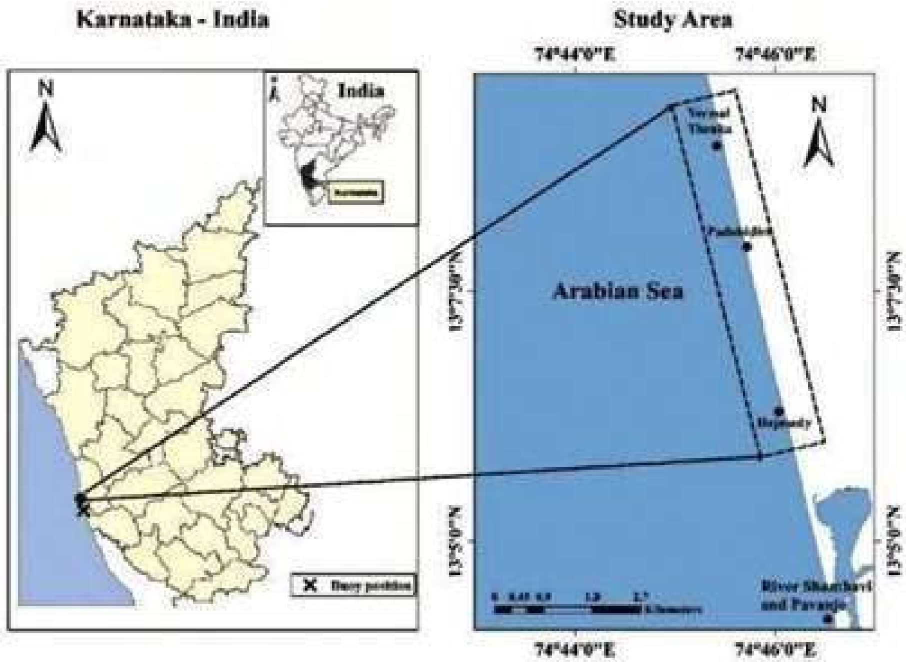


Figure 2.16: Location Map
[Estuarine, Coastal and Shelf Science 183 (2016)]

They were the beginners to note shoreline changes from earlier satellite images for past 35 years and future 35 years. The authors commented that computations done alternatively with the help of artificial neural network (ANN) satellite images data predicts a smaller rate of rise (1.66 m/year than those obtained from numerical methods (2.21 m/year). They obtained 37% rise in annual mean Hs over a period of next 35 years through numerical modelling and discoursed 3 times increase in sediment. Variance in erosion rates predicted by Numerical Modelling and ANN are shown in Figure 2. 17. Considering the impact of changes in climate they documented the shifts of the shoreline in future [37].

Patil K. et al. (2016) demonstrated the technique for predicting site-specific dependable forecasts of SST (sea surface temperature) by merging results from mathematical estimations and ANN (Artificial Neural Networks).

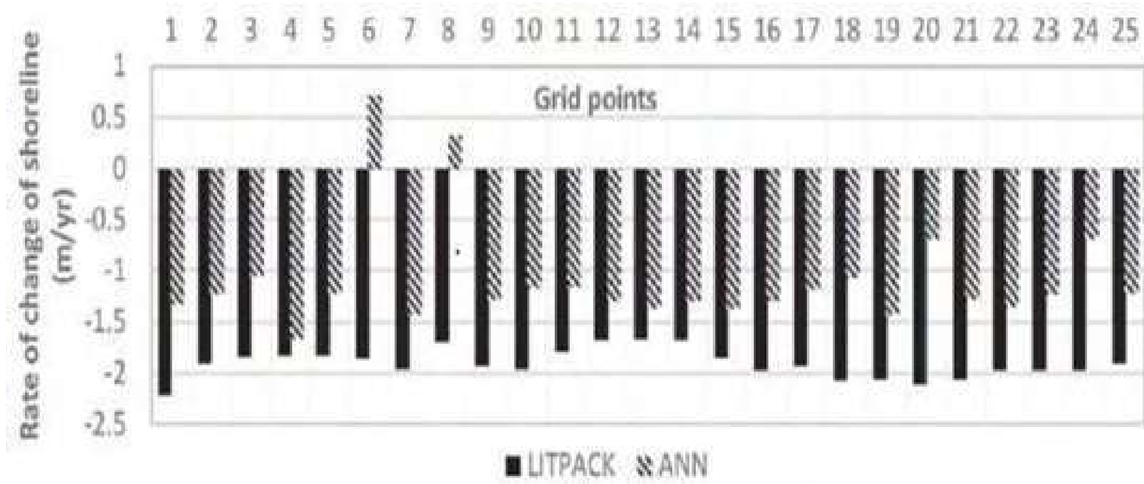


Figure 2.17: Annual rates in change future shoreline - output fromthe numerical and ANN, compared.
[Estuarine, Coastal & Shelf Science 183 (2016)]

Within the Indian Ocean at particular 6 locations viz. AS, BoB, WEIO, EEIO, THERMO and SOUTHIO (Figure 2.18) predictions were assessed through error statistics using Neural Wavelet Network on time scales of a month, a week and per day basis.

There were large deviations between the numerical estimations and corresponding measurements, which necessitated evolving innovative techniques for prediction of SST for future. They commented that combination of numerical and neural techniques, adopted by them produced accurate SST at the selected locations. The authors depicted the advantage of their adopted method when making predictions for SSTA (SST anomaly) [38].

Saha et al. (2016) predicted ocean currents through ANNs alongwith numerical models and found that the numerical ocean circulation models reportedly work better for short-term prediction result of current but may be inaccurate for station- specific predictions. Prediction of errors for future

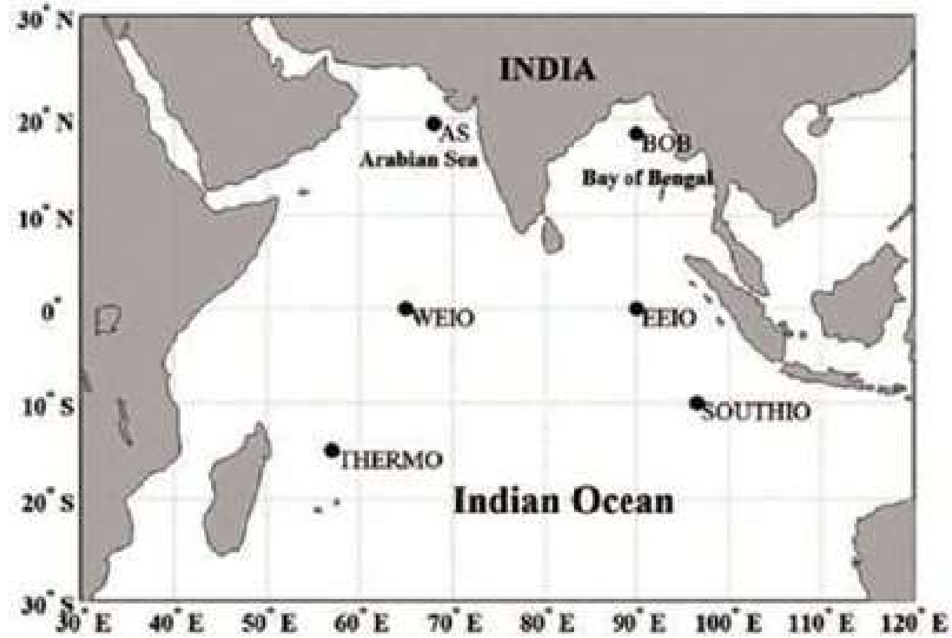


Figure 2.18: The study locations (AS; BOB; EEIO; WEIO; SOUTHIO; THERMO)
[Journal of Atmospheric and Oceanic Technology, Volume 33]

obtained from an ANN (Artificial Neural Network) over time series was added to the numerical estimation for forecasting velocities of current at 2 deep-water points (80N-900E & 120S−80.50E) at the Indian Ocean (Figure 2.19). The authors opined although ANN is faster than computational numerical methods, it has some limitation and suggested station-specific numerical outcome may need post-processing [39].

2.19 Works in the Year 2017

Singh P. et al. (2017) studied the rise in sea level affected by climate change in an administrative block of Mumbai. They demonstrated the applications of GIS as one of the useful tools in analyzing the scenarios due to changes in climate for coming years. They opined that global mean sea level will not be same everywhere as there will be significant deviation of local changes in oceanic circulation. The area expected to be inundated in the concerned wards for an increase in Sea Level respectively by 1 m, 2m and 3 m were plotted in the municipal map (Figure 2. 20). GIS was stated to be a satisfactory means

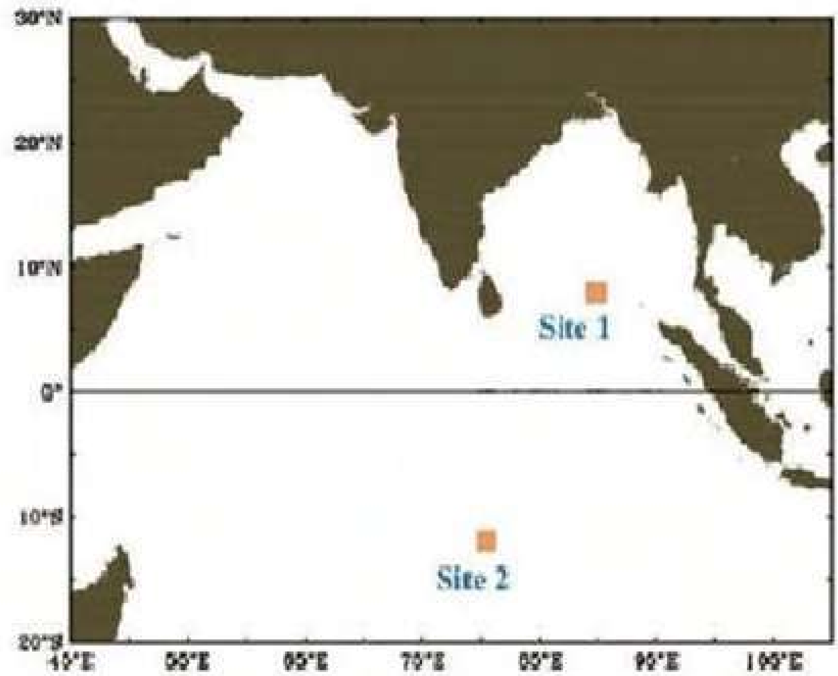


Figure 2.19: The Site-1 and Site-2 of the study

(Environmental SystemResearch, A Springer Open Journal)

in recording position wise changes in climate and they suggested that resolution DEM should be higher for better result [40].

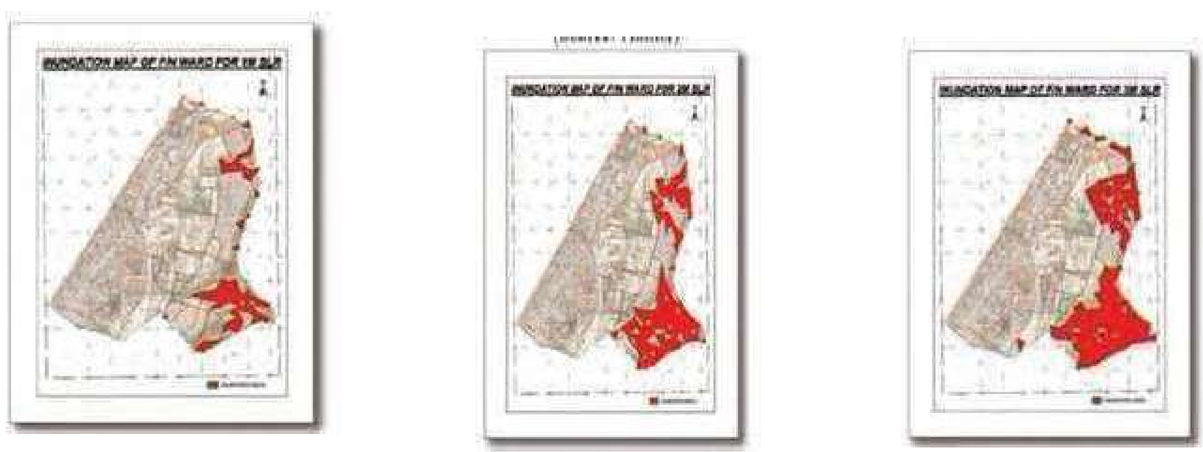


Figure 2.20: Area of Inundation Map for SLR of 1 m, 2 m and 3 m

Nidheesh et al. (2017) observed robustness of variableness about the level at per decade basis and opined depictions in Indo-Pacific Ocean as feeble and unreliable. Before 1980 past reconstructed statistics on sea level were not available which has been stated as the reason for inconsistencies. However, the incremental rise in water level at Indian Ocean is acknowledged [41].

Sunder S. et al. (2017) made an evaluation of the shoreline documented by most widely used mapping methods at different stretches of coasts within India [42]. The authors stated that out of the several existing methods for shoreline mapping, depending on total volume of data some advantages and drawbacks are seen. The comparison of the available methods was felt necessary for obtaining a guideline for choosing a methodology for identifying shoreline at a particular location. Along four different coastal stretches of India (Figure 2.21) they compared indices conceptualized by other scientists using multitemporal Landsat data. The aim of such study was to detect most appropriate technique for determination of shoreline from the available types of multispectral satellite imageries.

Figure 2.21: Locations of study

The authors validated the results with the multispectral images from Google Earth. They also analyzed the performance of the compared indices using stochastic methods to validate correctness. All the indices were observed to perform well except small differences due to site specific parameters. The AWE (Automatic Water Extraction) Index was found to yield 80% accuracy for all sites [42].

2.20 Works in the Year 2018

Kulkarni S. et al. (2018) took an effort to quantify the benefit of RC (Regional Climate) Models utilizing Co-ordinated Regional Downscaling Experiment in the parent GCMs (General Circulation Models) at Indian offshore areas. The seasonal statistics of wind and climatology within RCMs and GCMs were compared from three different data sets. It was detected by the authors that for certain sub-regions simulate variability of winds through RCMs were generally unsuccessful to reproduce the spatial pattern. From corresponding maps of wind vectors causes of biases for the RCMs were assessed. The necessity of correct assessment of the winds yielded from RCM was highlighted. GCMs and most ofthe RCMs indicate and that in monsoon time around 70% of the Indian offshore locations will face mean wind power potential more than 200 W/m^2. On careful assessment of the observed data and its consistency at Indian coast blindly adopting the available RCMs may not be fruitful and it was advocated by the authors that present pool of regional climate models be re-evaluated [43].

Rajasree B. R. et al. (2018) evaluated the shoreline shift using neural network as a substitute of numerical modelling taking reports from satellite imageries and simulated waves for past 36 years and future 36 years. Their paper stated [44] that in future 36 years, waves will intensify and there will be shift in wave direction at their study area near Gangavali river's estuary meeting Karnataka's shoreline. of attack and the wave activity at this site would intensify. This study was discoursed as a generic process to assess the shoreline movements and sand transport etc. Also considering traditional one-line shore protocol in the model is a limitation as two-dimensional behaviour of shoreline is ignored. Since there are other factors like uncertainties in climate change, difference in coastal geometry, there is enough room for research for coastlines at other places in the Indian Coast to have more specific results [44].

Misra Ankita et al. (2018) found the estimations of depths obtained from satellite-derived bathymetry as dependable and recommended machine learning approach, for coastal studies. The errors between measured bathymetry and retrieved data from Landsat was were compared. It was inferred that the processof estimation of bathymetry using SVR (Support Vector Regression) model had a satisfactory performance based on the medium-resolution satellite imageries. The potential of SDB (Satellite-Derived Bathymetry) datasets were highlighted and medium-resolution imageries from Landsat was considered as fruitful coastal analysis [45].

Rajasree B. R. et al. (2018) summarized the changes in shorelines where RCMs are used for future wind and waves, instead of historical wind data to detect sediment transport and shoreline change. At a place where an artificial structurelike a port facility was created it was measured through numerical modelling. These data were applied for assessing the vulnerability of the concerned coastal stretches subjected to future environmental cum socio–economic exposures. It was reemphasized that magnitude and behaviour of historical wind and waves will surely change in future due to heating and associated variations in climate. It was found in all the three spots that the sediment transport will increase, rates of accretion/erosion will accelerate, and rates of shoreline change will increase.

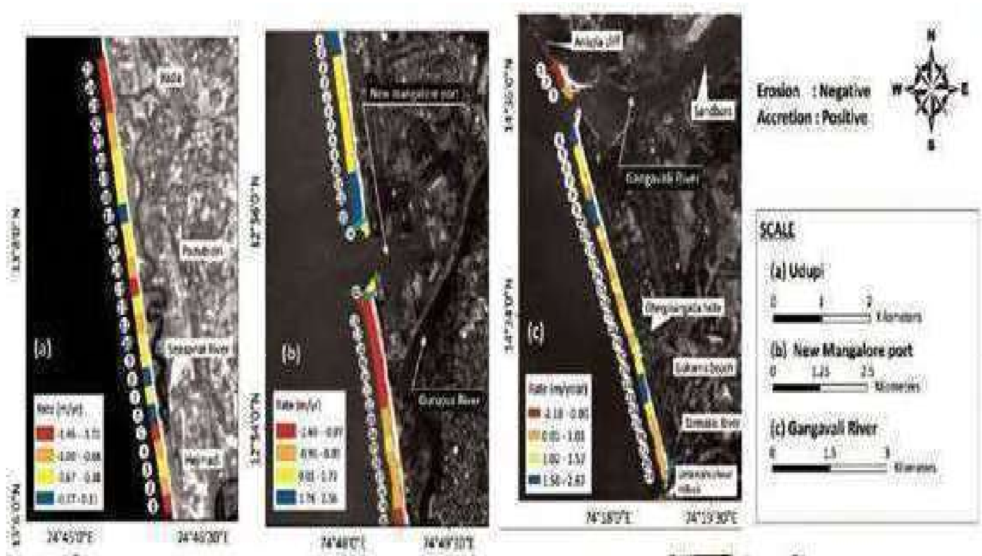


Figure 2.22: Shoreline changes along Udipi, New Mangalore Port andGangavali River (https://www.researchgate.net/publication/330906002)

Comparison between forecasts by satellite imageries, and ANN and numerical models exposed that the results obtained from ANN was higher than those obtained from satellite imageries and smaller than those obtained from the numerical models The annual mean significant wave height was stated as likely to be 29% more over next 36 years, and would provide a 109% rise in transference of sediment. The study location was at India's central west coast facing Arabian Sea on uninterrupted coastline at Udipi, Karnataka coastline interrupted by estuary of River Gangavali, and discontinuous coast interrupted by Mangalore Port (Figure 2.22). [46].

Garner et al. (2018) stated predictions of SLR as obtained from various separate studies differs and are usually observed to be more than those in upper predictions from IPCC. Prediction of upper projections is non-uniform in various studies and the correctness of research outputs are unreliable. These uncertainties in future assessments of rises in sea level indicates lot of suspicions and knowledge gap. The results time to time obtained from the processes and assumptions differently considered by scientists raises doubt about the efficacy of research. The prediction of rises in sea level varies widely and remaining extremely equivocal as there remain unconformity within the span of

SLR forecasts, which are not even across various studies. [47].

2.21 Works in the Year 2019

Verne K. et al. (2019) investigated the hydrodynamic and morpho- dynamical parameters at the coast of Maharashtra (Figure 2.23) for evaluating the near shore bed level variations due to seasonal cycles of hydraulic changes. They carried out a detailed seasonal morpho-dynamic analysis running Delft 3D model calibrating the same for simulation of sediment dynamics at two locations viz. Malvan and Vengurla in southern Maharashtra. In the near shore bed region, for one-year period in year 2017, a simulated regeneration was run for assessing the seasonal variations. The sources for wind and wave, tidal elevation and bathymetry data was like General Bathymetric Chart of the Oceans (GEBCO), National Hydrographic Office (NHO) and other authentic sources. The input data were corroborated with past estimated results in scientific and records from International Hydrographic Organization (IHO) and related Indian Organizations. At Vengurla coastal region a sand bar was formed during monsoon due to the action of waves whereas the Malvan region was found to be primarily eroding. Respectively, the southerly sediment transport was observed to be 1.367x105m3/year (gross) and 0.479x105 m3/year (net). The authors stated that they only considered non-cohesive sediments as the sediment concentration data for the monsoon was unavailable. The authors acknowledged the limitation of their study because under their considered calibration parameters the model underestimates the net sediment transport and overestimates the total sediment transport [48].

Beal et al. observed (2019) that in the Indian Ocean some gaps arise within the information mostly from deficiency of longstanding data. The Observing System at Indian Ocean (IndOOS) aims to fill those gaps in knowledge for fulfilling the international endeavor of enhancing substantial knowledge-base [49]. At IITM, Pune, Indian climate scientists also agreed (2020) that nonavailability of data sufficiently for century is a shortfall which needs augmentation [49].

Figure 2.23: Location Map – Maharashtra

Long-term water level data for Indian Ocean has been one of the main deficits for deriving a dependable multi-decadal rise of sea-level.

At Indian Ocean only two tide gauges, one in a location at western coast of India (Mumbai) and the other at western coast of Australia (Fremantle) in the interior ocean which goes back to nineteenth century.

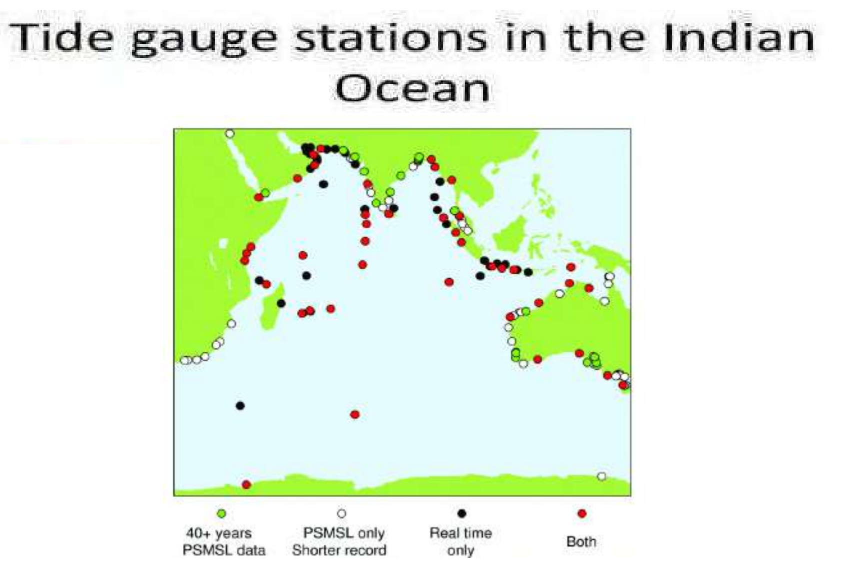


Figure 2.24: Location of tide gauges at Indian Ocean [49]

Santosh Kumar B. et al. (2019) well thought out that changes in climate impacts the sea environment, which in turn is likely to hamper the coastal infrastructure adversely. They recorded the results of health evaluation report of a berthing structure at the bank of a backwater at Kochi at the shore of the Arabian Sea in India. The authors articulated their concerns that due to rise in water level as an effect from change in climate various parameters will vary largely, which will certainly accelerate the corrosion rate on Marine Structures. They reiterated Earth Observatory, NASA's judgment that seawater becomes acidic after absorbing carbon dioxide from the troposphere is detrimental for components in marine infrastructure viz. concrete, reinforcement etc. During the health inspection the age of the structure was 43 years, and it was seen that although the design was supposed to be for 50 years, there are severe damages in the concrete and corroded exposure of the underlying reinforcements. The rapidly happening climate change is changing the sea water to be more severe and the acidic nature of sea water will result to spalling of cover and imbibes damage to rebars (Figure 2.25). It is detected by the authors that the structure has undergone damage for which contributing factor is ascertained as sea level rise owing to climate change. They concluded that due to the continuous change the aggressive nature of the sea environment is not expected to reduce and hereafter they alerted that the design codes for coastal infrastructures need to be revised accordingly, considering protective measures to combat with the future harsh atmosphere [50].

Rajasree B. R. et al. extended their earlier studies in 2016 [37] and 2018 [44] and acknowledged the necessity of rigorous evaluation of Coastal Vulnerability Index (CVI) due to ever-increasing rising population along the coasts and persistent need of development of coastal infrastructure. While accounting for the changes in climate, it was confirmed that marine parameters and configuration of shoreline predominantly contributes towards assessment of vulnerability of coast, and it does not depend on historical data only.

Figure 2.25: Exposed Rebar in Deck Slab, Piers and RC Fenders

The authors accredited that they used MIKE 21SW (DHI) to simulate wave conditions and acknowledged that accuracy of the projected condition of climate rest on the particular model also. Four socio-economic indicators and seven physical-geomorphologic indicators were re-analyzed in the hierarchical process for calculating the CVI in this study and the ranks of CVI in the same place of earlier study in 2018 [44] are plotted (Figure 2.26).The authors explained the reasons for difference in rankings obtained and the result of the study was evaluated in conjunction with Coastal Zone Management Report (CZM 2003) of Govt. of Karnataka to envisage future guidelines for coastal reforms in the zone and called for changes in strategies. They opined that although the work is of generic type, it can be repeated in other coasts. However, the results may have limitations as global sea-level is considered whereas there may be numerous site-specific uncertainties and different physio-morphological variations in data [51].

Mehta et al. (2019) referred about the historical incident when 944 mm of precipitation showered over Mumbai only within a day i.e., within 24hours on 26th July 2005, causing cataclysmic flooding, which has been the most disastrous occurrence of inundating in India at the city. They mentioned

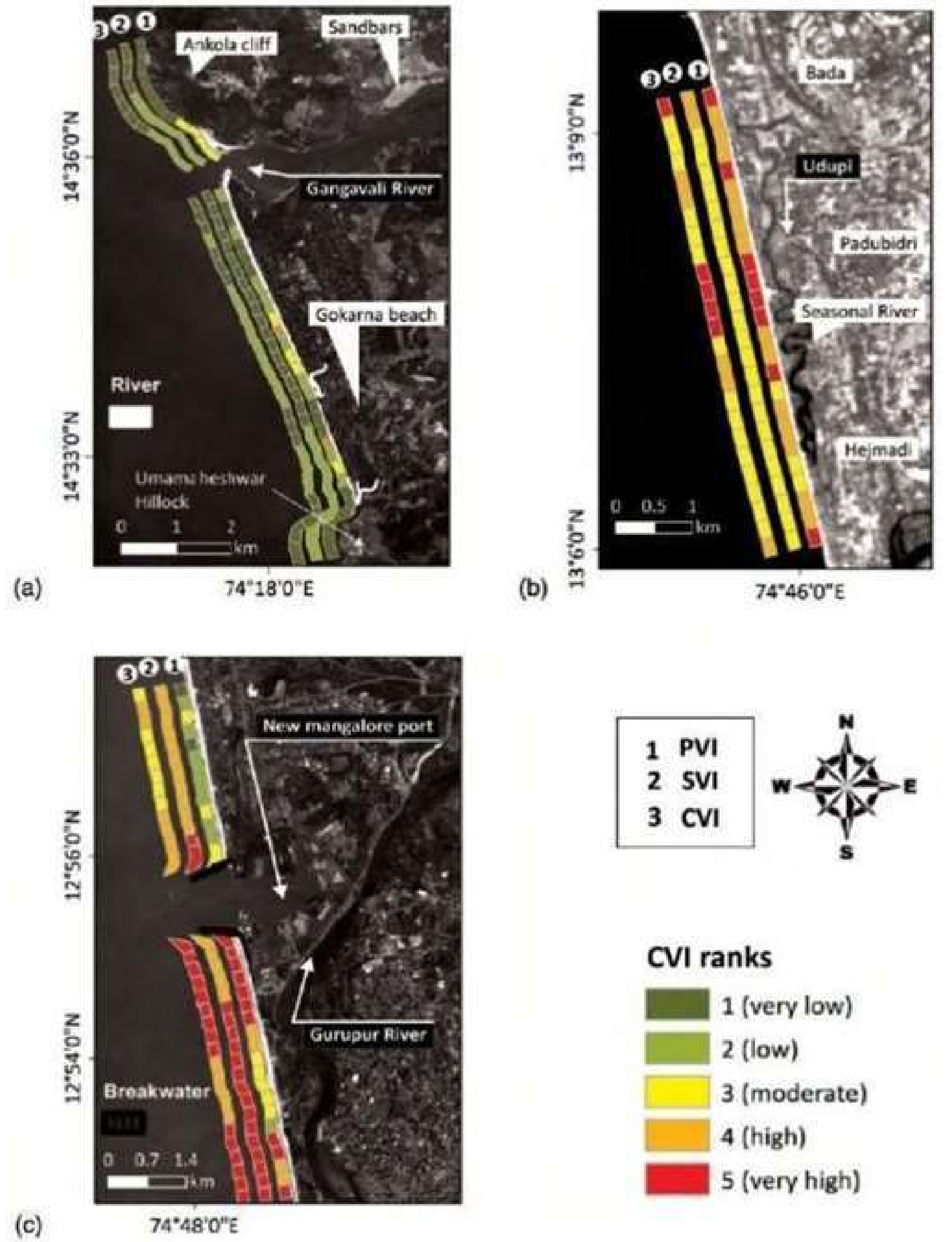


Figure 2.26: CVI Ranks for (a) Gangavali estuary; (b) Udupi coast; and (c) NewMangalore Port.

[J. of Water world, Coastal. and Ocean. Engg. 146. 05019005 1-17]

that disputes of indecision in changes in climate have appeared as a challenging affair for researchers, and the authors stressed upon necessity of better understanding of change in climate and resolving the uncertainties [52].

Maher et al. (2019) in their paper 'Advancing Earth and Space Science Model Hierarchies for Understanding Atmospheric Circulation' highlighted theimportance of Model Hierarchies. The principles in understanding the location wisecirculation stands out as the utmost important factor to find the research outputrealistic. They have stated that probably every model is wrong, but only a few canbe suitable and accordingly the concept should be given due priority for organizingmodel hierarchies and decide benchmark models for use from place to place [53].

2.22 Works in the Year 2020

Abadie et al. (2020) announced about a severe degree of ambiguity about probable damage to the form of the icesheets and sea-level rise [54]. By comparing the probability distribution of risk, they discovered the influence of the ambiguity on financial impairment due to rise in sea-level out of 136 coastal cities, Mumbai has the 2nd highest risk of inundation so far as menace is measured.[54]

Dhiman et al. (2020) studied GIS unified integrated handling of danger in megacities at coastal boundaries including at Mumbai, and developed CMIS (Coastal Management Information System). This CMIS tool is a pilot initiative enabling an accessible valuation of coastal resources online itself using advanced GIS techniques for dynamic mapping application for coastal areas. The study stimulated the engagement of GIS techniques to enhance the transparency of seaside physical parameters among innumerable end using operators which can restrict misuse of resources to some extent and thereby a modified and developed framework could help the movement towards a more maintainable and stronger built-up situation [55].

Fan, X., Miao, C., et al. (2020) compared the efficacy of CMIP6 against CMIP5 for corelating excesses heat at the surface of the land of our Globe. compared CMIP5 and CMIP6. They noted that particularly for diurnal changes in temperature during summer, the three-dimensional study in CMIP6 models has, nights, cold spell duration, and, pattern skill scores in some discrete are upgraded in comparison to earlier CMIP5 models. CMIP6 models provide a basis for reliable future projections of climate by simulating data from historical extreme climates. However further improvements towards more accuracy have been suggested. [56].

Garbe et al. (2020) in their paper pointed out that Antarctic Ice Sheet by far holds more than 50% of Earth’s freshwater. Under future warming conditions, Antarctica will be the biggest probable source for rise in water level at sea globally. Response to variations in temperature from Earth's atmosphere, ocean, ice and land shows possible paradoxes. It is enforced that a complete constancy analysisof the Antarctic Ice Sheet for different spreads of global heating is required to be studied [57].

Slater et al. (2020) tracked Ice-sheet losses for prediction of rises in sea‒level and observed that being activated by changes in climate, ice calving and surface melt has accelerated in the last 20 years in Greenland. It is stated that the polar icebergs cumulatively at Antarctic as well as at Greenland together hold adequate water to increase global sea water levels respectively by upto 58 m and7 m. Being the major deposit of ice even minor losses from these ice blocks willalso contribute to rise in sea level and may surge coastal flooding. According to them the quantity of water obtained from loss of icesheet due to aspects of changes in ice volume in the jurisdiction of Antarctica as well as liquification of Greenland ice matches with the predictions from AR5 Report IPCC on sea‒level particularly with upper range [58].

Rander et al. (2020) reiterated about the consequence of the risk of change in climate and through a new climate model named ESCIMO, examined a hypothetical scenario assuming all human‒induced GHG emissions are stopped in 2020, and reported that self-sustained melting of permafrost and ice will continue in upcoming centuries. Melting (in ESCIMO) is the resultant from warming and is the collective effect of 3 phenomenon.

(i) Driven by liquification of the Arctic ice.

(ii) Upsurge of vapour in troposphere.

(iii) Variation of GHG concentrations.

They have unconditionally declared in ESCIMO about requirement of removal of huge amounts of CO_2 from the troposphere to stop continuation of sustainable rise in temperature leading to warming. Right now, nothing much can be done excepting reducing emissions [59].

Chiang et. al. (2020) narrated that unexpectedly, the Universe is becoming hotter and hotter as time goes on and it expands. The recent findings are contrary to the earlier theoretical concepts of possibility of cooling. A comparative mass balance of Polar Ice Sheets between Antarctica & Greenland is presented in Figure 2. 27. Astronomers have understood this for almost a century that the Universe is in a state of expansion [60].

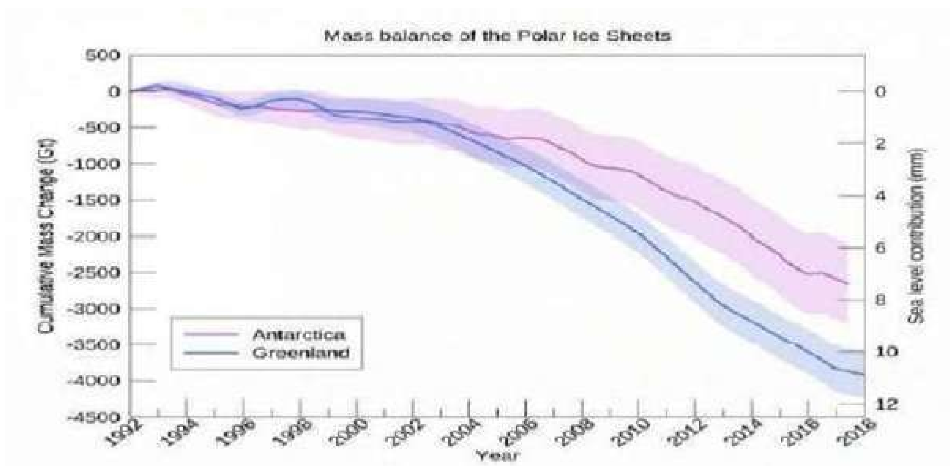


Figure 2.27: Mass balance of the polar ice sheets–Copernicus Climate Change Service

Lockley et al. (2020) commented about Geo-engineering which includes the idea of freezing the seabed, using albedo, encircling icebergs with seawalls to block entry of warm sea water below ice chunks, thickening ice by buttressing, adding snow in cloud, strengthening hydro fractured ice blocks etc.

While the plethora of novel concept of various climatic geo-engineering approaches, particularly regarding glaciers came out in literature some concepts have limitations also. The scientific community although observed that all the ideas are not judged reasonable, the concept of Geo-engineering is a well-thought of one to evaluate how much time is required to restrain glacier melting to retard sea levelrise [61].

2.23 Reports of IPCC

In 1990 first assessment report of IPCC AR1 considered long-term emission scenario originally known as SA90 which got partially modified in 1992 and named as IS92. For impact assessments of Global Climate such scenario was adoptedas a standard. The future evolution is highly uncertain. It is extremely difficult to apprehend how the world will change by 2100. An estimated population by 2100 as 11.30 billion and 2.3% per annum economic growth between 1990 and 2100was considered, with use of an admixture of both conventional and renewable energy sources. Future greenhouse gas (GHG) emissions will have a large contribution to Global changes including Climate Change, which again depends on the ever-changing evolutions in civilization, population, industrial growth, and varies as per zonal requirement, developments related to narrowing down economic differences and geographical requirements. The emission scenarios being multifaceted continuously changing system are aptly evaluated by some scenarios conceived by scientists. The entire gamut of the chronological changes in concepts and scenarios are synoptically summarized in SPECIAL REPORT EMISSIONS SCENRIOS (SRES)-Summary for Policymakers, IPCC; published jointly UNEP and WMO, 2000 [62].

The following reports of IPCC being the legacy of international reports areof paramount importance as they form the main resource material and deserve deep insight for carrying out research on the captioned subject of this thesis.

- ✓ IPCC AR 2: 1995 (SAR)
- ✓ IPCC Emission Scenarios, 2000
- ✓ IPCC AR 3: 2001 (TAR)
- ✓ IPCC AR 4: 2007 (AR4)
- ✓ IPCC AR 5: 2014
- ✓ IPCC AR6 ,2021
- ✓ National Climate Assessment 3 (Climate Change Impacts in US)
- ✓ Climate Action Tracker
- ✓ MOES Report
- ✓ Emissions Gap Report 2020 - U N E P
- ✓ Reports from:
  - MCGM
  - MMRDA
  - Govt. of Maharashtra,
  - MbPT etc.

In the following paragraphs some of the most pertinent and relevant details associated with Sea Level Rise has been excerpted from the available study materials to illustrate the various phenomenon involved and to identify the sourceof information related to the topic of the research. The other materials include information and data about the specific area of study including allied socio- technical information on the city of Mumbai as obtained from websites of various authorities at Mumbai.

2.24 Scenarios

Scenarios are hypothesized realistic imaginations of imminent, or substitute expected scenes for later times. They are neither estimates nor guesses. As per IPCC (SRES, 2000) fossil fuels upholding their foremost position in energy field to 2030 and beyond upsurge of emissions by (CO_2-eq) by between 2000 and 2030is projected as 25 to 90% [64]. The SRES considered a finite but extensive variety in future emissions. The IPCC described their scenarios coherently by narrative storylines. From economic developments including demographic to technological scenarios were considered in SRES covering for driving forces related to emissions in future.

2.25 Assessment Report 4 (2007)

The Synthesis Report of IPCC AR4 (2007) provides unified view of changes in climate. Chapter 12 in IPCC-AR4 explains Scenarios on changes in Climate considering different scenarios of emission. In IPCC AR4, four types of scenarios i.e., A1, A2, Bl, and B2 termed as "families" were conceived. SRES also provide inter linkages between environmental quality and development choices (Figure 2.28) corresponding to the stated 4 families.

a) The A1 family designates an upcoming fiscal growth as rapid, increase in number of people as low with implementation of effective technologies as rapid. A1 family describing alternative in energy related technologies develops into three groups of energy system

   (i) A1FI (with intense use of fuel from fossil),
   (ii) A1B (stable) and
   (iii) A1T (predominantly with fuel from non-fossil sources).

b) The A2 family scenario labels a mixed world where regionally oriented development is considered when per capita growth is fragmented and slower

c) The B1 family pronounces a convergent world with low populace similar toA1 storyline, with fast changes in future economics

d) The B2 family designates world with regional solutions (to financial, societal, and eco-friendly maintainability), moderate populace growth, fiscal growth intermediate, and scientific change diverse less speedy and further than those in the B1 and A1 storylines.

Altogether the scenarios set consists of six groups from the 4 families.

- **A2, B1, B2 -** 3 scenarios and

- **A1B, A1FI, A1T -** 3 groups inside A1 scenario.

Summarily as per AR4 the subsets of SRES scenarios capturing the range ofemissions are: (i) B1, (ii) A1T, (iii) B2, (iv) A1B, (v) A2 & (vi) A1FI (Figure 2. 29).

2.26 Assessment Report 5 (2014)

IPCC AR5 Chapter 12 explains Scenarios on Climate Change consideringdifferent emission scenario based on Radiative Forcing Value.

2.26.1 Radiative forcing

Radiative forcing also acknowledged as climate forcing is the variance among absorbed amount of solar energy and energy released to space. Causing temperatures to increase or failure, Climate Forcing is the changes in Earth's radiative equilibrium through decades. Radiative forcing is positive when earth receives more energy from sunlight than radiating to space. Warming happens for gain in energy. Cooling happens from negative radiative forcing when earth loses more energy to space than received from sun. Radiative Forcing Value reckoned on Carbon Dioxide Concentration is measured in Watts/m^2. Zero radiative forcing means system is in equilibrium.

2.26.2 Carbon Dioxide Concentration

The emissions for all GHGs like carbon dioxide, methane, and nitrous oxides, is represented by this term 'Carbon Dioxide Concentration' which is measured in ppm (parts-per-million) [CO_2 content per mol. of dry air in 10^{-6} mol.].

IPCC considers RCP (Representative Concentration Pathways) as the trajectories for concentration (not the emissions) of greenhouse emission. As per etymology the RCPs include a large series of probable deviations in forthcoming anthropogenetic (i.e., caused by human population) emissions of GHG, for denoting their concentrations in atmosphere (*van Vuuren, et al.,2011*) [67].

A synoptic representation of methods for rationalizing RCPs in terms of Radiative Forcing is presented in Table 2.2 [24] and a quantitative relation between RCP vis-à-vis Radiative Forcing with CO_2 is presented in Table 2.3 [66]for reference. IPCC AR5 assumed 4 radiative forcing values in 2100 denoting 4 probable scenarios corresponding to 4 'greenhouse gas concentration trajectories' (viz. RCP 2.6, 4.5, 6.0 and 8.5). As per various RCP scenarios under AR5 (Figure 2.30) projections of increase in global warming (°C) & rises in global mean sea level (m) increases projections till 2021 as per increment in the CO_2 concentration (ppm).

Figure 2.28: Summary characteristics of the four SRES storylines IPCC (2007)

[researchgate.net/publication/265142559 - Toni Lyn Morelli]

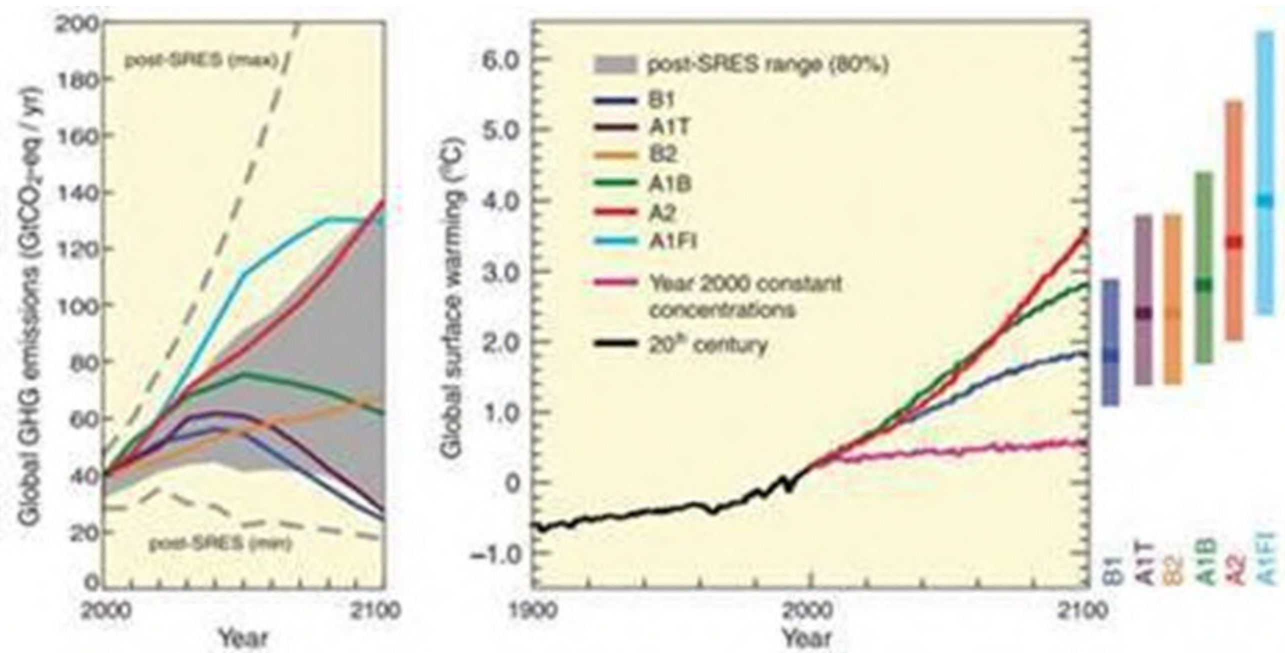


Figure 2.29: Global GHG Emissions Scenario [Source: NOAA Technical Report (https://www.researchgate.net/publication/327273082)

Table 2.2: Radiative forcing and CO_2 as per RCPs of IPCC AR5 [66]		
Name	**Radiative forcing**	**CO_2 equivalent (ppm)**
RCP8.5	8.5 W/m^2 (During 2100)	1370
RCP4.5	4.5 W/m^2 (After 2100)	0650
RCP2.6 (RCP3PD)	3 W/m^2 (Before 2100) Reducing to 2.6 W/m^2 (During 2100)	0490

2.27 Comparison of AR4 and AR5 Approaches

AR4 outlined qualitative and quantitative approaches in describing uncertainties as per evidence from theory, observations, or models and the level of consensus in the literature on specific finding.

Table 2.3: RCP scenarios [66]		
Name	**Description**	**Developed by**
RCP2.6	Radiative forcing level reaches upto 3.1 W/m^2 by middle of century, and declines to 2.6 W/m^2 in 2100. Emissions substantially reduced Overtime at this scenario	Netherlands Environmental Assessment Agency·
RCP4.5	A scenario where total radiative forcing steadies before 2100 by reducing GHG emissions with choice of technologies and strategies	Pacific North west National Laboratory's JointGlobal Change Research Institute.

RCP6.0	Radiative forcing steadies after 2100 in totality without exceeding by deploying a series of skills and strategies for lowering GHG emissions.	National Institute for Environmental Studies, Japan.
RCP8.5	Representative scenario towards higher level of GHG absorption by upsurge in GHG emissions over time	International Institute for Applied Systems Analysis (IIASA), Austria.

Consistent treatment and communication of uncertainty across became key for the IPCC. AR5 aims for refining the dissimilarity and change between different metrics to apply them consistently. Warming scenario in different RCPs are givenin Figure 2.31. The RCP scenarios as per radiative forcing (+2.6 to +8.5 watts/m^2) that results by 2100 are simply numbered only. Warming Versus SLR in various RCPs are given in Table 2.4. Comparison of SRES & RCP / AR4 vs AR5 are presented in Figure 2.32.

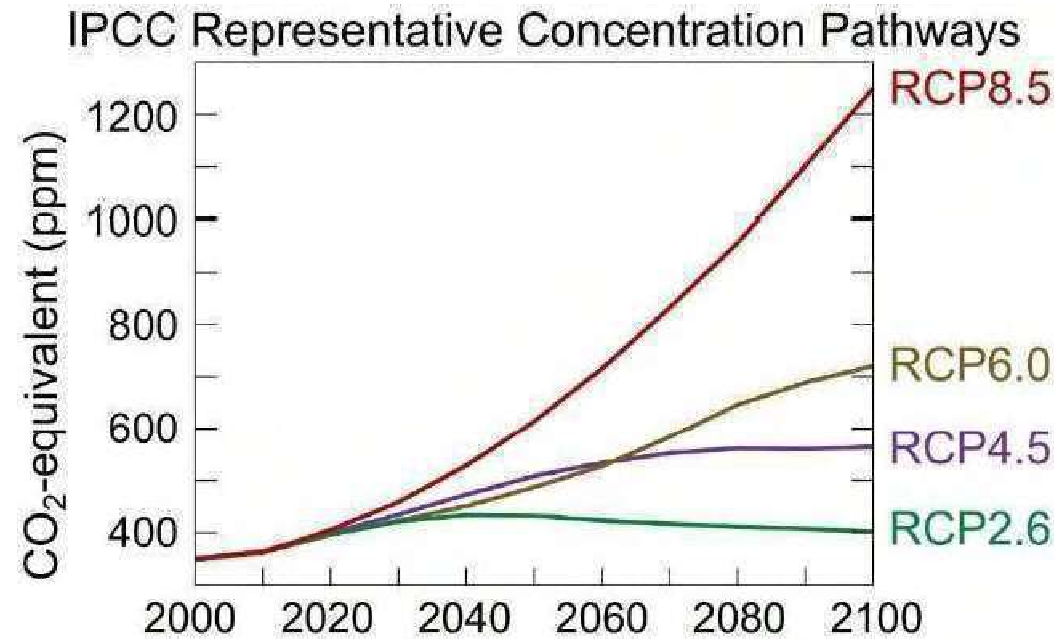


Figure 2.30: RCPs at IPCC Climate Change Scenario

[wikipedia.org/wiki/Representative Concentration Pathway]

CO_2-equivalent concentrations in ppmv for 4 RCPs (IPCC AR5) for making predictions.

2.28 MoES & IITM

IITM, Pune has the best set-ups in India to study and forecast Climate Change. MoES-IITM 2020 describes coupled feedback on atmosphere–ocean– land–cryosphere system in details. MoES (Ministry of Earth Sciences), Government of India's recent report, 2020 [63] contains results based on CMIP6) projections. MoES agreed that rise in Sea-level influenced mainly by the thermal expansion is not uniform in Indian Ocean. It records since 1901 the rise in global mean sea level 1.7 mm per year and since 1993 it has enhanced to 3.3 mm per year. The first climate model from India i.e., IITM Earth System Model contributedto IPCC AR6, 2021.

Table 2.4: Warming vs SLR in different RCPs [Source: Summary for Policymakers: IPCC AR5 WG1 2013]

Projection of increase in global warming (°C) as per AR5		
	From 2046 till 2065	**From 2081 till 2100**
Scenario	Mean & *Likely* range	Mean & *Likely* range
RCP 2.6	1.0 (0.4 to1.6)	1.0 (0.3 to 1.7)
RCP 4.5	1.4 (0.9 to 2.0)	1.8 (1.1 to 2.6)
RCP 6	1.3 (0.8 to 1.8)	2.2 (1.4 to 3.1)
RCP 8.5	2.0 (1.4 to 2.6)	3.7 (2.6 to 4.8)
Rise of mean global temperature is projected from 0.3 to 4.8°C by 2100 in all RCPs		

Projection of increase in mean sea level (m) globally as per AR5		
	From 2046 till 2065	From 2081 till 2100
Scenario	*Likely* range and mean	*Likely* range and mean
RCP 2.6	(0.17 to 0.32) 0.24	(0.26 to 0.55) 0.40
RCP 4.5	(0.19 to 0.33) 0.26	(0.32 to 0.63) 0.47
RCP 6	(0.18 to 0.32) 0.25	(0.33 to 0.63) 0.48
RCP 8.5	(0.22 to 0.38) 0.30	(0.45 to 0.82) 0.63
Rise of MSL globally is projected from 0.26 to 0.82 m by 2100 in all RCPs,		

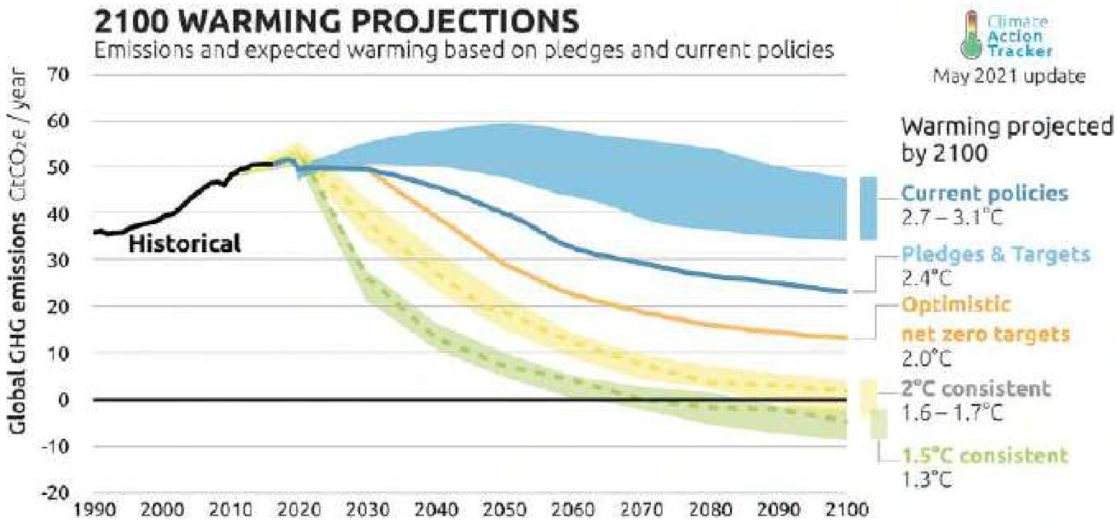


Figure 2.31: Warming Situation in different RCPs[Source: Climate Action Tracker. org]

It is already established that rise of water level at sea in Indian Ocean happened quicker in recent decades i.e., 3.6 mm per year than 1.4 mm in the last century and the rise in sea level at Mumbai is about 0.78 millimeter/year [63]. Excessive extraction of groundwater, gradual build-up or removal of sediments deposited by rivers in delta regions also may contribute to vertical movement of land mass and both the lands and the ocean's movements need to be accounted to assess the changes at sea level. Relative 'Sea Level' is the variation at water level at sea, compared with a point on shore and is measured by Tide gauges installed at Indian coast. Float-activated tide gauges are replaced by more reliable electronic gadgets. The tide gauge in Mumbai, installed in the late 1800s by the British was the only observatory in the country recording century's worth of sea level measurements. To comprehend sea level rise from climate, change several decades' worth of continuous data are required from the 36 observatories on India's mainland coastline and islands with tide gauge. Satellite altimeters measure the absolute level at sea whereas RSL (relative sea level) is measuredby tide gauges. It does not measure if land nearby is rising or sinking. To assess what's happening or going to happen on the coast at local level say, in Mumbai, data from the coast is also essential for correlating. The need for continuous monitoring of the Indian coastline has been advocated in IITM-MoES, 2020 report.

It is confirmed that the sea level around India also isn't just rising– it's accelerating. Figure 2.33 shows consistent warming tendency for short period, midterm and longstanding scenarios. Yearly rise of temperature (0C) as per CMIP5 model for 4 RCP scenarios are predicted for 2030s, 2060s and 2080s relative 1880s. In RCP8.5 huge heating upto 80C can happen in the Himalayas and Kashmir areas by 2099.

The probable variation temperature at India-level in various RCP scenarios till 2080s shown in Figure 2.34. It shows that under RCP2.6, the temperature rise considered being 20C, rise in temperature of about 1.4 0C minimum and about 2.80C maximum may happen in many regions. The minimum rise in temperature increases to 20C under RCP4.5 and 3.40C under RCP8.5. RCP6.0 considers similar increase in temperature but larger than under RCP4.5. Increases in temperature under RCP8.5 from those in RCP2.6 are fast as seen from the width of the distribution. Because of two reasons (i) ice sheets as well as glaciers in Greenland and Antarctic are melting faster this century than they did earlier and (ii) ocean is becoming more hotter and expanding than before, the cause being 90% of the excess heat due to greenhouse gases is absorbed by oceans. IPCC's predictions are based on level models which is not always adequate to understand regional conditions for which regional projections needs to be concentrated upon.

In Figure 2.35 Taylor diagram shows that performance of temperature simulation is more reliable than those for precipitation. For assessing land movements in India, gaps in our understanding on sedimentation and groundwater extraction particularly in places like the Sundarbans delta region in India needs to be mitigated, where already three islands have completely disappeared.

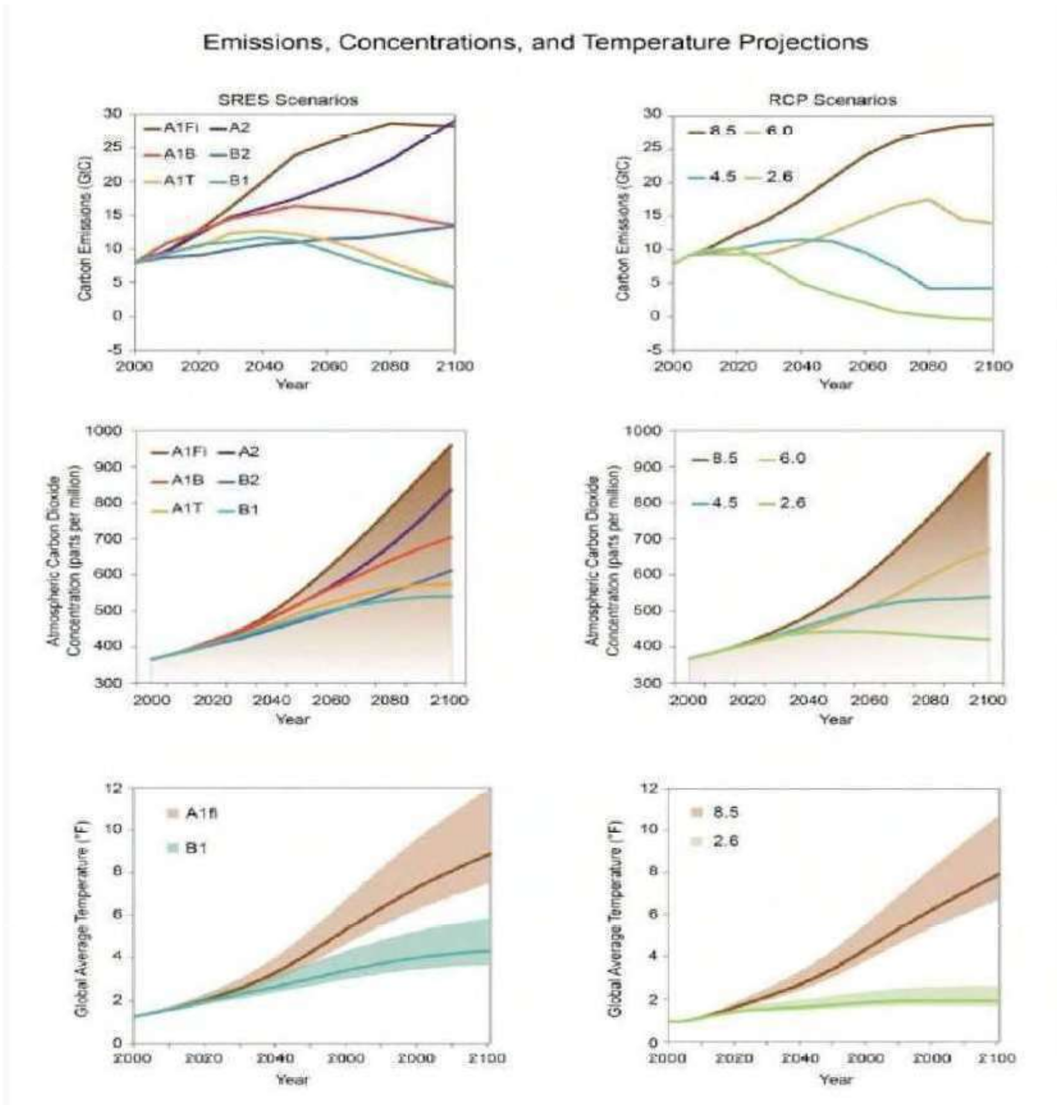


Figure 2.32: Comparison of SRES & RCP / AR4 vs AR5 SRES (left) and RCP's (right); annual carbon emissions from SRES and RCP (top),

equivalent levelsof carbon dioxide (middle),

temperature change (central),

likely series (shaded areas) of climate sensitivity (bottom)

[Source: ClimateActionTracker.Org]

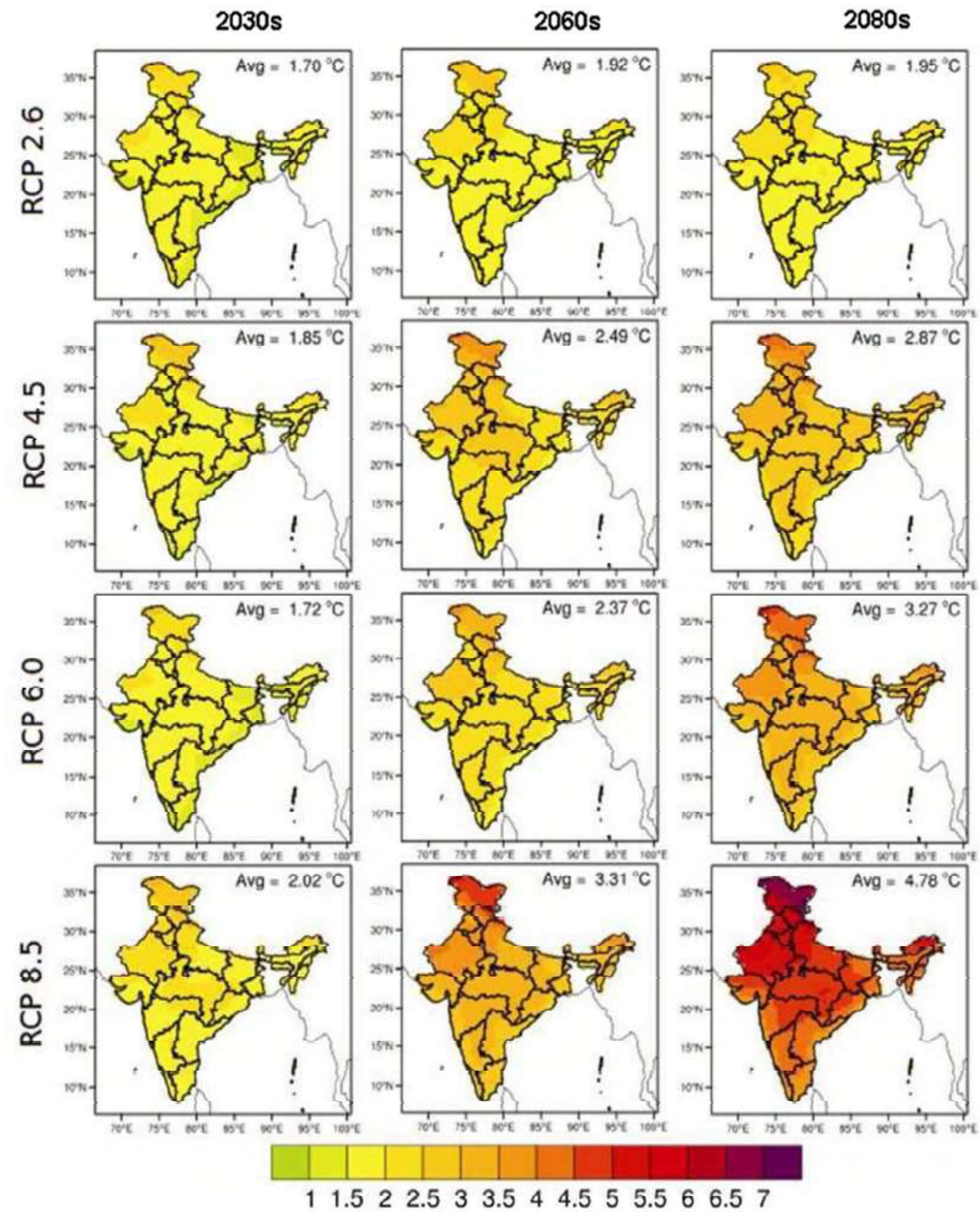


Figure 2.33: Changes in mean temperature (^{0}C) projected from 2021 to 2050 (2030s), 2046 to 2075 (2060s) and 2070 to 2099 (2080s) relative to the preindustrial period i.e., 1861 to 1900(1880s) as per CMIP5 model ensemble [24].

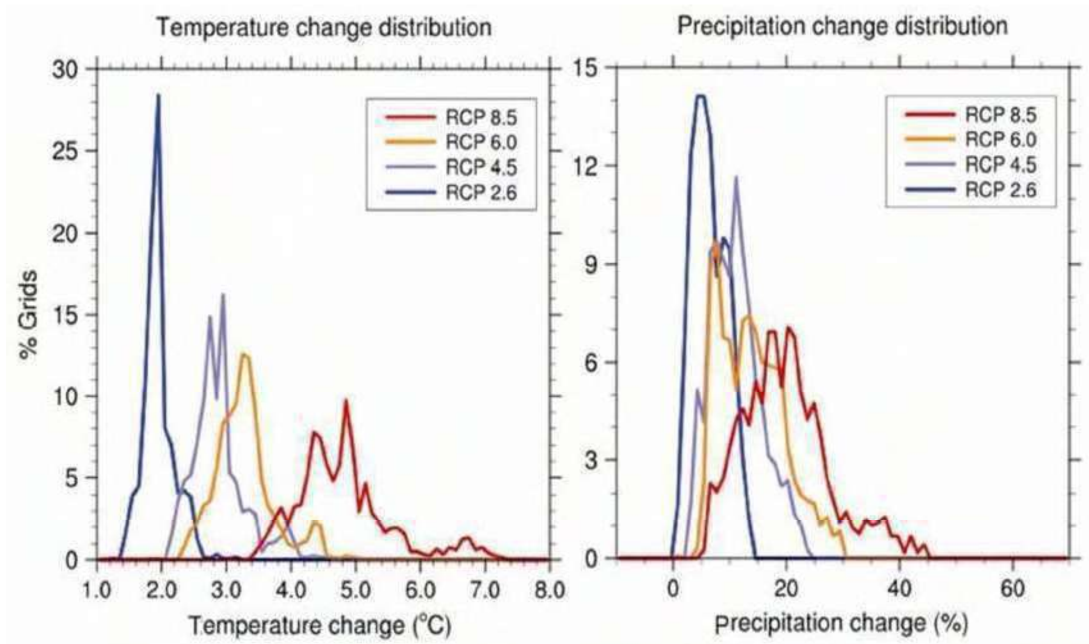


Figure 2.34: Temperature and precipitation change distribution under different RCPs at India 2070-2099 relative to 1861-1900 [24]

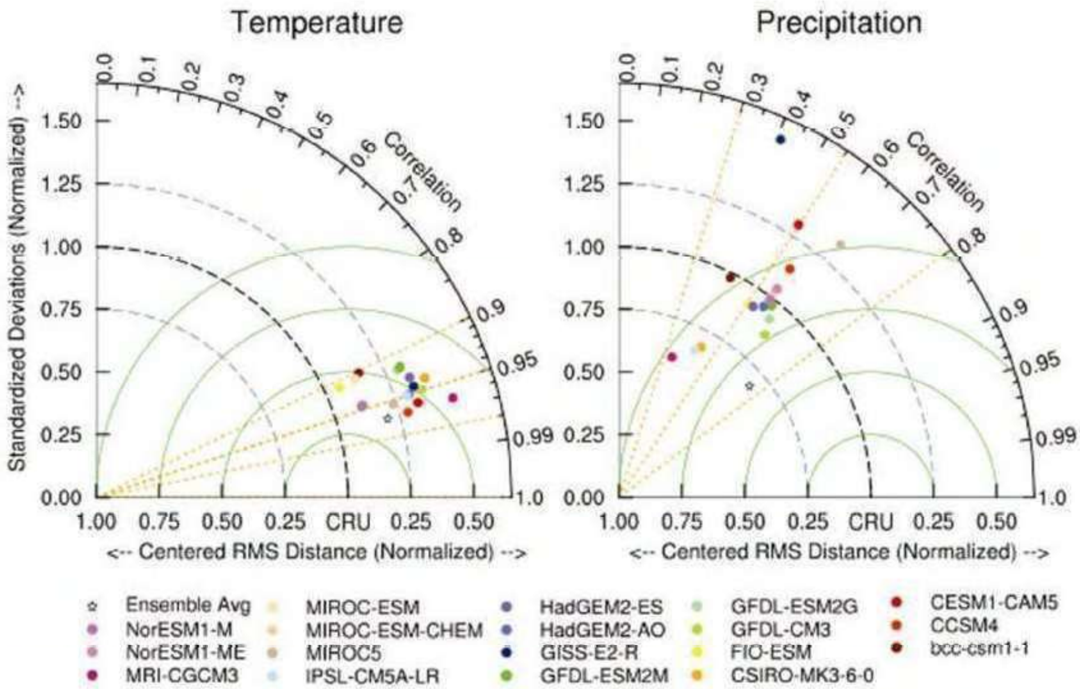


Figure 2.35: Temperature and precipitation for the period 1971–2000,Compared through CMIP5 model for India [24].

2.29 Pertinent Information from Concurrent Researches

The inadequacy of datasets related to variations of decadal sea-level at Indian Ocean is established as a shortfall in information (*Nidheesh et al.2017)* [41]. Indian Ocean lacks in multidecadal observations on oscillations, which is a shortcoming to assess past Sea Level and forecasting future (*Unnikrishnan et.al.2015*) [68]; Knowledge of long-term steic sea level, hydrographic profiles and variations in salinity in the Indian Ocean basin is limited (*Swapna et al 2017*) [69]. The inadequacy of datasets related to variations of decadal sea-level at Indian Ocean has been attempted to be completed by the IndOOS (*Beal et. al.2019*) [12]. Large part of the anthropogenetic excess heat (90%) warms the sea and the remaining 10% heat melts terrestrial and sea ice (*Trenberth et al. 2014*) [70]. Climate change will continue throughout the coming years. GCMs (Global climate models) also found positive links between increase in atmospheric CO2 and increase in temperature globally (*Beal et. al.2020)* [49].

2.30 Climate Scenarios

IPCC 5th Assessment Report (AR5), 2014 considered CMIP5 climatemodels which is still in force. For improved adaptation of regional climate changeassessment of impact CORDEX provided co-ordination of Regional Climate Modelling in CMIP5 at global level. Rise in Sea level is linked with rise oftemperature globally. A scenario assuming no noteworthy change in technology, economics, or policies in future, expecting continuance of unaffected circumstances known as 'Business-as-usual' situation falling within RCP6.0 &RCP8.5 (Chaturvedi et.al.) and preindustrial times 1850-1900 lies under RCP6.0and RCP8.5 scenarios respectively [24]. Parameters considered in CMIP6; the new state-of-the-art climate model has been included in IPCC AR6 (released in 3rd quarter of 2021) has not been incorporated in this study. A very long time isrequired to revise the simulation softwares for determining rise in sea level.

2.31 Future Warming in CMIP6

CMIP6 is likely to address the following in future:

a. Response of Earth system to forcing.

b. Origin of systematic model bias and the consequences thereon.

c. Given uncertainties in scenarios assessing future climate.

As more model runs will come in, more results will be available, range of values inCMIP6 will be wider than CMIP5.

2.32 Climate Data Projections

Key projected climate trends **in Temperature/Precipitation** are as follows**:**

- ✓ Average rise in Sea water level at Mumbai area is predicted as within 300 mm and 800 mm until 2100 with predicted increase in temperature within 1.5 and 1.8 °C by 2050(*IPCC-Special Report, 2000*) [62].
- ✓ Rise in precipitation (minimum and maximum) will be about 18% and

expected more frequent tropical cyclones will become a threat to Mumbai(*MoES -IITM, 2020*) [63]. According to MoES report, 2020 in RCP 8.5 scenario in our country the rise in average temperature in 2100 is expected to be 4.4^{0}C (*MOES,2020*) [64].

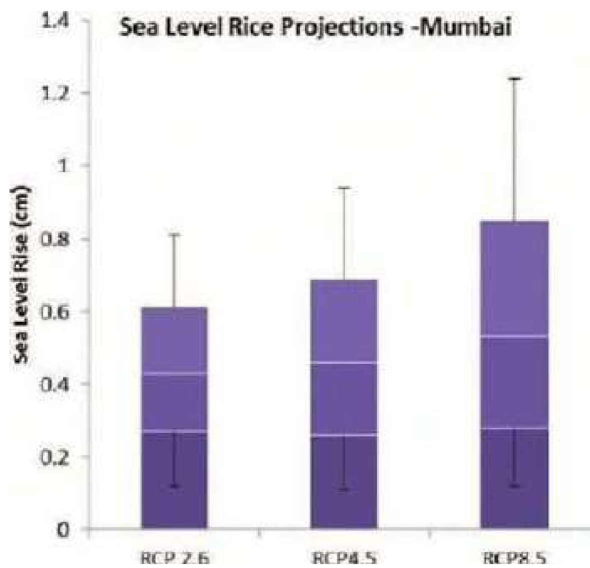


Figure 2.36: SLR at Mumbai in different RCPs [66]

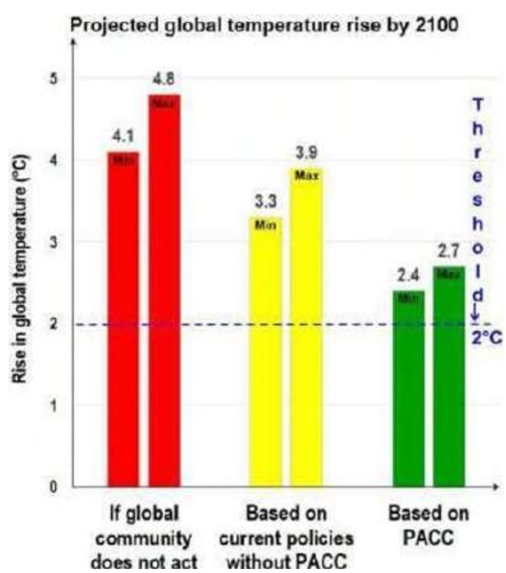


Figure 2.37: Projected global temperature rises by 2100 as per Paris Agreement

The SLR at Mumbai in different RCPs is presented in Figure 2.36. Employing severe lowing in carbon concentration under RCP 2.6, the rise in sea water level can be about 81 cm [(Dhanya Praveen et.al.2018) [66]. The projected global temperature rises by 2100 as per Paris Agreement is presented in Figure 2.37.

2.33 Regional Ocean Modeling System (ROMS)

ROMS is currently being used to set-up INDOFOS (Indian Ocean Forecast System; at INCOIS. In ROMS, discretization of hydrodynamics and thermodynamics are done using Finite Difference and used in the primitive equations to obtain numerical solutions. ROMS essentially is a revision of Oceanic General Circulation Model. Application of the regional oceanic modeling system (ROMS) has been advocated by Shchepetkin et. al. for its advantages (*Shchepetkin et.al.*) [71].

2.34 Uncertainties

Predictions of SLR from individual studies are generally found higher than upper projections predicted by IPCC. The prediction of rises in sea level varies widely and remaining intensely indefinite as the higher prediction windowsfor the forecasts on SLR are not similar as obtained from various studies (*Garneret al. (2018*) [47]. Some Scientists indicate IPCC projections were erroneous – a conservative bias which may doubtlessly impede risk management. Scientific explanations for the projection (s) of SLR are extraordinarily tough. Currently, the primary sources of knowledge relating to water level rise projections are — IPCC and National Climate Assessment (NCA), though these assessments use totally different strategies (IPCC depends upon numerical method models; the NCA uses semi-empirical models) and the results of one match with that of other. The contemporary rise in annual sea level at Mumbai lies between 2.5 and 3 mm along its coastline (*Mehta et al.2019*) [52]. The greatest uncertainty lies with finding how fast and how much the icebergs are going to melt and contribute towards rise of sea level in ocean globally.

2.35 Equivalence between SRES & RCP's

A. According to 'carbon dioxide concentrations' and 'change in global temperature'the equivalence of scenarios from SRES and RCP scenarios are observed as:

1. SRES A1FI matches RCP 8.5.
2. SRES A1B matches RCP 6.0 and
3. SRES B1 matches RCP 4.5.

Most common scenarios from multi-model global averages are: 1. A 2, A1B (RCP6.0) and

2. B1 (RCP4.5)

The corresponding warming situation are indicated by the respective temperature in Table 2.5

Table 2.5: Scenario-wise Global Mean Warming [Present & Future]

(Source: Table 10.5 [75])

Global Mean Rise in Temperature (^{0}C)

Scenario	2011 to 2030	2046 to 2065
A2	0.64	1.65
A1B	0.69	1.75
B1	0.66	1.29

2.36 Sea Level Rise Phenomenon

Rise in Sea-level is happening from Global Warming. Alongwith warming from Global Greenhouse Gas (GHG) emissions, cumulative contributionin recent years from melting of ice needs to be continuously restrained. Further to Global Climate Change Projections in IPCC AR4 Chapter 10 & IPCC AR5 Chapter 12, Rise in Sea Level is described in Chapter 13 of IPCC AR5. It is already documented that non-climatic anthropogenic driver also plays important role in increasing vulnerability of coastlines.

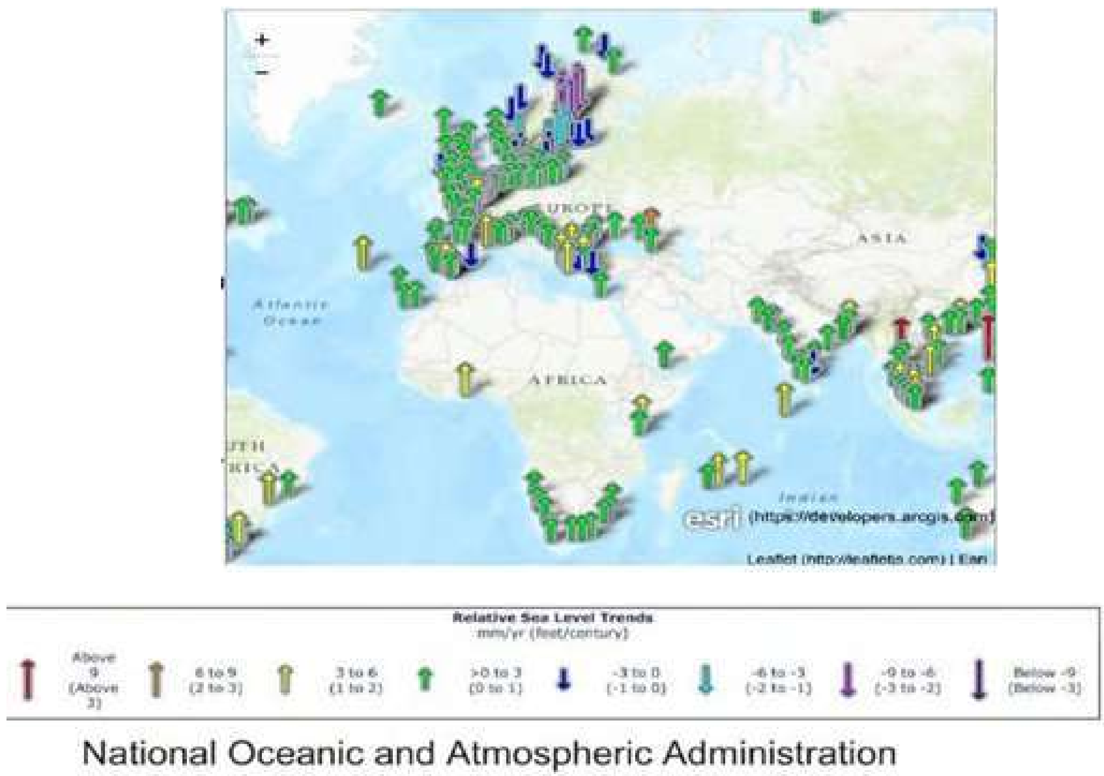


Figure 2.38: Rising Trend at India vs. Global Trend as per NOAA

In past century rise of water level was from 1–2 mm per year which now is in theorder of 3-4 mm per year and can further increase upto 4 to 9 mm/year within RCP2.6 and 10 to 20 mm/year within RCP8.5 during top of this century. IPCC says under RCP2.6, GMSL rise will be 0.24 m (0.17–0.32 m) and under RCP8.5 will be 0.32 m (0.23–0.40 m) up to 2050. It's expected that change in water level will varyat regional levels, showing noteworthy differences from the general change in world mean.

2.37 Regional Variation

There are lot of uncertainties to ensure the quantum of melt ice as Regional Sea Level (RSL) can vary continuously as the process also involves solid Earth deformation, gravitational and rotational changes. Such regional changes happen as the geoid changes due to addition of water into ocean because of which ocean floor is deformed as the rotation of the Earth is altered which in turn change sea level. Anthropogenic subsidence, wave run up along with the dominant modes of climate variability also contribute towards the change in sea level at the coast. IPCC reports with high confidence, that the ocean level globally is currently accelerating at the speediness of 3.6 mm once a year. The mix of maximum water level (ESL) events like tides, surges, and waves in association with the gradual change in Mean water level is undoubtedly going to cause serious impacts on coasts. The Rising Trend at India vs. Global Trend as per NOAA is presented in Figure 2.38.

2.38 Present Global Scenario

UNEP's Report on Emissions Gap, 2020 [73], states although CO2 emissions was found lower during COVID-19 pandemic, the present temperature trend is moving towards more than 3°C this century, which does not commensurate with goals of Paris Agreement (Figure 2.39).

2.39 Relative Sea Level Rise

NOAA, USA following global tide gauge records and those from Permanent Service for Climate Change predicts rates of rise in RSL [104]. From the Figures to 2.42, it may be seen that RSLR at Mumbai is about 0.8 mm/year (MoES),the indication remains the Relative Sea Level is on the upper trend.

Figure 2.39: Rising Trend in Mumbai as per NOAA

2.40 Sea Level Rise Trend in Indian Ocean

The RSL trend at Mumbai (0.8 mm/year) is based on sea level data from 1878 to 2011. Based on data for the period from 1878 to 1993 the 'Coastal Road Detailed Project Report' mentioned an average rise in sea level about 1.27 mm/year in EIA(P 98), in spite of the fact that rise in sea level rise has doubled in India and increased upto 3.2 mm per year within a period from 1993 to 2012 (in just over one decade) inline with global rates whereas trend in rise of net sea-level–rise was 1.08mm / year (*Unnikrishnan et.al.2015*) [35]. Over a period of 1993–2012 satellite altimetry data discloses that the rate of rise in sea water level rise at north of Indian Ocean followed the similar trend in rise of mean sea-level globally (i.e., 3.2 mm per year). At that time the tendency of rise in the north of Indian Ocean (3.28 mm per year) is also close tothe trend of 3.2 mm/year in global mean sea-level (with an ambiguity of 0.4 mm peryr.) (Figure 2.41). However, the recent tendencies regarding rise in sea water level obtained from satellite altimetry are higher in comparison to what is estimated over longer periods from records of tide gauge, during the past century (*Unnikrishnan et.al.2015*) [35]

2.41 Shoreline Shifting

The results of Brun's rule indicated that under RCP-4.5 the shifting of shorelines at selected coasts till 2100, may be upto 14.10–29.22 m, and underRCP-8.5 upto 21.05–45.40 m. Figure 2.41 shows the inclination in rise of Sea water at Indian Ocean [35].

The linear relationship between shoreline shift and sea level rise. is explained inFigure 2. 42. Earlier Mumbai ranked fifth amongst 20 cities in terms of relative vulnerability for city level flood risk (Nature Clim Change 3, Hallegatte et al.,2013).

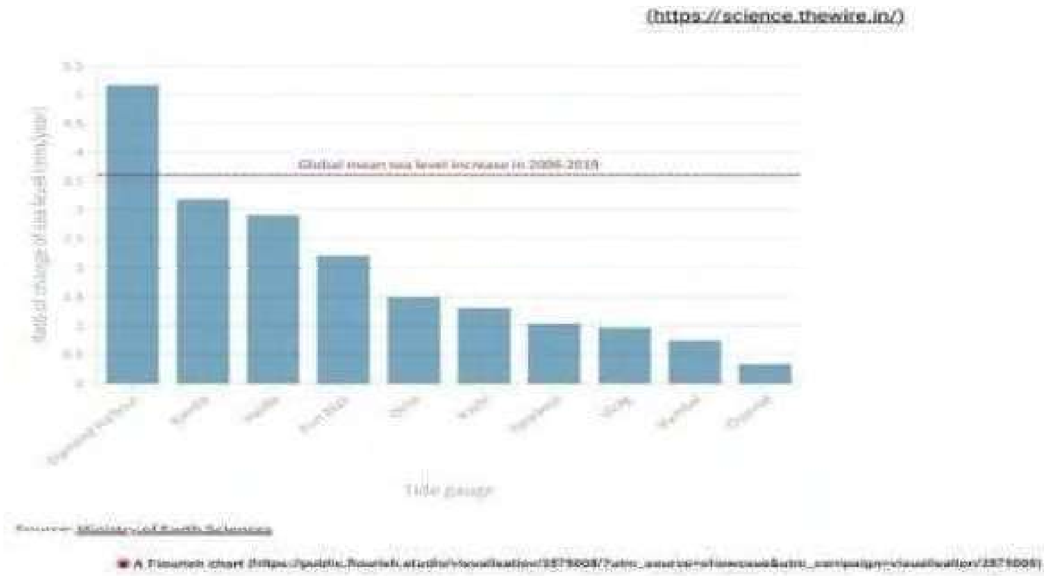
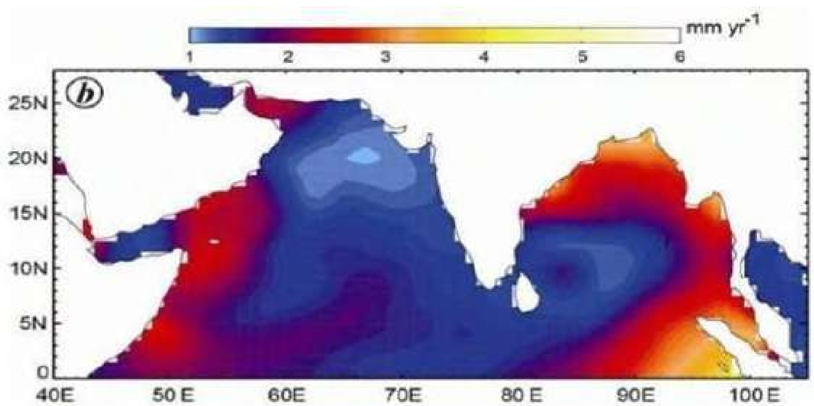


Figure 2.40: RSLR rate at different places in India [MOES]



a, Spatial map of sea-level-rise trend (1993–2012) estimated from satellite measurements of annual mean sea-level anomalies over the north Indian Ocean (monthly mean sea-level anomalies are averaged over each calendar year to get annual means). ***b***, Sea-level-rise trend uncertainty at the 95% confidence level based on a two-sided student's t-test with the degrees of freedom = $N - 2$, where $N = 20$ (total number of years).

Figure 2.41: Sea Level Rise Trend in Indian Ocean [35]

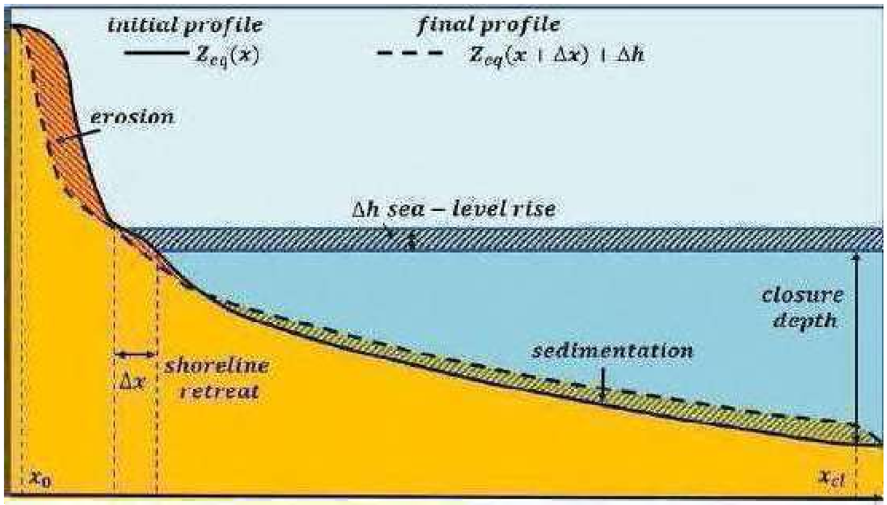


Figure 2.42: Brun's rule regarding shore shifting for SL

Study was conducted near the beach segments close to all the 13 Indian major ports and maximum shifting of shoreline was projected at places nearby Mumbai (Patil et.al. 2020) [83]. Recently Probabilistic Coastal Recession (PCR) model or its derivatives has been applied in place of Brun's Rule in Japan, Australia, Netherlands, Sri Lanka, France, Spain etc. (Dastgheib et al. coastaleng.2021.104079) to obtain projections of coastline recession. It is not known if the PCR model (Ranasinghe et.al. Climatic Change 110, 561–574,2012) has been applied to coast of Mumbai to find shoreline changes, which may show a different status of coastline recession.

2.41 Summary

In case high-emissions RCP 8.5 scenario referred as "business as usual" is going to continue, rise in sea level can indeed be huge. Each RCP provides only one level of radiative forcing out of many possible pathways. RCP 4.5 is the most plausible starting point situation (no climate policy) taking the exhaustible properties of non-renewable energies into account. RCP8.5 scenario is ridiculed in recent years as reduction of fossil fuel not started by many countries. RCP8.5 can't be the no-climate-policy scenario, as its assumptions differ from other RCPs (*Wilbanks et al.2020*) [68].