A Paradox in Environment and Economic Development in the context of probable impacts due to Sea Level in Low Elevation Coastal Zones: The Case of Surat City

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Abstract:

Low Elevation coastal zone (LECZ) houses almost 13% of World's urban population and two thirds of world's large cities with more than 5 million population. These areas are not only environmentally delicate, but also house some of the most important economic activities (McGranahan , Balk and Anderson 2007). According to IPCC predictions, sea level can rise between 8-88cm between 2000-2100 AD (IPCC,2001). A 1m rise in sea level will have massive impact on land up to 10m above current MSL. With the increase in tendency among people and development to move towards the coasts, sea level rise is a serious issue to be considered in developmental decisions. For a coastal area that is prone to sea level rise, there should be serious consideration in developing coastal areas that should take into account the relationship between anthropogenic activities within these zones and environmental impacts of sea level rise. We tried to identify micro indicators and its characteristics and their relations to macro indicators in terms of sea level rise. It has been found that the anthropogenic activities along coast can be classified as those, which are highly vulnerable to SLR while others that aggravate the process. The most important factor that determines the decision making of setting up of an economic activity in this zone is TIME. Plotting the unique resource of the region and gradual threat, against time, we arrive at most critical years for the uniquely identified activity of the selected region. This is demonstrated through a case of Hazira, Surat. Hazira is the most important industrial investment region in Gujarat and in 2003 accounted for 11% of state domestic product. The paper argues for coordination between various stakeholders both at micro and meso levels. It calls for policy intervention at various levels. Therefore the most important aspect is to look into the role of government and governance in addressing the situation and to evolve suitable framework and policies that would prevent some of the possible damage scenarios analyzed in the paper.

Low Elevation Coastal Zones (LECZ) and Economic importance: Introduction

The coastal zone is a transition between the land and the sea. It is one of the most fragile, complex yet a productive ecosystem. Bestowed with enormous resources that are both living and non-living, coastal areas have higher potential for recreation as well as to harness non conventional energy resources such as wave and wind energy. This is a zone of dynamic activity, both complementary and conflicting to each other (Joliffe 1988).

LECZ is a continuous area along the coast that is less than 10m above sea level- represents two percent of the World's land area but contains 10% of its total population (ie., over 600 million people) and 13% of its urban population (360 million people). Almost two-thirds of the world's large cities with more than 5 million inhabitants are at least partly within this zone. Low income and middle-income nations have a higher proportion of their urban population within this zone than higher income nations. The least developed nations, on average, have higher proportion of their total population in this zone than high-income nations; they also have nearly twice the proportion of their urban population in this zone, compared to high-income nations. Both urban disasters and environmental hotspots are already located disproportionately in low-lying coastal areas. Climate change therefore, will increase the risk of both (McGranahan, Balk and Anderson, 2007).

India has a coastline of about 7500km, its peninsular shape jutting into the Indian Ocean. The western coastline has a wide continental shelf with an area of about 310000sq km, nearly twice that of the eastern shelf. Beaches occupy 55% of Indian shores. Uses and activities on urban waterfront and back beaches areas which support/accommodate activities of high economic value require more attention than near shore and offshore zones. Coastal activities may be classified according to their relation to the coast (Clark 1977)

- Land based
    - a. Coast –dependent
        - i. Ports and harbors
        - ii. Oil terminals
        - iii. Paper and pulp mills
        - iv. Metallurgical plants
        - v. Fish processing
        - vi. Power plants
    - b. Coast preferring
        - i. Urban, commercial and residential development
        - ii. Tourism and beach recreation

   iii. Agriculture

c. Coast independent

   i. Defense

   ii. Any other industry not dependent on sea

- Water based

   a. Ocean thermal energy conversion

   b. Mining for aggregates and placers

   c. Navigation

   d. Naval defense

   e. Water sports

   f. Fishing

   g. Mari culture

   h. Dredging and land reclamation

The impact of global warming- induced sea level rise due to thermal expansion of near surface ocean water has great significance to India due to its extensive low lying densely populated coastal zone. Industries, agriculture, fisheries, tourism, human settlement, freshwater resources are among few sectors that are vulnerable to climate change. India, has been identified as one amongst 27 countries which are most vulnerable to impacts of global warming related accelerated sea level rise (UNEP, 1989).

Sea Level Rise

The projected increase in global warming by the middle of the next century ranges from 1.5 to 4.5 deg C. (Barth and Titus, 1984). Sea level changes can be of two types: **(1)** changes in the mean sea level / Eustatic and **(2)** changes in the extreme sea level/local. The former is a global phenomenon while the latter is a regional phenomenon. (Unnikrishnan, Kumar, Fernandes,Sharon, Michael, Patwardhan, 2006), These impacts will depend not only on local geomorphologic factors but also on the climatic fluctuations and the coastal practices of the region. While the eustatic rise in sea level is uniform the rise in relative sea level and consequent impacts are essentially regional. The choice of response will also necessarily have to be location and resource specific, given the variations in these effects in the socio economic characteristics of the region and in the response capabilities of nations.

A rise in sea level represents a potential threat to existing coastal economic, social and environmental systems. The effects of sea level rise can be classified into four broad categories: Physical, ecological/environmental, socio economic and legal & institutional. Increasing trade and market driven movements, often supported by government incentives are still attracting people to the coast. This has also led to an increase in net in-migration to these zones world over. The main driver of city expansion (or stagnation or contraction) is where new or expanding profit seeking enterprises choose to concentrate (or avoid). This is also largely true for how each urban centre develops - as the localities or districts within and around the urban centers with the most rapidly growing population is associated with where new or expanding economic activities concentrate (torres, Alves, Aparecida de Oliviera, 2007). Attempts by government to change the spatial distribution of their urban population or of the economic activities that underpin urban development can impose high economic costs - as this undermines the economic success of enterprises. Therefore, it is important to look at the vulnerability of both natural resources and the human activities that are dependent on it.

Broadly SLR will affect land, people and their activities and natural environment and ecosystem. Potential land lost to SLR is due to inundation and erosion. This is mainly because there are large areas within 1 m elevation of present high water partly reflecting the extensive areas of natural and claimed intertidal habitat around the world's shores. Above 1m elevation, land area is an almost linear as a function of elevation, although the threatened area does diminish slowly with elevation. Over 5x10^6 sq km lies within 10m of the mean high water levels and 8x 10^6 Sq km lies within 20m of mean high water levels across the globe (Brooks,Nicholls,Hall,2006).

Erosion is the physical removal of materials from coastal areas which is likely to increase as a result of SLR .The simple 'rule of thumb' from the Bruun Rule suggests that erosion is roughly 100 times the rise in Sea level (Nicholls,1998). Inundation is likely to be more important process than erosion (Walkden and Hall, 2005). Population and activities are under risk from inundation and flood. A 1995 estimate puts almost 60 million people to live within 1m and 275 million within 5m from mean sea level. These figures are projected to increase to some 130 and 410 million respectively by the end of the 21st century (Nicholls, 2004). Therefore, assuming a constant population or spatially uniform population growth, roughly 10% of the World's population could be displaced by a 10m rise in Sea level and 15% of the World's population could be displaced by a 20m rise in Sea level. When trends are extrapolated to the decade of 2080s and assuming to be fixed thereafter, 0.9 to 2.6 billion people might have to be relocated away from land threatened by inundation.

SLR- India and Gujarat

With the above references it is necessary to look at how India might be affected due to SLR and identify the vulnerable areas. Mean-sea-level data from coastal tide gauges in the north Indian Ocean were used to show that low-frequency variability is consistent among the stations in the basin. Statistically significant trends obtained from records longer than 40 years yielded SLR estimates between 1.06–1.75 mm yr−1, with a regional average of 1.29 mm yr−1, when corrected for global isostatic adjustment (GIA) using model data. These estimates are consistent with the 1–2 mm yr−1 global sea-level-rise estimates reported by the Intergovernmental Panel on Climate Change (Unnikrishnan, Shankar,2007). Mumbai, Kochi, and Vishakhaptanam showed an increase of about 1 mm yr−1 and Chennai showed a slight decrease (Unnikrishnan, 2007).

Past observations on the mean sea level along the Indian coast indicate a long-term rising trend of about 1 mm year-1 on an annual mean basis. However, the recent data suggests a rising trend of 2.5 mm year-1 in sea level rise along Indian coastline. Model simulation studies based on an ensemble of four A-O GCM outputs indicate that the oceanic region adjoining the Indian subcontinent is likely to warm up at its surface by about 1.5-2.0oC by the middle of this century and by about 2.5-3.5oC by the end of the century. The corresponding thermal expansion related sea level rise is expected to be 15 to 38 cm by the middle of century and 46 to 59 cm by the end of the century (Lal & Aggarwal, 2000). This simulated rise in sea level by 46 to 59 cm along Indian coastline is comparable with the projected global mean sea level rise of 50 cm by the end of this century and may have significant impact on coastal zones of India.

Table 1:Potential effects of 1m Sea Level Rise on India's coastal area and population (source: TERI,1996)

	Coastal Area (million Hectare)			Population (millions)		
State/Union territory	**Total**	**Likely to be inundated**	**Percentage**	**Total**	**Likely to be affected**	**Percentage**
Andhra Pradesh	27.504	0.055	0.19	66.36	0.617	0.93
Goa	0.37	0.016	4034	1.17	0.085	7.25
Gujarat	19.602	0.181	0.92	41.17	0.441	1.07
Karnataka	19.179	0.029	0.15	44.81	0.25	0.56
kerala	3.886	0.012	0.3	29.08	0.454	1.56
Maharashtra	30.771	0.041	0.13	78.75	1.376	1.75
Orissa	15.571	0.048	0.31	31.51	0.555	1.76
Tamil Nadu	13.006	0.067	0.52	55.64	1.621	2.91
West Bengal	8.875	0.122	1.38	67.98	1.6	2.35
Andaman and Nicobar Islands	0.825	0.006	0.72	0	0	0
Note: Coastal Areas and population are based on the 1981 and 1991 census						

Table 2: Loss of land in various states of India, (source: Lal and Aggarwal,2000)

State	Cultivated land	Cultivable land	Forest land	Land not available for agriculture
Gujarat	0.03	0.08	0	0.89
Maharashtra	0.39	0.21	0.09	0.31
Goa	0.65	0.03	0	0.31
Karnataka	0.51	0.13	0.13	0.23
Tamil Nadu	0.39	0.39	0	0.21
Orissa	0.68	0.15	0.05	0.12
West Bengal	0.74	0.04	0	0.22

The most vulnerable areas along the Indian coastline are the Kutch region of Gujarat, Mumbai and South Kerala. Deltas of rivers Ganges (West Bengal), Cauvery (Tamil Nadu), Krishna and Godawari (Andhra Pradesh), Mahanadi (Orissa) and also the islands of Lakshadweep Archipelago would be totally lost (Lal and Aggarwal, 2000).

Table 1 indicates that by 2050 & 2080 if the sea level would rise by 38 and 59 meters respectively, then Goa would lose maximum percentage of its land and its population ie 4.34% and 7.25% respectively, while in the state of Gujarat the increase in sea level will affect maximum coastal area and almost 0.5 million population. Though the population that will be affected is not too high compared to the rest of the states, the type of land that will be affected indicates larger economic vulnerability of state of Gujarat compared to rest of the states. While comparing the four main categories of land such as cultivated land, cultivable land, forest land and land not available for agriculture, it could be noted that state of Gujarat has a larger share of land which is under non agricultural use that is highly vulnerable. Gujarat being an industry driven economy, this rings a red alarm.

The vulnerability of Indian coastline can be defined based on majorly three factors: Land, Population and Natural resources.

Like any other developing countries India is currently facing increasing stresses and shocks as a consequence of cumulative environment change driven by population growth, urbanization, industrial development, trade and capital flows, liberalization of transnational corporation activity and lifestyle, unsustainable growth leading to degradation of coastal zones and eco-system (Lal and Aggarwal, 2000). Human activities such as coral mining, land reclamation, high ground water extraction, sand dune removal, sand mining, removal of coastal vegetation due to high coastal population for the construction of coastal infrastructure makes these areas more vulnerable to sea level rise.

Land is an important economic asset. Land becomes a very crucial parameter as it supports human life and human activities. Therefore, inundation of land can directly affect the population and their activities generating income. It is also important to note at this juncture the importance of low elevation coastal zones, which account for 2% of the World's land

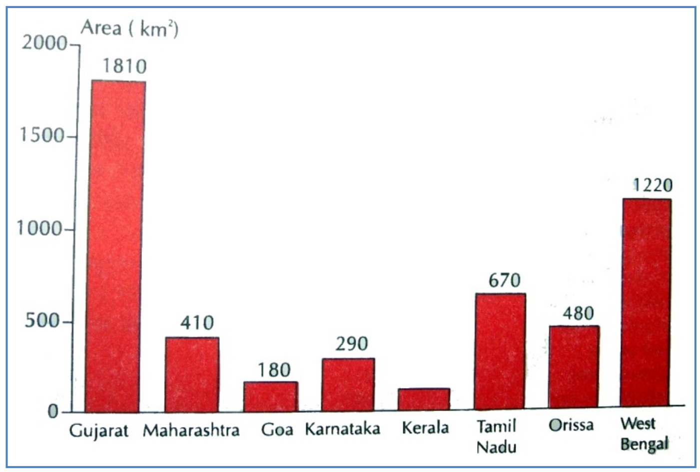


Figure 1: Area at risk, Indian Coastal States. (Source: TERI,1996)

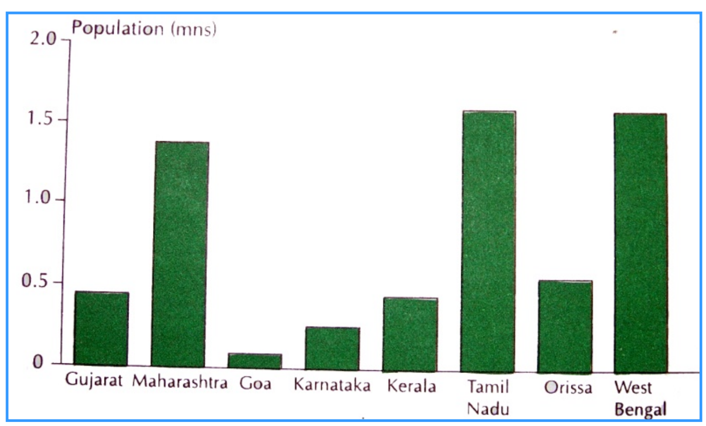


Figure 2: Population at risk, Indian Coastal States. (Source: TERI,1996)

area but contains 10% of the World's population and 13% of the World's urban population.

Nine of the Indian states, Union territories and island groups form the coastal areas of ecological and economic importance in the country. In addition to their importance for livelihood of the people living in these areas, they are also strategic locations for industrial development. (JNU 1993). Currently, total area of 5763 km2 of coastal states of 1.4 x 10^6 Sqkm or 0.41 % of the total coastal population lie within LECZ.

Study Area: Criteria for Selection and Characteristics

In India of the total population 4.6% is estimated to be at risk (JNU,1993). The most vulnerable areas being coasts of Gujarat, Northern Malabar, Kerala, deltas of river Cauvery, Krishna, Godavari, Mahanadi and Ganges.

Coastal zones have multiple uses including fishing, aquaculture, heritage areas, natural reserves, forestry, navigation, defense, power generation, sand mining, human settlements, disposal of wastes, tourism and recreation. In India, with economic liberalization, each state is competing for investment and certainly coastline adds to its advantage due advantage for port development. The exclusive Economic zone extends up to 2.02 million square kms.

Statistical analysis shows that though West Bengal, Tamil Nadu and Maharashtra are most vulnerable in terms of population, Gujarat state has highest land susceptible to Sea level rise (JNU, 1993). However, considering the contribution to country's GDP and the level of economic activity and investment in its coastal region, Gujarat state becomes the apt example to consider for the study purpose. Gujarat state has the longest coastline of 1663 km length, which is highly vivid and distinct from others in terms of geomorphology, natural resources and human activities. This makes the Gujarat coast even more sensitive to impacts due to climate change.

Gujarat Coastline is little more than 20% of the Indian coastline. It has a continental shelf of 1,65,000 Sq km, which is 35% of the Indian continental shelf. There are two major indentations - the Gulf of kachch and Gulf of Kambhat accounting for 60% of Indian coastline. According to GEC studies, the coastal and marine environment of Gujarat support rich fisheries, coral reefs and mangrove vegetation on creeks, estuaries and mud flats around the coast. The coral reefs in Gujarat are in the Gulf of Kachch covering about 150 Sq km in about 15 of the 40 odd islands. The mangroves cover a large area of about 1000 Sq km. The best patches are in the Indus deltaic region of western Kachch, accounting for nearly 80% of the mangroves in the state.

For the purpose of identifying the area for study three major parameters have been defined. These include:

1) Geomorphology
2) Ecology / Natural resources
3) Human activities

Being one of the most industrialized states of India, Gujarat has been following a development strategy that had a clear focus on industrialization and urbanization. In the environmental front, ground water situation appears more serious than any other indicator. Salinity affected areas have increased and area covered under mangroves has shrunk. The last four decades have seen growth in heavily polluting industries along the golden corridor. The saturation of the golden corridor has shifted the attention to the coastal zone. It is emerging as the prime mover of economic growth, not just for the state but also given its role as a gateway for hydrocarbons, for the Nation. Oil terminals, storage and berthing facilities and refineries and ancillary units are being set up rapidly. Special economic zones, road networks, habitation facilities and desalination units are being set up. From the three parameters cited above two areas weigh equal importance ie., Kutchh and Surat Coast. The coast of Surat has been taken up for the detailed study. Hazira being highly industrialized which shares almost 11% of the Gujarat's GDP has been selected for the detailed analysis.

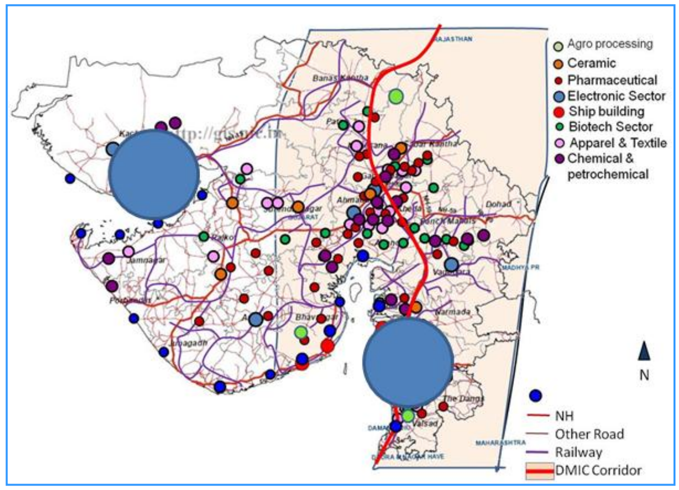


Figure 3 : Industrial nodes in Gujarat, Most vulnerable areas highlighted in blue

Methodology and Analytical framework:

The methodology adopted is a case substitution type. It is worked out in five stages as mentioned in the diagram below:

Selection of the site is based mainly on three factors such as geomorphology, natural resources and economic importance. Within the site, resource unique to this area and activity dependent on the unique resource has to be identified. Based on the SLR scenarios, activity Vs time graph and resource Vs time graph are plotted to identify the critical years for the selected site. Based on the critical years economic loss in terms of GVA(Gross Value Add) is calculated to highlight threats faced by the selected site. Further, address micro level policy options to counter the issue.

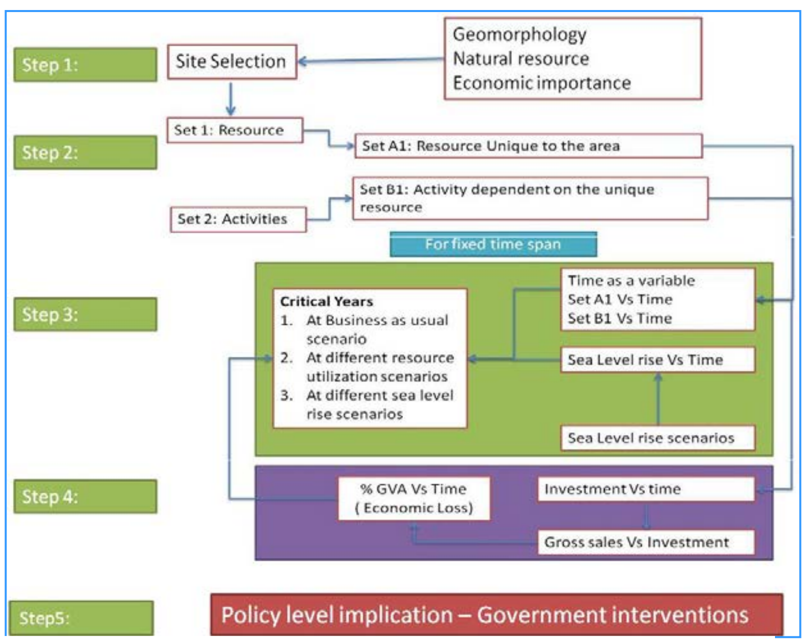


Figure 4: Analytical Methodology

The analytical framework has been worked out based on various assumptions, which have been discussed below.

After identifying the area to be studied upon, suppose we say an area of X Sq km, selected based on the vulnerability criteria set:

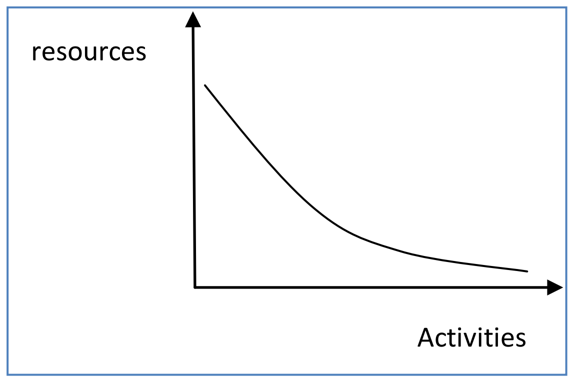
1. Geomorphology
2. Natural resources
3. Economic activities contributing to state/national GDP.

Let us assume two distinct sets A and B. Set A would consist of all identifiable/ significant economic activities taking place within the selected area A. Set B includes resources of an area on which the activities located in the area depend on. Representing it mathematically,

Set A={X II X is the kind of identifiable economic activity}

Set B= {R II R is resources on which activities of an area depend on}

It can be observed that as the number of activities increases with time, the tendency to consume resources increases leading to depletion of the resources. The time taken to regenerate the resources will be comparatively less compared to the rate at which it will be consumed.



Graph 1: Resource Vs Activity

The Subsets:

In turn the above mentioned sets , namely Set A and Set B , can be further bifurcated into Set A1, Set A2 and Set B1, Set B2 respectively.

Lets Assume Set B1, consisting of resources both natural and man-made that are unique to the area of study namely X. And B2 to be the set of resources excluding the ones that are unique to this area. Similary, Set A1 consisting of activities unique to the area and Set A2 remaining activities of the area.

Set B1 = { i II i is the resource unique to the area X}

Set B2= Set B – Set B1

Set A1 = { j II j is the activity unique to the area}

Set A2 = Set A – Set A1

The Threats:

Location theories give a theoretical framework for studying the location decisions made by firms and households based on transportation cost and spatial differences in the accessibility of inputs and markets for outputs. There are a number of factors influencing these location decisions (Erdman,1991:Murphy,1989). Krugman(1991) in an influential work has summarized five factors :

- Costs of production and marketing i.e all transaction costs inclusive of transport costs, local wages, taxes,subsidies and incentives.
- Economies of scale
- Activity specific backward and forward linkages,proximity to buyers and sellers and local amenities
- Innovation and knowledge spill over
- **Unpredictable chance events and historical accidents.**

But there is always a risk, external in character for conducting an activity in a particular place. This could be classified as threats. Therefore, let us assume a set C which includes all the threats (majorly due to natural disasters) in a particular area. Here we consider only the threats due to natural hazards, as these are generally not addressed by classical location theories. Today, with climate change and its effects posing a major threat to many parts of the globe, this factor becomes very significant. Therefore,

Set C = Threats to an area

Set C1= Threats to activities located in that area

Set C2 = Threats to resources of the area.

But threats to resources could eventually affect the activities located in the area that are dependent on the resources. It is also important to bifurcate these threats into sudden threats and gradual threats. Climate change induced sea level rise can be classified under the category of gradual threat, while storm surges and floods due to the same phenomenon falls under the category of sudden threats.

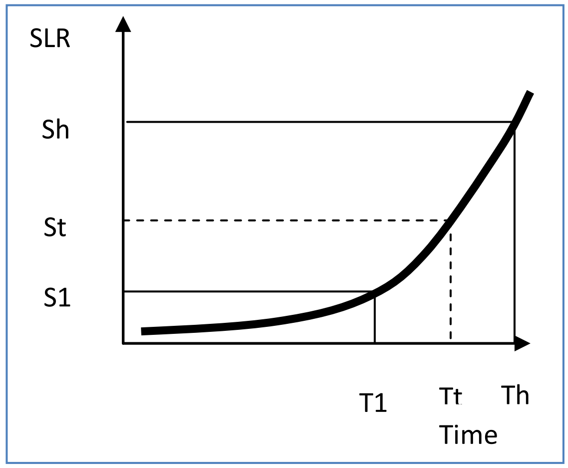
This argument brings out a major variable in our analysis, ie Time(T). An incident can be classified as sudden or gradual depending on Time T. Any decision on mitigation, adaptation or prevention depends on Time and impact. Therefore, T becomes crucial.

From the above framework we come down to majorly 3 factors:

1. Resources unique to the area
2. Activities unique to the area (due to unique resources)
3. Sea level rise – a gradual phenomenon
4. Time T

Now if we try to relate each of these above considered factors to each other and plot them against the time T, we get graph 2 & 3 as given below:

SLR Vs Time



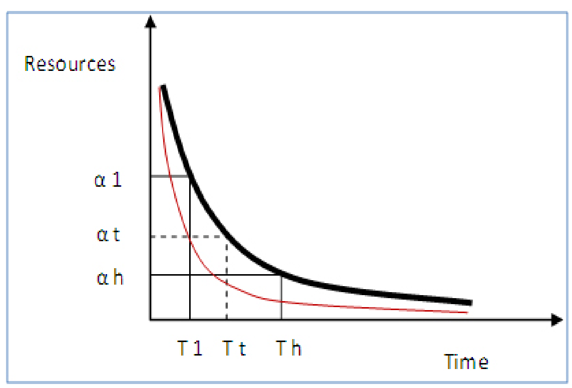
Graph 2:Sea Level rise Vs Time

Sea level rise is not a one-time phenomenon. Sea level changes can be of two types: (1) changes in the mean sea level/Eustatic and (2) changes in the extreme sea level/local. The former is a global phenomenon while the latter is a regional phenomenon.(Unnikrishnan, Rupa, Fernandez, Michael and Patwardhan, 2006). These impacts will depend not only on local geomorphologic factors but also on the climatic fluctuations and the coastal practices of the region. While the eustatic rise in sea level is uniform the rise in relative sea level and consequent impacts are essentially regional or location specific. Primary effects of rising sea levels will be increased coastal flooding, erosion, storm surges and wave activity. Already existing vulnerability to flooding and storm surges could be aggravated by : erosion and higher water levels(Titus 1986).

As mentioned above, the information regarding the changes in Sea level at a local level becomes difficult to analyse due to lack of data. Therefore, considering the levels to be the same as that of Eustatic levels, we plot SLR against Time (Graph 2).

S1 is the current level of sea at time T1. At Th, with a rise from S1 to Sh, an area gets totally inundated by SLR. Therefore, at time Tt, St becomes the threshold level that an area can withstand the direct effects due to SLR.

Resource Vs Time



Graph 3: Resource Vs Time

Activities **j1** to **jn** which are located in an area X with a resource base i1 to in. Assuming these activities to be dependent on the resources, Lets say,

Current stock of resources = α

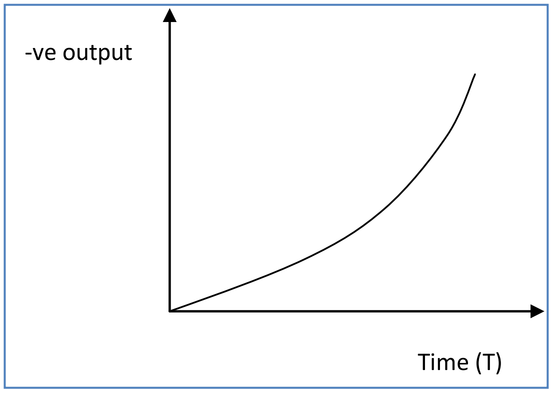
Rate at which it gets depleted = γ

At a time T1 the resource base is α

Assuming a minimum requirement of stock for locating activities be α h, which at the current rate of depletion, reaches that level by time Th. Therefore the optimum condition is reached at Tt with a stock of α t. This time Tt is a very crucial moment.

Negative Outputs:

Now, lets assume that an Activity A consumes resources Ri to Rj where I and j are variables, produces not only outputs that are useful (positive outputs), but also byproducts such as emissions, pollutants etc (negative outputs) that aggrevate the phenomenon of SLR. This increases with time, thereby increasing the rate at which Sea level rise would increase.



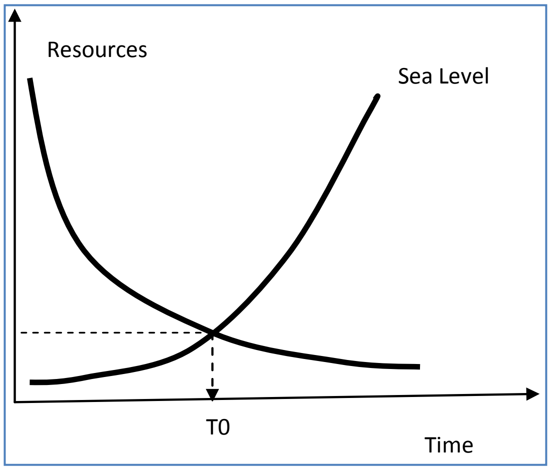
Graph 4: Negative Output Vs Time

Therefore it becomes important to know time T0. After the time T0 the increase in sea level rise could affect the resources that are present, affecting the activities in the place. At T0 area may be inundated due to sea level rise.

Understanding T0:

Determining T0 becomes the most important in determining the impact of Sea Level rise on economic development of a region. For this we need to define the relation between Set A1 and Set B1 with Set C. Ultimately pointing out at the policy initiatives required to reduce risks due to SLR in low elevation coastal zones.

The rate at which the number of elements of set A1 increases affects the rate at which the number of elements of set B1 decreases. Therefore graph 2 becomes (represented by the red line in graph 6):



Graph 5: Resource and Sea Level Rise relationship with respect to time

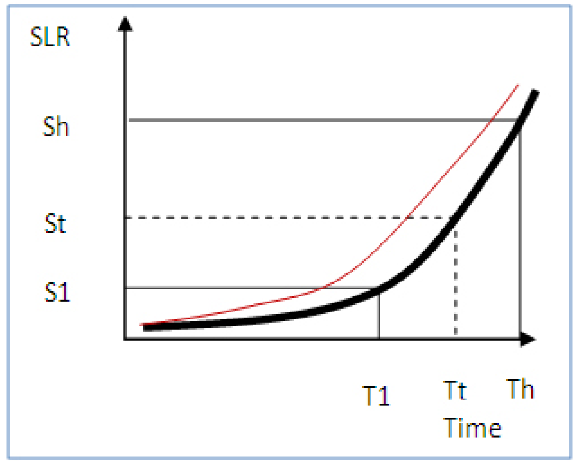
And as resources depletes at a faster rate the number of elements in set A1 starts reducing.

These activities may result in aggravating the impact due to sea level rise including both physical and economic impact. This could possibly through :

1. Production of negative outputs that pollute air and water
2. Due to location of these activities that aggravate the geography of the region.
3. Affects the natural barriers that can dampen the effects due to sea level rise like mangroves.

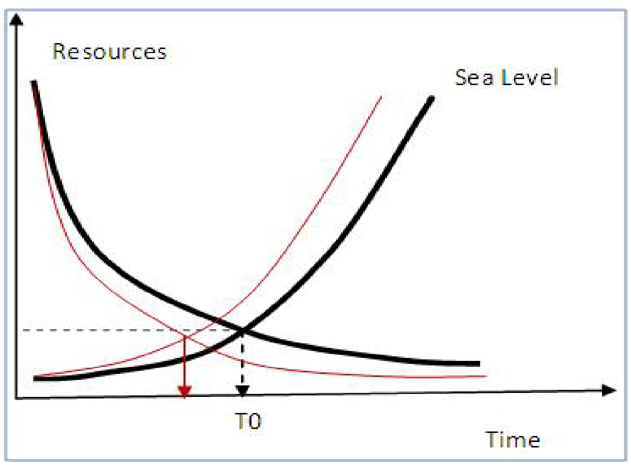
As a result T0 shifts further towards the right of the graph:

Therefore, while locating an activity within a low elevation coastal zone it becomes very important to take care of the most important factor Time with respect to Sea level rise. What is important is not just by how much the sea level rise will increase but by when does the sea level rise? This will also depend on the activities and the natural coping mechanism that are present in a specific site 'X'. The implications of these will depend on various policies and practices related to locating activities by the coasts especially in low elevation coastal zones.



Graph 6: Increase in rate of Sea Level Rise as the activities increase

The methodology followed is case substitution type. For the same purpose it is required to identify a geographic area that fits into the proposed framework. Here the geographic area of Hazira, Surat has been taken into consideration



Graph 7: TIME , the crucial factor

The Case : Hazira, Surat.

Hazira is one of India's and Gujarat's most significant industrial concentrations, located along the western seacoast just off the city of Surat. The Hazira area has a large concentration of nearly 20 medium and large industries with a combined capital investment of over Rs. 350,000 million(2003). This is expected to rise to over Rs. 500,000 million (2025) of investment in the near future and represents nearly a third of the industrial

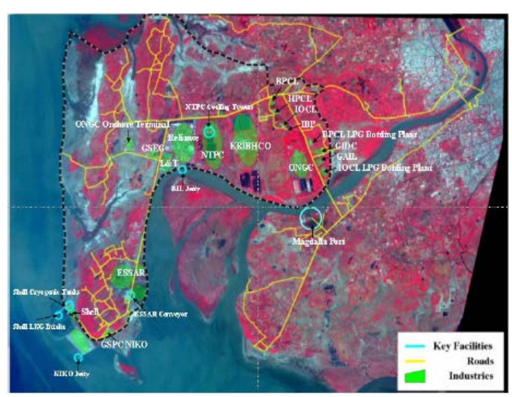


Figure 5: Satellite image of Hazira region. (Source: CEPT,2004)

investment in Gujarat and a tenth of its economic output. The Hazira area has many strategic advantages, including easy access to the sea, a major trunk railway network; ensured energy supplies; connectivity to a major city and trading centre with well-established institutions of commerce, industry and education.

During the last two decades (1981 to 2001) Hazira has witnessed phenomenal growth in terms of industrial activities, resulting in mammoth investment in very strategic areas. With better linkage to the Golden corridor and the available sea front, it has attracted few of the major industries such as ONGC, KRIBHCO, L&T, ESSAR etc to set up their industries in this area. Hazira is a classic example of port and infrastructure lead development, a stand taken by Gujarat government to promote industrial growth in the state.

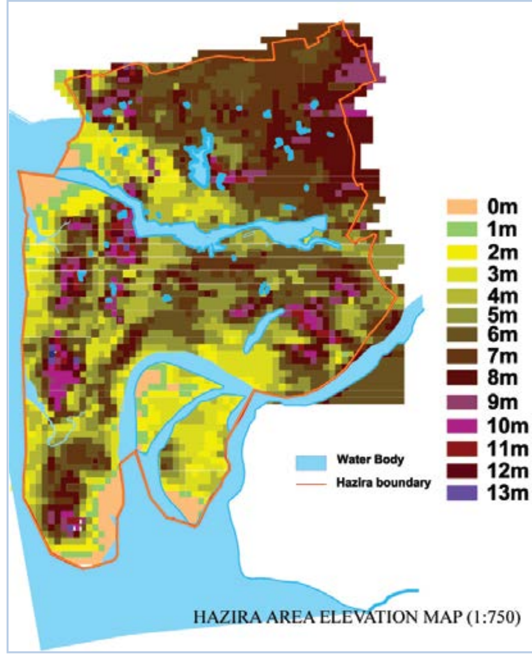


Figure 6: Hazira Topography

Contour height	Total land
1-3m	32
4-5m	50
6-7m	54
8-9m	25
10m and above	7

Table 3: Total land in Hazira under various contour levels

The physical boundary of Hazira is defined by waterfront on three sides. On the southern side, flows the river Tapi, on the western part is the Arabian Sea and on the northern part is the Tena creek. On the eastern part it is linked with Surat city. The river Tapi flows throughout the Surat district and merges the Arabian Sea on the southern part of Hazira region. At the southern part it bifurcates into two branches near the village Kavas - Limla. The right branch flows towards the agricultural lands of the Mora and Suvali villages making an island known as Gajrabet & Aliyabet. This branch of river is navigable and useful for small boats, powerboats, barges and ships. However, navigability of this section has been reduced.

Hazira has a total coastline of 30 kms starting from southern tip (Hazira village) upto the northern part of Tena creek. The Arabian sea forms two sea water insurges in the villages of Rajagiri and Suvali along its coast. This causes flooding during high tide and monsoons. The villages Suvali, Mora, Vansva, Damka, are affected due to this (CEPT,2004). Area selected for study consists of notified area of Hazira measuring 168 Sqkm. The whole area has been subdivided into unit squares of approximately 0.5 Sqkm each. But the total land available for development after reducing water bodies and wetlands is 106 Sqkm.

The Government of Gujarat has identified Hazira as a thrust area for major industrial development. The location advantages of this area have attracted several large and medium scale private, public and joint sector industries. Most of these units use natural gas as their basic resource. Approximately 20 large and medium sized industries are located in Hazira. It houses industries like KRIBHCO, L&T, ONGC, IOC, NTPC, Reliance, ESSAR etc came into existence.

The bulk of the existing industrial plants are located along the river or seaside to enable access to the water for transportation. However, this has placed them directly in the plain, inter-tidal zone or along the CRZ – exposing them to considerable risk to water related hazards. Two major driving forces for industrial development in this area are availability of cheap land and natural gas via ONGC's offshore pipeline from Bombay High. The ready availability of gas is expected to enable the significant expansion of existing facilities and development of new medium and large-scale industries in the area in future.

In order to service these industries, two ports at Hazira and adjoining port of Magdalla, significant investments in terms of port and berthing facilities and emphasis on development of better infrastructure facilities has been addressed in the master plan prepared for 2025 (CEPT,2004).

The estimated current capital investment in the region is over Rs 365,000 million. Close to Rs 190,000 million of proposed investment is awaiting environmental clearance. In addition to this, a significant volume of investment is expected to flow into the Hazira area with the expansion of current industrial unit capacity and in response to the new multiple purpose all weather Shell port that is being developed. The projected total investment is expected to exceed Rs 550,000 million.

Using the Incremental Capital Output Ratio (ICORs) for the Gujarat economy, the estimated gross value of sales of the current investment in the Hazira is close to Rs 650,000 million (at current prices). This is expected to rise over Rs 1,000,000 million once new units in the pipeline are established. Using a conservative estimate of 20 percent of gross value added of gross sales, the current Gross Value Added (GVA) could be estimated at Rs 130,000 million. Future the GVA could rise to close to Rs. 200,000 million.

This would place Hazira at close to 27 percent of the industrial investment in Gujarat and about 11 percent of the GVA of the state. This massive industrial concentration is, therefore, critical not only to Gujarat but also to the Indian economy.

The bulk of the Hazira peninsula consists of inter-tidal region and coastal plains with low ridges on which traditional settlements are located. Before its industrial development and intervention of laying of roads and other structures, there would have been a largely unimpeded flow of tidal waters in and out of Hazira as can be observed from topography map from the Survey of India (CEPT, 2004).

The physical consequences of sea level rise can be broadly classified into three categories: shoreline retreat, temporary flooding and salt intrusion. The most obvious consequence of a rise in sea level would be permanent flooding (inundation) of low-lying areas. Many coastal areas with sufficient elevation to avoid inundation would be threatened by a different cause of shoreline retreat: erosion. It also alters the relationship of shore profile to water level. With this context it is important to look at the existing hazard risks of Hazira.

Table 4: Land under direct and indirect impact due to 1m Sea Level Rise

100cm rise: Direct effect on 5m and indirect effect on 5-10m			
Effect	Current area	Current industries	Future industrial development
Direct effect	82	24	32
Indirect effect	86	31	38
50cm rise: Direct effect on 2.5m and indirect effect on 2.5-5m			
Effect	Current area	Current industries	Future industrial development
Direct effect	32	8	11
Indirect effect	50	16	21
10cm rise: Direct effect on 1m and indirect effect on 1-2m			
Effect	Current area	Current industries	Future industrial development
Direct effect	13	8	11
Indirect effect	18	8	11

The above table shows that a 1m rise in sea level would have a dangerous impact on the existing industries and infrastructure as well as the proposed ones. But unlike other hazards, Sea level rise is not a one-time process it is a gradual phenomenon. Therefore Time becomes an important factor for determining the impact SLR will have on the economy of a place. With the above knowledge on topography, hazard vulnerability and the resources of the Hazira region, it is necessary to work out the critical year and the subsequent economic loss. For this, two levels of analysis has been conducted one to arrive at the critical year and the other at the economic loss.

Economic Loss

In the context of rising sea level, the most clearly measurable loss is that of land submerged by inundation. To translate this physical loss into an economic value is a complex exercise because one has to choose the most appropriate measure of the value of land. It is argued that for sea level rise impact studies the relevant concept in valuing land is its opportunity cost rather than its rental or capital value. This opportunity cost is defined as the stream of future output/income/services from land. Opportunity cost is not defined in the usual sense of highest net return but refers instead to what actually occurs or is likely to occur given various constraints. Therefore in this study the economic loss is calculated based on the investments that will get affected due to loss of resource, in turn affecting the GVA from the investment.

Hazira is famous for the existing heavy industries that mainly depend on natural gas as a main source of input. However, the bulk of the existing industrial plants are located along the river or seaside to enable access to the water for transportation.

Therefore,

Set A1 = Land { the most clearly measurable loss is that of land submerged}

Set B1 = Industries dependent on serviced land for functioning

{ those located/ planned to be located along the river/sea front }

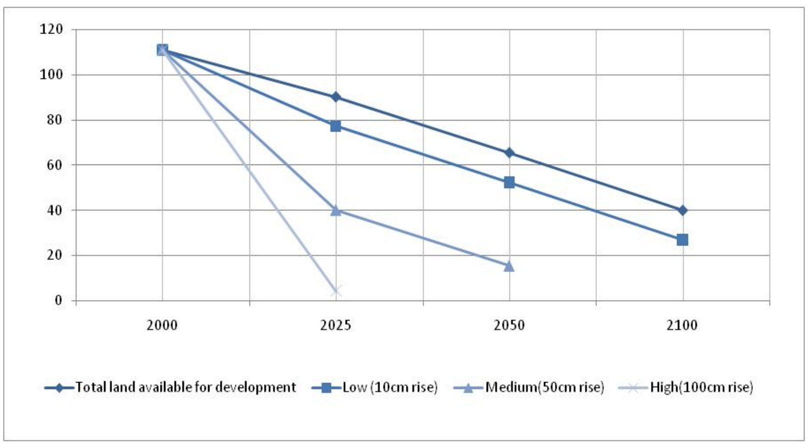
In order to know how much land will get affected by various sea level rise scenarios, it is important to look at the existing and proposed land use pattern. This is then overlaid with the contour map (with high tide line) to get the area directly affected by the two sea level rise scenarios (optimistic and pessimistic). Similarly area under industries that are currently set up and proposed to set up is also taken into consideration.

Land use map overlaid with levels have been worked out. Of the total 168 Sq Km considered for the study approximately 50% of the land are under 5m from MSL. That means 50% of the land, which is under threat from direct impact of 1m Sea level rise. Now for each of the sea level rise scenarios of low, medium and high-rise, the loss in land has been worked out. Now, with the above worked out area under land if we plot graphs of:

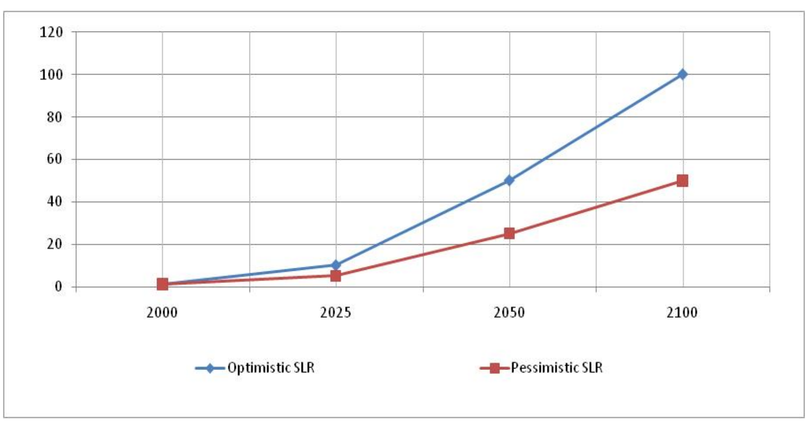
Land as a resource Vs Time and

Sea level rise Vs Time

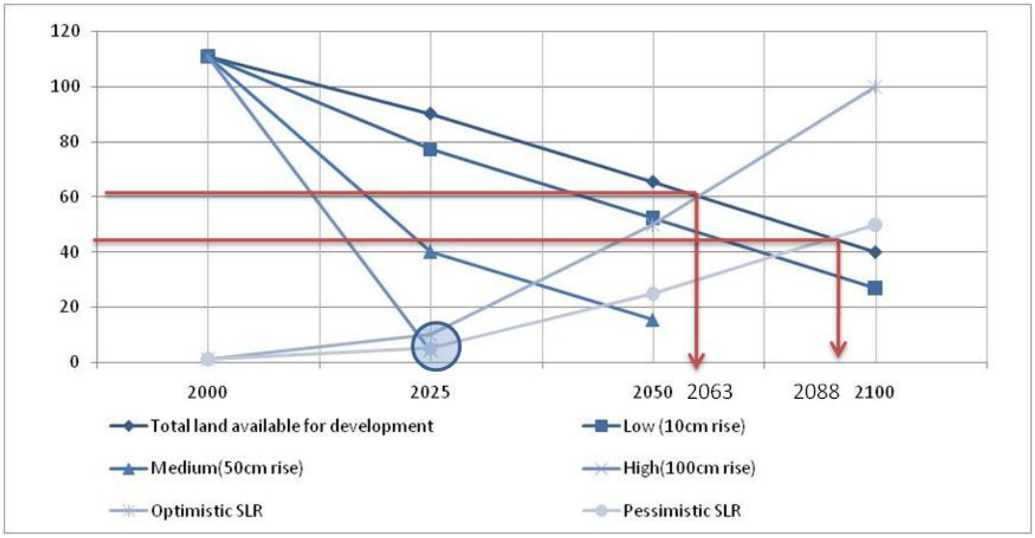
The point of intersection of both the curves gives the most critical year for investment. In the light of sea level rise any decision to invest in the area has to be given a second thought. It is assumed that it is better for the companies to invest either in a numeraire asset or establish the industry in another region with slightly altered resource base. In the current case the critical years are found to be 2063 and 2088, but 2025 is a crucial year with the current SLR predictions by IPCC. This is been demonstrated by the graph given below.



Graph 8: Land available for development Vs Time



Graph 9: Sea Level Rise Vs Time



Graph 10: Graph showing critical years for development in Hazira Notified area.

With the above found critical years, it is indeed important to find out how much economic loss will be incurred during these years under various scenarios. This is analyzed in terms of % of Gross Value Add (GVA) lost due to loss in land. GVA has been taken into consideration because valuing land at the market price for next hundred years will give a highly inaccurate and distorted figure as market value of land for next hundred years will be difficult to predict.

Table 5: Role of Hazira in the economy of State of Gujarat. (Source: CEPT, 2004)

	Current	Proposed (2025)
Estimated Value of Gross sales(cr)	64000	99000
Estimated Gross Value Add(cr)(@20% of gross sales)	12800	19800
Hazira GVA proportion of Gujarat GSDP (at current prices)	11%	16%
Proportion of Gujarat's total manufacturing investment	27%	32%

For the same purpose, three cases have been built for analyzing the loss in value of production, with a loss in unit land to impacts due to Sea level rise. The cases are built as given below:

Case 1:Assumption: Direct correlation between Land and investment (106 Sq km max available land for development excluding water bodies and other natural features left untouched)

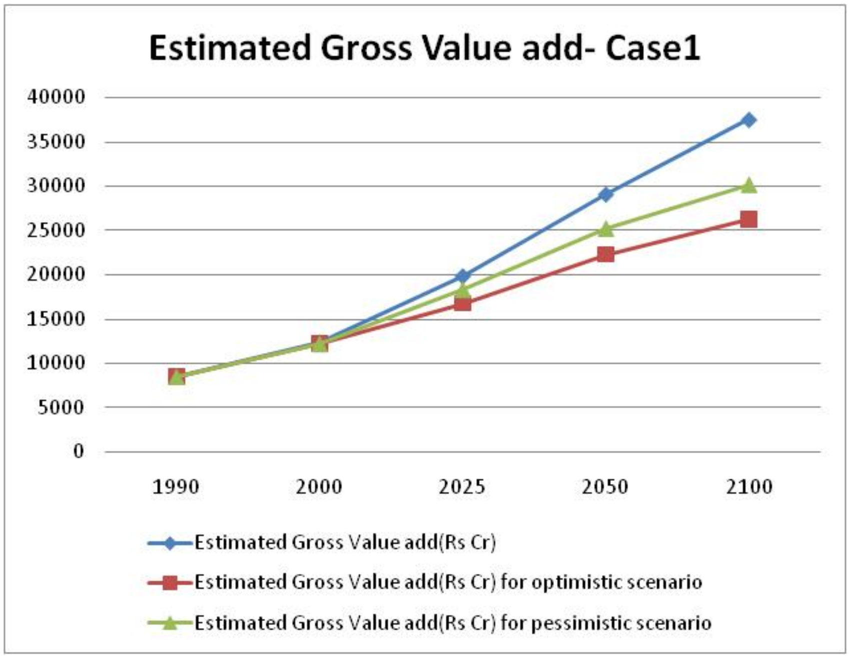
As defined towards the beginning of this chapter, the opportunity cost of land is the use it is put under. In this case the only opportunity taken into consideration is the industrial activities. Though other activities such as commercial and residential activities also add value to land, in this study it has not been taken into consideration.

Regression equation was used to project the investment (Rs Cr) for 2050 and 2100 (ref: Table 10, Annexure). This investment then gets translated into Gross sales (Rs Cr). 20% of the Gross sales is taken into consideration as Estimated gross value add (Rs Cr). In Case 1 it is a business as usual scenario. Similarly for both pessimistic and optimistic sea level rise scenarios GVA has been calculated. While calculating this area that gets affected by SLR is taken into consideration and the GVA arrived with is then demonstrated as a % to the current GVA (2000). This gives an approximate picture of loss in terms of money due to the effect of SLR on the existing and proposed industries.

By interpolating the values for 2063 and 2088, we find that more than 50% of the current GVA will directly get affected at a business as usual scenario. While, 2025 will affect almost 25% of the current GVA which when converted to real money is Rs 5000 Cr – Rs 20000 Cr. With introduction of better production techniques, these numbers tend to rise.

Loss in Cr Rs		
Year	Optimistic	Pessimistic
2025	3111	1556
2050	6076	3472
2100	9336	6127

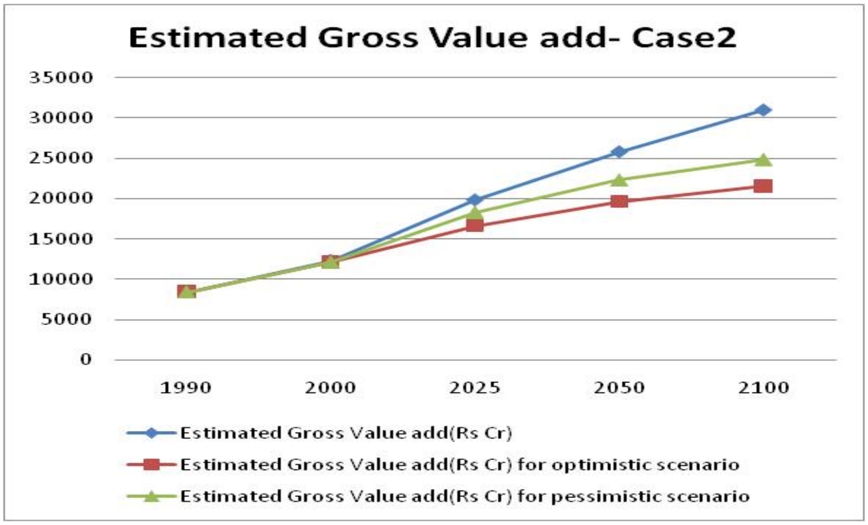
Table 6 : Case1: Economic Loss in Rs Cr at Optimistic and Pessimistic Sea Level rise Scenario



Graph 11: Case 1, GVA(in Rs Cr) affected at both optimistic and pessimistic sea level rise scenarios

But this need not be the case, as by 2025 the investors get a feel of the effects and might slowly withdraw their investments or reduce the rate at which investment is made in the region, this is described in Case 2.

Case 2: Assumption: After 2025 the investment will increase by 30% from 2025-2050 and increase by 20% from 2050-2100 unlike the current 50% due to visible SLR impacts and with no mitigation measures.



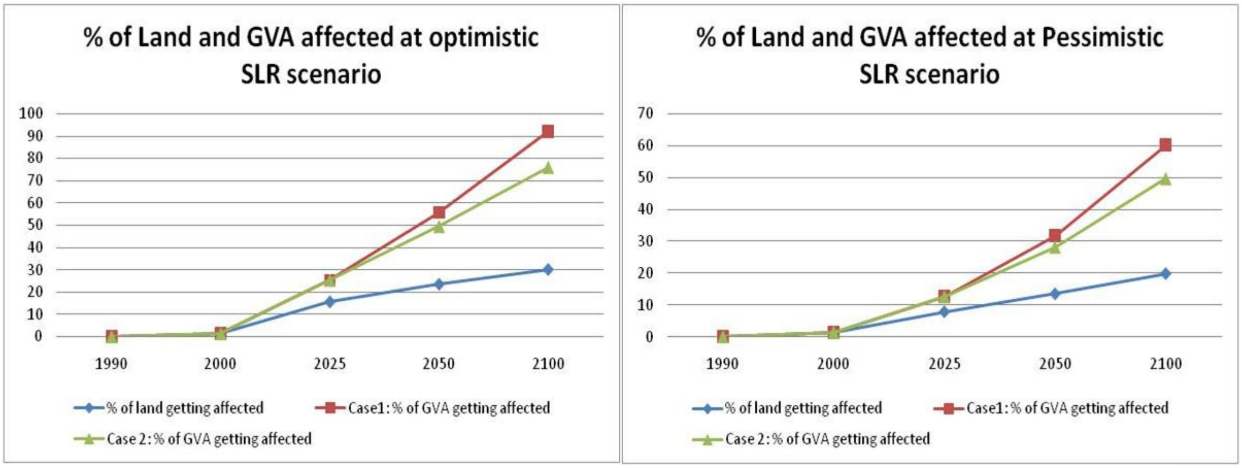
Graph 12: Case 2: GVA (in Rs Cr) affected at both optimistic and pessimistic Sea Level Rise Scenario

Currently the there is 50% increase in investment in this region for the past decade and proposed for next decade. This trend was assumed to remain same in Case 1. Now assuming an anticipated sea level rise, the rate of investments were to reduce between 2025-2050 and 2050 and 2100. Then the % GVA lost is being worked out in the table given below.

Loss in Cr Rs		
Year	**Optimistic**	**Pessimistic**
2025	3111	1556
2050	6858	3919
2100	11327	7433

Table 7: Case 2, Economic loss in Rs Cr at Optimistic and Pessimistic Sea Level Rise scenario

Even in this case 30 – 75 % of the current GVA is lost due to sea level rise. This will change if some mitigation or adaptation measures are taken by the industries or government to combat the SLR issue. This case is discussed below:



Graph 13 : % of land affected and % of GVA affected at optimistic and pessimistic Sea Level Rise Scenario

Case 3: Assumption: After 2025 the investment will increase at the current rate but at the cost of protecting oneself from SLR threats (Mitigation and Adaptation)

In this case it is difficult to value the cost of mitigation or adaptation measures taken. Moreover, it is difficult to pin point the kind of mitigation measures one can take to protect the region from aggravated sea level rise. One of the responses that could be considered is that of building coastal defenses, such as floodwalls, mud embankments etc. It is assumed that once the measures are in place the economic activity proceeds as before. For each defense option considered, capital cost, O&M costs, capital recovery factors and design lifetimes needs to be considered. This is out of the scope of the study and difficult to quantify.

Now this leaves us with two major questions:

1. **Is it better to loose land (resource) or combat Sea level rise?**
2. **Is mitigation or adaptation that is required?**

Adaptation and Mitigation

In order to answer these questions, it is necessary to first look in detail what is adaptation and mitigation and how it will affect the current industrial, land use regulations and coastal management policies.

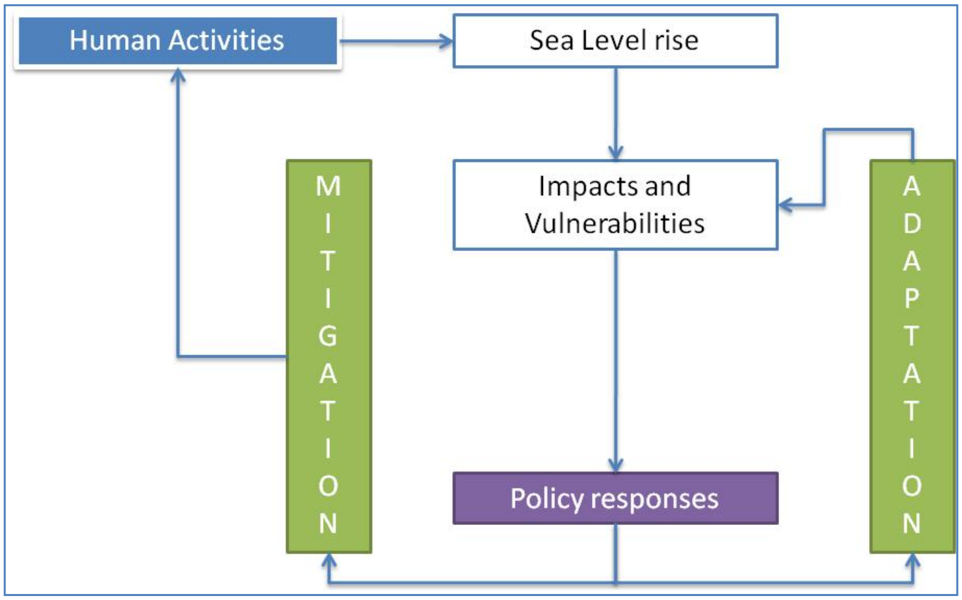


Figure 7: Analytical Framework

There are numerous methods that are available to prevent, mitigate and respond to erosion, flooding and salt water intrusion from sea level rise. Communities and individuals must decide whether to attempt to protect themselves from the consequences of sea level rise or adapt to them. Generally, prevention will be economically justifiable only at valuable locations such as population centers, defense installations, historical sites and areas of environmental importance.

Prevention of erosion requires keeping waves from attacking the shore. This is generally achieved by intercepting the waves offshore or by armoring beach itself. Offshore breakwaters limit the size of incoming waves. Revetments armor the beach itself and can be useful for moderate size waves. Several means of preventing inundation and storm surge also serve to limit erosion. Seawalls, levees and bulkheads are vertical wall structures made of materials of various strengths, depending on the size of the waves. With a rising sea, however these structures may require protection themselves.

Adjustment to the physical consequences of a sea level rise may sometimes be more appropriate than prevention. Policies must address this issue to prevent subsequent losses to effects due to sea level rise. In the case of Hazira, there are two sets of industries: 1) Already existing ones 2) proposed industries. Issue of adaptation of these industries must be dealt differently at policy level. Therefore, it is necessary to review the current Industrial policy of Gujarat. Also coastal management must put in place regulations for such heavy developments along coasts. Development control regulations of urban bodies, in the case of Hazira, regulations made by Surat urban development Authority were reviewed.

Table 8: Adaptation and mitigation measures at various levels

Measures	**Policies for review**
Mitigation	Higher level (national / International) policy options
	Local level mitigation measures (permanent and temporary structures)
Adaptation	**Existing Industries**
	Industry rehabilitation
	Industrial Incentives to combat natural disasters
	Proposed Industries
	Land use regulation
	Coastal zone management
	Industries location policy

An excerpt from Gujarat's Industrial Policy states thus: ***"The Government of Gujarat has recently promulgated ordinances to facilitate setting up of Special Economic Zones and Industrial Parks. In order to attract entrepreneurs for investing in the Zones, the Government has also decided to offer certain incentives. The industrial units setting up a power plant for his captive requirements would be offered electricity duty exemption for a period of 10 years. The units coming up in the Zone are also exempt from the levy of stamp duty or registration fees on transfer of land, loan agreement, credit deeds, mortgage documents or any other contracts. Sales tax, purchase tax, motor spirit tax, luxury tax, entertainment tax and other taxes are also exempted for the units set up in the Zone. The Government has also exempted the tax on the supply of raw materials from the domestic tariff area to the units located in the Zone. In Gujarat, at present, Special Economic Zones at Kandla and Surat are already in place. The State Government also plans to set up such SEZs at locations like Dahej, Hazira and Mundra in the near future, of which permissions for SEZs at Dahej and Mundra from Government of India have already been received."***

According to coastal regulations Hazira falls in the **CRZ-III** zone i.e. **Areas that are relatively undisturbed and those, which do not belong to either Category-I or II. These will include coastal zone in the rural areas (developed and undeveloped) and also areas within Municipal limits or in other legally designated urban areas that are not substantially built up.** Major observations after studying the CRZ-III are:

- **The existing industries in Hazira have encroached the 500m mark from the high tide line.**
- **Also existing construction and filling up of lowlying areas for industries has altered the original tidelines.**

- **The proposed industrial development (Hazira Area Master plan) also do not completely follow CRZ III regulation.**

This calls for reworking the CRZ regulations and HTL. With the gradual increase in SLR, which is bound to happen in another 100-year's time, it is important to decide on the shifting HTL and how development should address this issue. It requires a detailed analysis of the current land use and development control regulations and areas of intervention at the local level.

The most fundamental question suggested by the study on effects of sea level rise is whether to retreat or hold back the sea. Scientists have predicted the gradual conversion of agricultural and higher productive land into wetlands. Few suggestions in literature includes government to purchase land or prohibit development, but the usefulness of this approach is limited due to high expense in purchase of land and the assumptions in sea level rise predictions. To channel new economic development to high ground whenever possible would be the most highly recommended suggestion.

Hazira area is governed by Hazira notified area authority and is proposed to have an independent governing authority called Hazira Area Development Authority. Looking at most of the cities and their governance structure, the land use zoning is done by city urban development authority. A part of the 168 Sq Km of Hazira areas lies in Surat Urban development authority (SUDA) and the growth of this area s governed by SUDAGDCR – General Development control regulations.

Surat urban development Authority's Development control regulation has been reviewed for land use zoning restrictions in hazard prone areas and how it addresses the issue of industrial location. Major findings include:

- The frequency/return period of floods and storm surge/cyclone in Hazira is very high for 100yr return period.
- Current GDCRs provides options of physical intervention in flood-affected areas, than future safe zoning of such areas.
- Hazira though falls under the category of land mentioned under para 6, the developments are not according to that.
- Clause 3.3.1 may be applicable in Hazira, however steps taken to implement this is yet to be looked into.

It is clear from this analysis that development control regulations must not only look at Hazira as a hub of economic activities but also from vulnerability of these economic activities to an environmental threat that is gradual. This questions the relevance of adaptation options for the existing industries, which has further life span of more than 25 years, and for the proposed industries to be located within the Hazira Notified Area. This calls for a separate development model for Hazira notified area and such similar precincts dotting Indian coastline. This leaves us with major questions: What could be the adaptation strategy for areas similar to Hazira that have high economic productivity and high threat from natural disasters? What are the policy level interventions to be made and who all will be the major players? Currently these are the grey areas and need immediate attention not only at the micro level but also at the macro decision-making level.

Adaptation Strategies:

Adaptation strategies could be at two levels:

- Micro adaptation strategies
- Meso level adaptation strategies

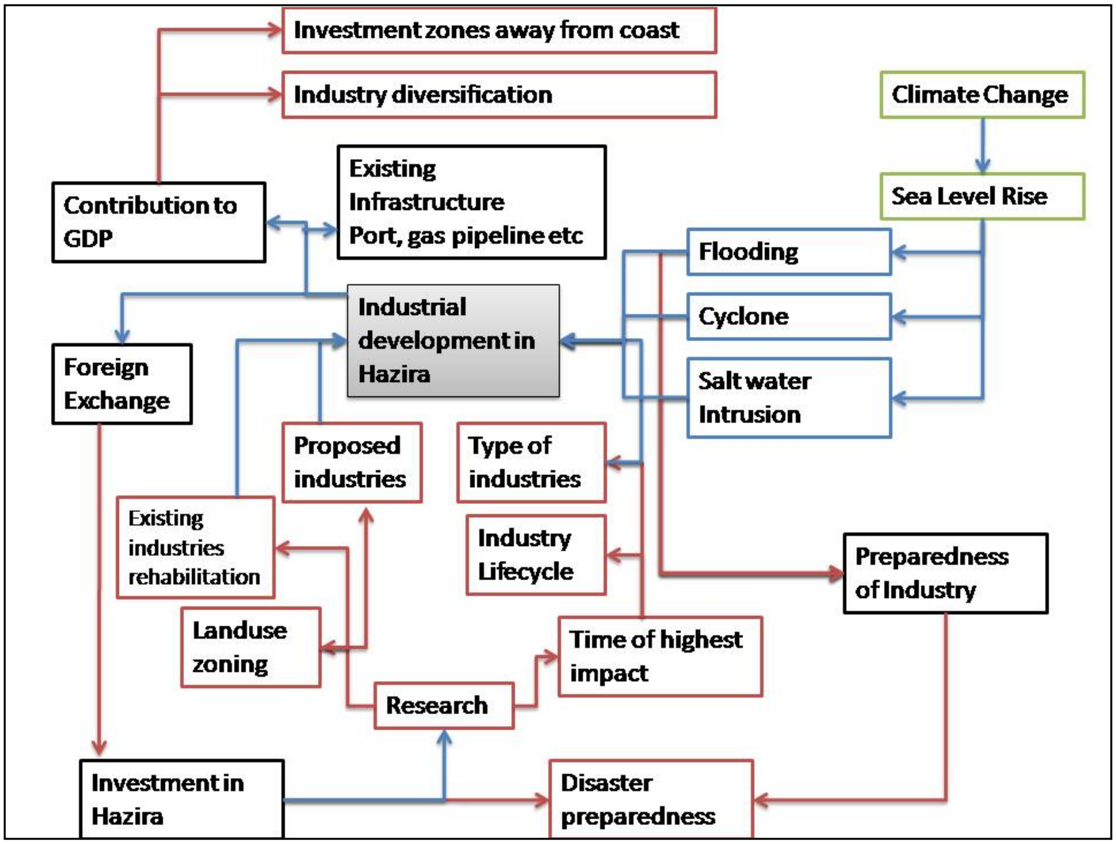


Figure 8: Factors that affect investment in Hazira and adaptation strategies at various levels

Micro adaptation strategies

In areas like Hazira, micro level adaptation strategies can be more effective than larger area or meso level strategies.

Table 9: Role of various agencies in coordinating

Significant Zones	Agencies	Policies	Anomalies
Coast	MoEF	Coastal regulation Zone	Alteration and Encroachment into the highest tide line and 500m from HTL.
Industrial Area, SEZ	GIDC,GPCB	Gujarat Industrial Policy, SEZ Policy	SEZ's exempted from CRZ, Port and infrastructure based development strategy, SEZs exempted from EIA
Urban Area	SUDA,HADA	Land use Zoning, General Development Control Regulations.	No restrictions in land use within hazard prone area, flood prone areas and development strategies not considered
Disaster Zone	GSDMA	Disaster management and preparedness plan	Projection of Hazira to be a high risk zone for industrial and infrastructure development by GSDMA but investment continues to flow.

This can be further sub divided into:

MESO LEVEL: Region specific and Activity specific and,

MICRO LEVEL: Site specific and Industry specific.

It is interesting to note at the global front what are the strategies adopted for adaptation to sea level rise at micro levels:

- Rising dykes all along the vulnerable areas
- Abandoning of low lying areas
- Shifting all activities to highlands
- Building sea wall and rising structures on stilts
- Land use planning policy to reflect a " hold off wait and see" attitude; moratorium on development.
- Create a margin of liberty for the sea (review, alter and condemn the building zone)
- Cost benefit analysis of protection options, study and model possible features.
- Create a condition for possible retreat (accompany the population on economic, social and psychological levels)
- Redistribute local economy
- A combination of accommodation and retreat is more likely the adaptation strategy.

In all the above cases the adaptation strategy could be through physical measures or policy measures. But this may have impact on the site as well as its surroundings, unique to each case.

With the above said strategies, if we try to analyze the case of Hazira, there are three levels of adaptation that one needs to address:

- Disaster preparedness and awareness among the investors and the region as a whole
- Time of highest impact having an effect on the type of industries and industry lifecycle.
- Land use zoning and how it affects the existing industries and proposed ones.

All of these will directly impact the investments in Hazira. Thus this calls for coordination from various government agencies to develop a development model for regions of high economic value and worst affected by natural disasters. Various agencies and statutory bodies responsible and their functions have been identified, while, it is beyond the scope of this study to designate the their levels of intervention.

Conclusion:

A 1m sea level rise is bound to happen anytime between 2000 to 2100 AD. With the rise many of the low elevation coastal zones are going to be adversely affected in terms of economic as well as social loss. India with its long coastline and large investments along the coast will be one among the worst affected. The effect can be felt especially in large coastal investment hubs such as Mumbai, Cochin, Surat etc on the western coastal strip of India. Gujarat being the most industrialized state with the largest coastline will be one of the worst hit in terms of economic development.

The most important factor here is the time at which the region will be worst hit. The main aim of the study was to develop an analytical framework for determining the decision making to locate an economic activity in such low elevation coastal zones threatened by sea level rise. A case of Hazira was used to demonstrate the effects and the probable time of maximum threat with various sea level rise scenarios. In the context of Hazira one needs to consider both mitigation and adaptation options, even though the country has very limited scope for mitigation. This is because mitigation options involve global efforts to execute and adaptation options are more local in nature. So, effective adaptation policies should be developed and implemented to minimize sea level rise impacts on Hazira.

Hazira was used to demonstrate the ill effects of planning economic centers with little emphasis to gradual environmental threat like sea level rise. There are many more such vulnerable sites attracting large scale investments all along the Western as well as Eastern coast of Peninsular India. Most of the current development activities have been planned without taking into consideration a potential threat from natural hazard such as sea level rise. Therefore, with a potential threat like sea level rise and with its numerous manifestations and high uncertainties, will have a massive impact on our country's otherwise potential LECZs. It is high time we channelize the current growth taking into consideration the future threat instead of troubleshooting. This calls for better understanding of current and future scenarios with coordination from various stakeholders at macro, meso and micro levels including state and central government to take precautions and policy level interventions at both physical as well as policy levels.

Annexure

Table 12: Case 1 Assumption: Direct correlation between Land and Investment affected GVA as a % of current GVA

Case 1:Assumption: Direct correlation between Land and investment (106 Sqkm max available land for development excluding waterbodies and other natural features left untouched)

					Optimistic SLR					Pessimistic SLR				
year	Area(Sqkm)	Investment(Rs Cr)	Estimated gross sales(Rs Cr)	Estimated Gross Value add(Rs Cr)	Sea Level rise(cm)	Area affected(Sqkm)	Affected Investment(Rs Cr)	Affected GVA(Rs Cr)	% of current GVA	Sea Level rise(cm)	Area affected(Sqkm)	Affected Investment(Rs Cr)	Affected GVA(Rs Cr)	% of current GVA
1990	47	23629	42000	8401										
2000	57	36000	64000	12300	1	0.8	505	173	1	1	0.8	505	173	1
2025	70	55359	99000	19800	10	11	8699	3111	25	5	5.5	4350	1556	13
2050	89	81180	145320	29064	50	21	19155	6858	56	25	12	10946	3919	32
2100	106	104708	187600	37520	100	32	31610	11327	92	50	21	20744	7433	60

Table 11: Case 1: % of land affected

CASE 1				
Year	Optimistic		Pessimistic	
	% of land getting affected	% of GVA getting affected	% of land getting affected	% of GVA getting affected
2063	22	60	14	39
2088	29	82	19	53

Table 13:Case 2: Assumption: after 2025 the investment will increase by 30% from 2025-2050 and increase by 20% from 2050-2100

Case 2: Assumption: After 2025 the investment will increase by 30% from 2025-2050 and increase by 20% from 2050-2100

					Optimistic SLR					Pessimistic SLR				
year	Area(Sqkm)	Investment(Rs Cr)	Estimated gross sales(Rs Cr)	Estimated Gross Value add(Rs Cr)	Sea Level rise(cm)	Area affected(Sqkm)	Affected Investment(Rs Cr)	Affected GVA(Rs Cr)	% of current GVA	Sea Level rise(cm)	Area affected(Sqkm)	Affected Investment(Rs Cr)	Affected GVA(Rs Cr)	% of current GVA
1990	47	23629	42000	8401										
2000	57	36000	64000	12300	1	0.8	505	173	1	1	0.8	505	173	1
2025	70	55359	99000	19800	10	11	8699	3111	25	5	5.5	4350	1556	13
2050	89	71967	128763	25753	50	21	16981	6076	49	25	12	9703	3472	28
2100	106	86360	154628	30926	100	32	26071	9336	76	50	21	17109	6127	50

Table 10: Case 2:% Land affected

CASE 2				
Year	Optimistic		Pessimistic	
	% of land getting affected	% of GVA getting affected	% of land getting affected	% of GVA getting affected
2063	22	51	14	31
2088	29	69	19	43

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