Chapter-1

Introduction

Climate change, associated sea level rise and impact on the coastal zone are current issues of global magnitude and concern. The increase in human population and associated developmental activities of modern era such as industrial development, urbanization, agricultural practices, destruction of forests, fossil fuel burning, development of transport system, draining wetlands, adoption of modern technology in farming and livestock rearing etc. have put tremendous pressure on the natural resources and led to the present degraded state of global environment. In recognition of the influence of humans on the Earth, including the global climate, the time since the nineteenth century is being referred by scientists as an Anthropogenic Era (Pearce, 2007; Zalasiewicz, et. al. 2008). Currently, multidisciplinary research addressing various issues related to impact of climate change on natural resources as well for framing suitable strategies for protection of life, property and environment are being pursued. Remote sensing and Geographical Information System (GIS) techniques are modern tools that provide accurate, reliable measurements from space on various multidisciplinary aspects. Coastal vulnerability assessment using remote sensing and GIS techniques is one such step towards planning mitigation and adaptation strategies to the threat of predicted sea level rise.
1.1 Global Concern of Predicted Sea Level Rise

1.1.1 Global Warming and Its Impacts

Intergovernmental Panel on Climate Change (IPCC, 2013) estimated that the atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased by about 40% (390.3 to 390.7 ppm), 150% (1801.2 to 1805.2 ppm) and 20% (324.0 to 324.4 ppm), respectively, between 1750 and 2011 year (Hartmann et al. 2013). The level of carbon dioxide and other greenhouse gases and climate changes are interlinked during most of the earth’s history (Goodwin et al. 2009).

The impacts of the increased greenhouse gases like carbon dioxide in the atmosphere are already noticeable. Fineren (2009) reported that the top 11 warmest years in the recorded history have occurred in the last 13 years. Comparing the altitudinal distribution of 171 forest plant species between 1905 and 1985 and 1986 and 2005 along the entire elevation range up to 2600 m above sea level, Lenior et al. (2008) observed that the global warming has resulted in a significant upward shift in species optimum elevation averaging 29 m per decade. The warming is also worsening the public health problems such as the alarming spread of malaria in Africa and elsewhere, and the increasing risk of respiratory diseases and metabolic disorders owing to poor air quality and rising temperature (Hoyle, 2008).

The global average temperature has increased by around 0.85°C over the past century, out of which the past three decades alone recorded a rise of 0.6°C, at the rate of 0.2°C per decade as greenhouse gases became the dominant climate forcing in recent decades (Hartmann et al. 2013; IPCC 2013; IPCC, 2007; Hansen et al. 2006; Rosenzweig et al. 2008; Wood 2008). Climate model projections summarized in the IPCC report indicate that the global surface temperature is likely to rise a further 1.1 to 6.4 °C during the 21st century.

An increase in global temperature will cause sea levels to rise and will change the amount and pattern of precipitation, probably including expansion of subtropical deserts (Lu Jian, 2007). The eustatic rise in sea level is due to thermal expansion of seawater and addition of ice-melt water (Meehl et al. 2005). The intergovernmental Panel on Climate
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Change has predicted that the global sea level will rise within a likely range of 26 to 82 cm by the 2100 (IPCC 2013). Construction of sea levels over the past 2000 years suggest that the melting of glaciers, disappearing of ice sheets and warming water could lift the sea level by as much as 1.5 m by the end of this century (Strohecker, 2008).

There is a further possibility, in the event of the collapse of the Greenland and West Antarctic ice sheets, of increases of as much as five meters (Oliver-Smith, 2009). Already there are evidences of large-scale ice melt in the three major ice repositories of the world – the Arctic, the Greenland and the Antarctic regions. The average rate of ice loss from Antarctica increased from 30 Gt yr\(^{-1}\) over the period 1992–2001, to 147 Gt yr\(^{-1}\) over the period 2002–2011 and the average rate of ice loss from Greenland ice sheet has increased from 34 Gt yr\(^{-1}\) over the period 1992–2001 to 215 Gt yr\(^{-1}\) over the period 2002–2011 (Vaughan et al. 2013). The extent of Arctic sea ice has been decreasing at almost 8% per decade since the middle of last century (Stroeve et al. 2007).

1.1.2 Observation of Sea Level Change

Sea level means the height of the sea measured relative to a mark on the nearby land called the Tide Gauge Benchmark (TBM). Mean Sea Level (MSL) is usually described as a tidal datum that is the arithmetic mean of hourly water elevations observed over a specific 19-year cycle (Pugh, 2004). The global sea level changes either due to ocean volume or ocean mass changes. Ocean volume change is associated with thermal expansion of the ocean; as ocean water warms up, it expands, increasing the volume of global ocean producing a sea level rise. Change in the mass of the ocean is mainly due to melting of glaciers and ice sheets with some contribution from water stored in continental reservoirs or groundwater extraction. It is debated, however, which of the two causes: expansion of ocean waters, or freshwater input from the continents, dominated the 20th century global sea level rise. Nevertheless, observations over the last couple of decades suggest increasing contributions from both thermal expansions of the oceans and the melting of glaciers and ice sheets (http://www.psmsl.org/train_and_info/faqs/).

Local Mean Sea Level (LMSL) is defined as the height of the sea with respect to a land benchmark, averaged over a period, which is long enough to smoothen out the fluctuations caused by waves and tides. Rate of local sea level change reflects a variety of
local factors, including vertical land motion (subsidence or uplift) and changes in estuarine and shelf hydrodynamics, regional oceanographic circulation patterns and hydrological cycles (river flow) (NOAA, 2012).

According to Douglas and Peltier (2002), at the height of the last glacial maximum ~21,000 years ago, so much of the earth’s water was tied up in great high-latitude ice sheets that the oceans were about 120 m lower than today. Compared with those of previous millennia, the changes in global sea level occurring today are minimal. The global sea level increased by about 120 m as a result of the de-glaciations that followed the last glacial maximum. By about 5,000-6,000 YBP (years before present), the melting of the great high-latitude ice masses was essentially completed. Therefore, the global sea level rise was small, and appears to have almost ceased by 3,000-4,000 YBP.

Geologic evidence of the past 2,000 years suggests that global mean Sea Level Rise (SLR) has been relatively stable (approximately -0.1 mm/year to 0.6 mm/yr) until the late 1800s or early 1900s (Kemp et al. 2011). Since 1900, global mean sea level has been rising at a rate of approximately 1.7 mm/ year as recorded by tide gauges (Church and White, 2011). Measurements from satellite altimetry data, beginning in the early 1990s, suggest that this rate has increased to approximately 3.2 mm / year (Ablain et al. 2009, Church and White, 2011). This apparent recent acceleration in global SLR recorded with satellite altimetry may be attributed to a combination of decadal-scale climate and oceanographic patterns, differences in tide gauge and altimetry observation methodologies and measurement distribution, and an acceleration of global SLR associated with global warming (Church and White, 2011).

Modern sea level rise is a matter of urgent concern because of the possibility of its acceleration and consequent threats to many low-lying parts of the inhabited world i.e. coastal zone (Douglas et al. 2001; Church et al. 2001). It is generally assumed that sea level rise is caused by the melting of glaciers in Antarctica and Greenland and the expansion of sea water caused by temperature rise (Fjeldskaar, 2008). It was tide gauge data that provided the first evidence of an accelerated rate of sea level rise for the twentieth century relative to pre-industrial periods (Gehrels et al. 2006; Kemp et al. 2009). According to Holgate et al. (2007), “the rate of sea level change was found to be larger in
the early part of the last century (2.03 ±0.35 mm / year, for the period of 1904 to 1953 year), in comparison with the later part (1.45 ±0.34 mm / year for the period of 1954-2003 year). The highest decadal rate of rise occurred in the decade centred on 1980 (5.31 mm / year) with the lowest rate of rise occurring in the decade centred on 1964 (-1.49 mm / year). Over the entire century the mean rate of change was 1.74±0.16 mm / year”. Using the Gravity Recovery and Climate Experiment (GRACE) based estimation Cazenave et al. (2009) observed an increase of ocean mass at an average rate of 1.91+/ -0.1 mm / year over the period of 2003–2008.

1.1.3 Future Sea Level Rise Projections

According to the recent IPCC 2013 report, the global mean sea level will rise in range between 0.40 to 0.63 m to the end of next century (based on different Representative Concentration Pathway’s scenarios) (Figure 1.1 and Table 1.1).

By AD 2100, the 2009 Antarctic Science Report anticipated up to 1.4 m rise in sea level (Turner et al. 2009), while the 2011 Arctic Monitoring and Assessment Program estimated 0.9 to 1.6 m (AMAP, 2012), the 2012 U.S. National Research Council reported 0.5 to 1.4 m SLR (NRC, 2012), and the 2012 World Bank Climate Report predicted 0.27 to 1.23 m rise in sea level (World Bank, 2012), although there are some differences in the underlying scenario assumptions and exact time intervals used for the prediction. Sea-level scenarios prepared by the National Oceanic and Atmospheric Administration (NOAA) for the U.S. National Climate Assessment projected with plausible lower and upper limits of 0.2 m and 2.0 m (Parris et al. 2012). Eelco et al. (2013) predicted SLR of up to 0.9 m by 2100 century based on geological evidences. Horton et al. (2008) estimated 54-89 cm (acknowledging that this could be a lower limit), and Jevrejeva et al. (2010) projected median sea level rises of 0.57 m for the lowest forcing and 1.10 m for the highest forcing by 2100. He also reported that sea level will continue to rise for several centuries even after stabilisation of radioactive forcing with most of the rise after 2100 due to the long response time of sea level. Although the science of sea level rise has grown rapidly over the past two decades but the major challenges are significant predictions of sea level rise which requires observing systems to be improved and sustained, as well as an interdisciplinary approach by researchers (Willis et al. 2010).
Figure 1.1: Projections of global mean sea level rise over the 21st century (IPCC, 2013).

Table 1.1: Global sea level rise projection based on various RCP scenarios (IPCC, 2013).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Scenario</th>
<th>Mean</th>
<th>Likely range</th>
<th>Mean</th>
<th>Likely range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Mean Sea Level Rise (m)</td>
<td>RCP2.6</td>
<td>0.24</td>
<td>0.17 to 0.32</td>
<td>0.40</td>
<td>0.26 to 0.55</td>
</tr>
<tr>
<td></td>
<td>RCP4.5</td>
<td>0.26</td>
<td>0.19 to 0.33</td>
<td>0.47</td>
<td>0.32 to 0.63</td>
</tr>
<tr>
<td></td>
<td>RCP6.0</td>
<td>0.25</td>
<td>0.18 to 0.32</td>
<td>0.47</td>
<td>0.33 to 0.63</td>
</tr>
<tr>
<td></td>
<td>RCP8.5</td>
<td>0.30</td>
<td>0.22 to 0.38</td>
<td>0.63</td>
<td>0.63 to 0.82</td>
</tr>
</tbody>
</table>

1.1.4 Sea Level Rise along the Indian Coast

Sea level rise along the Indian coast has been investigated out by researchers such as Emery and Aubrey (1989); Douglas (1991); Unnikrishnan et al. (2006); Unnikrishnan and Sankar, (2007). According to Shankar and Shetye (2001), the mean sea level is higher in Bay of Bengal in comparison with Arabian sea due to the wind forced coastal circulation
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and the salinity gradient along the coast. Mean sea level rise at selected stations along selected Indian Ports namely Mumbai, Kochi, Chennai and Vishakhapatnam, has been studied by Unnikrishnan et al. (2006). They reported that Mumbai, Kochi and Vishakhapatnam showed a sea level rise of 0.78, 1.14 and 0.75 mm / year respectively, whereas the Chennai showed a decrease in sea level (– 0.65 mm / year). They also reported that this estimates of sea level rise need to be corrected using the rates of vertical land movements. Unnikrishnan and Shankar (2007) estimated that the mean sea-level-rise along the Indian coasts to be in between 1.06– 1.75 mm / year, with a regional average of 1.29 mm / year, after correction of Global Isostatic Adjustment (GIA) using model data.

1.1.5 Impacts of Sea Level Rise

The direct impact of sea level rise would be on the coastal zone which are low lying, in spite of being highly resourceful and densely populated, and hence would be subjected to accelerated erosion and shoreline retreat due to increase wave strength as water depth increases near the shore (Pye and Blott, 2006), besides leading to saltwater into coastal groundwater aquifer, inundation of wetlands and estuaries, and threatening historic and cultural resources as well as infrastructure (Pendleton et al. 2004). According to the UN Atlas of the Oceans, it is estimated that 44% of the population lives within 150 km of coastline. Of the world’s ten most densely populated cities, nine are located on the coast. Of these, five are in Asia, of which two are located in India viz. Mumbai and Kolkata.

Sea level rise would increase the susceptibility of coastal populations and ecosystems through the permanent inundation of low-lying regions, amplification of episodic flooding events, and increased beach erosion and saline intrusion (Mclean et al. 2001). The increased sea-surface temperature would also result in frequent and intensified cyclonic activity and associated storm surges affecting the coastal zones (Unnikrishnan et al. 2006). The rising sea level endangers several smaller island nations, such as Tuvalu, Maldives, etc., which are barely 2 m above the sea level (Brown, 2001). Millions of people in low lying regions of many other countries including Bangladesh, China (Strohecker, 2008), and Vietnam (Hanh and Furukawa, 2007) face the danger of being displaced. The impacts of sea level rise are scale-dependent and it will unevenly distribute
among and within nations, regions, communities (Clark et al. 1998). Sea-level rise will cause significant and often dramatic changes to coastal landforms (e.g. barrier islands, beaches, dunes, marshes), as well as ecosystems, estuaries, waterways, human populations and development in the coastal zone (Nicholls et al. 2007). Low-lying coastal plain regions, particularly those that are densely populated are especially vulnerable to sea-level rise and land subsidence and their combined impacts to the coast and to development in the coastal zone (McGranahan et al. 2007). Protection of life, property and coastal environment along the coast are major causes of concern.

1.2 Coastal Zone, Issues and role of Remote Sensing and GIS

The “coastal zone” is a broad transitional area in which terrestrial environments influence marine environments and in which marine environments influence terrestrial environments (Carter, 1988). Sorensen and McCreary (1990) defined the coastal zone as the interface or transition zone, specifically that part of the land affected by its proximity to the sea and that part of the ocean affected by its proximity to the land.

The term coastal zone means the coastal waters, wetlands and adjacent shorelands, strongly influenced by marine water or vice versa. Thus coastal zone includes the nearshore marine waters, islands, beaches, intertidal areas, wetlands and inland area to the limits of the coastal watersheds and flood-prone areas in which natural and man-made activities can affect the coastal waters (SAC, 1991). The coast is a unique environment where land, sea and atmosphere interact and interplay continuously influencing a strip of spatial zone defined as coastal zone (SAC, 2012). Coastal zones are unique, as mangrove forests, coral reefs, tidal flats, sea beaches, storm waves, tides and barrier islands are found only at the coast (UNEP, 1991). Most countries recognize the coastal zone as a distinct region due to its resources that require special attention. The limits of the coastal zone are arbitrarily defined, differing widely among nations, and are often based on jurisdictional limits or demarked by reasons of administrative ease (Chua, 1993). Typically, a combination of distance to coast and elevation data is used. Different countries use different distance criteria for defining the coastal zone. In India, 500 m distance from the high tide line (landward) is taken for demarcating the coastal zone (SAC, 2012).
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Coastal zone are the most fragile, dynamic and productive ecosystem. The terrestrial and marine process such as wind actions, tide, wave, currents, erosion / accretion etc continuously influence the coastal zone and make it dynamic and fragile. Coastal environment plays a vital role in a nation’s economy by virtue of coastal resources, productive habitat and rich biodiversity (Ramachandran, 1999). Many coastal systems throughout the world support small scale fishery activities that are vital for the livelihood of most coastal communities. Coastal zone features such as coral reefs, mangroves forest, beach and dune system serve as critical natural defences against storm surge, flooding and erosion. The coastal ecosystem maintains an ecological balance that accounts for shoreline stability, beach replenishment, nutrient generation and recycling. A coastal ecosystem reduces the impacts of pollution originating from land (example, wetlands absorbing excess nutrients, sediments, human waste). The fertile lowland of the coastal region, abundant marine resources, water transportation and aesthetic values made human settlements along the coastal region facilitating their livelihood and even military from ancient time to the present.

About 40% of the world’s population lives within 100 km of the coast (SAC, 2012). The population densities in coastal regions occur at approximately three times the global average with maximum densities occurring below 20 m in elevation (Nicholls, 2003). Two-thirds of the world’s cities occur along the coast (Crooks and Turner, 1999). About 35% of Indians live within 100 km of the country’s coast line measuring 7517 km (SAC, 2012). According to the United Nations Environment Programme (UNEP) report, the average population density in the coastal zone was 77 people/km$^2$ in 1990 and 87 people/km$^2$ in 2000, and a projected 99 people/km$^2$ in 2010 (UNEP, 2007).

The coastal zones are exposed to varied issues mainly, coastal erosion and loss of coastal habitat, urban pollution, industrial and agricultural development, dredging, disasters like storm surge, tsunami and also the global warming induced sea level rise.

The following issues are critical in context of coastal zone management (Nayak, 2002).

A. Coastal ecosystems and marine living resources
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i. Generation of reference or baseline data, conservation and restoration of vital and critical habitats such as mangroves, coral reefs, sea-grass beds, etc

ii. Reclamation of wetland for agricultural and industrial purposes

iii. Exploration and sustainable use of living resources

B. Shoreline protection

i. Identification of vulnerable areas including eroded areas and developmental activities

ii. Planning and implementation of coastal protection work (erosion, flood protection, salt water intrusion, etc.)

iii. Impact of engineering structures and dams on coastal processes of erosion, deposition and sediment transport

iv. Suspended sediment dynamics

v. Changes in bottom topography

C. Coastal water quality

i. Non-point and point pollution

ii. Phytoplankton blooms

D. Coastal Hazards and Climate Change

i. Cyclones, storm surges, sea-level rise and possible effects

ii. Emergency response plans for natural disasters such as cyclones, sea level rise, or anthropogenic activities such as oil spills

E. Coastal development

i. Appropriate site selection for industries, landfall points, aquaculture, recreational activities, etc

ii. Assessment of conditions in regulation zones, areas under construction setback lines, megacities, etc.

Among the various issues and problems related to a coast, coastal hazards are most significant which includes cyclones and associated tidal flood, coastal erosion, pollution, and sea level rise and its impacts. Remote sensing and GIS techniques are
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extremely useful to understand the dynamics of coastal environments and preparation of integrated coastal zone management plans.

Remote Sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand and Kieffer, 2000). On the other hand, Geographic Information System (GIS) is a powerful set of tools for collecting, storing, retrieving, at will, transforming and displaying spatial data from the real world (Burrough and McDonnell, 1998).

Intrinsically, remotely sensed information offers numerous benefits, which have been utilized in a wide variety of coastal and oceanographic applications. These benefits include wide range of spatial scale, unbiased content, repetitive coverage, multi-spectral data from varied satellite platform, economy and efficiency (O’Regan, 1996 and Nayak, 2002). GIS has emerged as the spatial data handling tools of choice for solving complex geographical problems. Guptill (1989) and Ricketts (1992) identifies the following as benefits which arise from using GIS technology for coastal and ocean management: (a) providing a receptacle for scattered data from diverse sources; (b) improving the visualization of such data for space-use management; (c) improving understanding of interactions between uses of and linkages between ocean and land-based processes in coastal areas; (d) supporting statistical, modelling and impact analysis; (e) making better use of remotely sensed data; (f) high quality graphical output for dissemination of information; and (g) development of efficient data and information management infrastructures.

2012; Gornitz et al. 1994; Navalgund et al. 1998; Pendleton et al. 2005; Kumar and Pravin, 2012; Mahendra et al. 2011; ManiMurali et al. 2013; Mahapatra et al. 2014c; Kumar et al. 2010; Dwarakish et al. 2009; Ju et al. 2012). Methodologies are developed and evolved to study the coast using satellite data, generate baseline data for the coast, map and monitor the coastal land use \ land cover, coastal wetlands, critical and vital habitats (coral reefs and mangroves), sediment transport, High Tide Line (HTL), Low Tide Line (LTL) delineation, shoreline changes, understanding the dynamics of coastal environment, understanding the possible impacts of the impending sea level rise and identifying vulnerable sectors of the coast.

1.3 Hazards, Disasters, Vulnerability and Risk

Hazards are threats, both natural and manmade, that have the potential to harm people (and the things they value) and place (NRC, 2006). Hazard may be defined as “a dangerous condition, event, process, or phenomenon that threat or have the potential for causing injury to life or damage to property or the environment.” Hazardous events vary in magnitude, frequency, duration, area of extent, speed of onset, spatial dispersion and temporal spacing. Hazards can be grouped into two broad categories namely natural and manmade. Natural hazards are hazards, which are caused because of natural phenomena (hazards of meteorological, geological or even biological origin). Examples of natural hazards are cyclones, tsunamis, earthquake and volcanic eruptions, which are exclusively of natural origin.

Disasters are those large-scale events that overwhelm the local capacity to effectively respond to recover from an event (NRC, 2006). A disaster is a natural or manmade (or technological) hazard resulting in an event of substantial extent causing significant physical damage or destruction, loss of life, or drastic change to the environment. It is a phenomenon that can cause great damage to life and property and destroy the economic, social and cultural life of people. Earthquake in an uninhabited desert cannot be considered a disaster, no matter how strong the intensities produced. An earthquake is disastrous only when it affects people, their properties and activities. So, all hazards are not disasters.
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The term “vulnerability” is used among a wide range of scientific discipline and policymakers from different aspects (Zou and Thomalla, 2008). Generally, Vulnerability is defined as the potential for damage or harm during a given hazard event. The IPCC-CZMS (1992), defines vulnerability of coastal zones by their degree of incapability to cope with the impacts of climate change and accelerated sea-level rise.

Different people who are vulnerable to natural hazards of various types and are having different social characteristics are likely to be harmed by a particular hazard to different degree (Cannon, 2006). Blaikie et al. (2004) defined vulnerability as “the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazards” (an extreme natural event or process). IPCC 2001, (third assessment report) defined vulnerability to climate change as the function of exposure, sensitivity and the adaptive capacity”.

Vulnerability is the degree of capability to cope with the consequences of climate change and sea-level rise (Klein and Nicholls, 1999). According to them the concept of vulnerability comprises:

a) The susceptibility of a coastal area to the physical and ecological changes imposed by sea-level rise;

b) The potential impacts of these natural system changes on the socioeconomic system;

c) The capacity to cope with the impacts, including the possibilities to prevent or reduce impacts via adaptation measures.

Hence, vulnerability assessment includes a combination of factors that determine the degree to which someone’s life, livelihood, property and other assets are put at risk by a discrete and identifiable event in nature and in society.

Identifying vulnerability of different coastal sectors to the possible impacts of the rising sea levels is an important aspect of coastal zone management. Quantification is needed to determine the degree of vulnerability experienced by a coast (Sanchez-Arcilla et al. 1998) since measuring vulnerability is a key step towards effective risk reduction (Birkmann, 2006). Using a selection of parameters that indicate vulnerability (such as
coastal landforms and coastal slope) is useful in offering a quick and cost-effective means for those involved with coastal zone management.

The vulnerability assessment comprising of susceptibility of the coastal zone to physical changes, potential impacts on socioeconomic and ecological systems, and the adaptation options (Harvey et al. 1999). Social vulnerability deals with those demographic and socioeconomic factors that increase the impacts of hazard on exposed populations (Tierney et al. 2001, Center, 2002).

Risk is the probability of a community and its property getting adversely affected by a hazard. Risk indicates the probable level of deaths, injuries and disabilities and the loss or damage to individual and community assets that may be sustained due to a single or set of hazards, in a given area and time. The common elements of risk are population, property, roads and communication network, basic community infrastructure and economic activities.

Risk is conventionally expressed by the equation

\[ \text{Risk} = \text{Hazard} + \text{Vulnerability}. \]

Extreme natural events or hazards such as storms, earthquakes, floods, cyclone, drought, landslides etc may directly influence the life of certain individuals living in a particular locality, or of society as a whole. The magnitude of a disaster is directly proportional to the degree of vulnerability of the exposed population. To mitigate the ill effects of hazards, a thorough understanding of the vulnerability causing factors is required. Vulnerability analysis, therefore, is the key activity in risk reduction and preparedness and management of the disaster. Accurate prediction of exposure to hazards, risk reduction and mitigation of the effects require a comprehensive interdisciplinary study of hazards, of vulnerability and risk, as well as proper sensitization, mobilization and capacity building of all stakeholders. Efficacy of policy intervention for disaster management would depend upon the proper understanding of the vulnerability of the exposed community and its coping capabilities.
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1.4 Objectives

The major objective of this thesis is to develop an approach to assess vulnerability of Gujarat coast to predicted sea level rise using Remote Sensing (RS) and Geographical Information System (GIS) techniques.

The detailed objectives are:

1) To understand physical and socioeconomic parameters influencing vulnerability of Gujarat coast to predicted sea level rise
2) To create geospatial database related to various coastal thematic information using remote sensing and GIS techniques for the Gujarat coast.
3) To develop geospatial model for coastal vulnerability assessment on regional scale using physical variables for entire Gujarat
4) To develop geospatial model for integrated coastal vulnerability assessment for selected coastal segment using physical and socioeconomic variables

1.5 Outline of the thesis

The thesis consists of seven chapters.

Chapter One provides the background information and objectives of the study. It describes the global concern of predicted sea level rise, global warming and its impact, sea level rise measurements, predictions and likely impacts, concepts of coastal vulnerability and role of remote sensing and GIS techniques.

Chapter Two reviews literature that focuses on various parameters for coastal vulnerability assessments and various methods of calculating vulnerability indices. This chapter also discusses previous work on inventory and monitoring of coastal zone of Gujarat using remote sensing and GIS techniques.
Chapter Three describes the salient characteristics of the study area including location, physiography, geology, climate, vital coastal resources, sea level changes along Gujarat coast etc.

Chapter Four outlines the materials and methodology. The basic of remote sensing, GIS and image interpretation are also discussed in this Chapter.

Chapter Five discusses about the coastal vulnerability assessment of entire Gujarat coast carried out on regional scale (1:50,000) using geospatial modelling and salient findings.

Chapter Six discusses geospatial modelling for selected five coastal segments (1:25,000 scale) and development of Integrated Coastal Vulnerability Indices (ICVI) and Maps along with salient findings. It also includes impact analysis due to IPCC, 2013 predicted sea level rise on land use/land cover of a selected coastal segment.

Chapter Seven gives summary and conclusions of this work. Some future scopes are suggested.

The list of references is added with this thesis at the end.