INTERNATIONAL JOURNAL OF ENVIRONMENTAL SCIENCES Volume 5, No 3, 2014



**Research article** **ISSN 0976 – 4402**

# Climate change and coastal ecosystem in India: Issues in perspectives

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doi:10.6088/ijes.2014050100047

## ABSTRACT

Climate change related Sea Level Rise (SLR) increases the vulnerability of coastal ecosystems by posing threat to many coastal cities, urban centres and coastal population in developed as well as in developing countries. Coastal areas are predominantly rich in resources, easily accessible and facilitate infiltration of people and investments. The 8118 km long coastline in India is characterized as fragile and highly productive. Rapid urban development, increase in the number of polluting industrial units, the growth of luxury tourism and the expansion of industrial shrimp aquaculture have considerable socioeconomic and environmental impacts on the coast of India. According to Census 2011, nearly 48% of India's population from coastal regions is currently living in urban areas. More than fifty percent of towns (2661) and 3827 villages are situated in the coastal regions of India. 64.45% of slum population from nine coastal states in the country also lives in poverty. Coastal states receive more than 60% of investment, 68% of total factories in India exist in coastal states. However, the frequent occurrence of coastal disasters as a result of climate change has many impacts in terms of human lives lost, destroyed infrastructure, ecological damage, disrupted social networks, displaced coastal fishing communities from their traditional living and occupational spaces. In this paper issues pertaining to climate change in coastal areas in general and India's coastal areas in particular are discussed based on literature and information collected from various secondary sources.

**Keywords:** Climate change, Coastal ecosystems, Vulnerability, Sea level rise, India

## 1. Introduction

Coastal ecosystems are most productive and highly threatened ecosystems in the world. These are the places where people live and where a spate of human activity affects the delivery of ecosystem services derived from marine habitats (MEA, 2005). The rapid increases in population density and economic activities near coastal areas significantly increase their vulnerability. The IPCC-CZMS (1992) defined vulnerability of coastal zones by their degree of incapability to cope with the impact of climate change and accelerated SLR. The socioeconomic impacts of climate change on coastal zones are primarily studied through SLR. The rise in sea level increases the number of people at risk of coastal flooding. A majority of the population currently exposed to coastal flooding are from South Asia and East Asia. These regions also continue to dominate while predicting future risks from SLR. However, the actual experience of flooding depends not only on SLR, but also on population, underlying socio-economic conditions, and mostly on assumptions about protection (Warren et al., 2006).

India has more than 8000 km long coastline including few islands in its territory. The coast line encompasses more than 60 districts in 9 coastal states. The two coasts (east and west) are

*Received on June 2014 Published on November 2014* 

different in many aspects. About one third of the India's population live in coastal areas and the density of population are increasing at an alarming rate. The densely populated and low-laying coastal areas are exposed to frequent occurrence of cyclones, storms, and environmental degradation. The change in climate is expected to increase the frequency and intensity of these events and further incite new hazards (like SLR, extreme weather events such as heavy rainfall) and vulnerabilities with different spatial and socio-economic impacts. This paper consists of two major parts, the first part (Section 2) deals with coastal ecosystem, values and functions derived from coastal ecosystem and climate change issues like SLR, flood etc. Vulnerability of coastal ecosystem is also discussed in the first part. The second part (Section 3) of this study deals with issues pertaining to climate change and coastal ecosystem in India. The evidence of SLR and other vulnerability studies are analysed in detail. Section 4 presents discussion and conclusion.

## 2. Coastal ecosystems: Functions and values derived

Coastal ecosystems provide a wide range of functions and values (see Figure 1). These include the indirect use values like regulation and supporting services such as shoreline stabilization, flood control, detoxification of polluted waters, and waste disposal. The direct use values measured through a production function are crucial as it captures the utility derived directly from the use of many living and nonliving resources. These functions include provision of space and a suitable substrate for human habitation such as the supply of food (fishery and aquaculture), fuel wood, energy resources, natural products, and amenity services such as tourism and recreation. The other values include the non-use and intrinsic values, i.e. the values derived from just knowing that a species or system exists. These functions are of high value not only to local communities living in a coastal zone (especially in developing countries), but also to national economies and global trade (MEA, 2005).

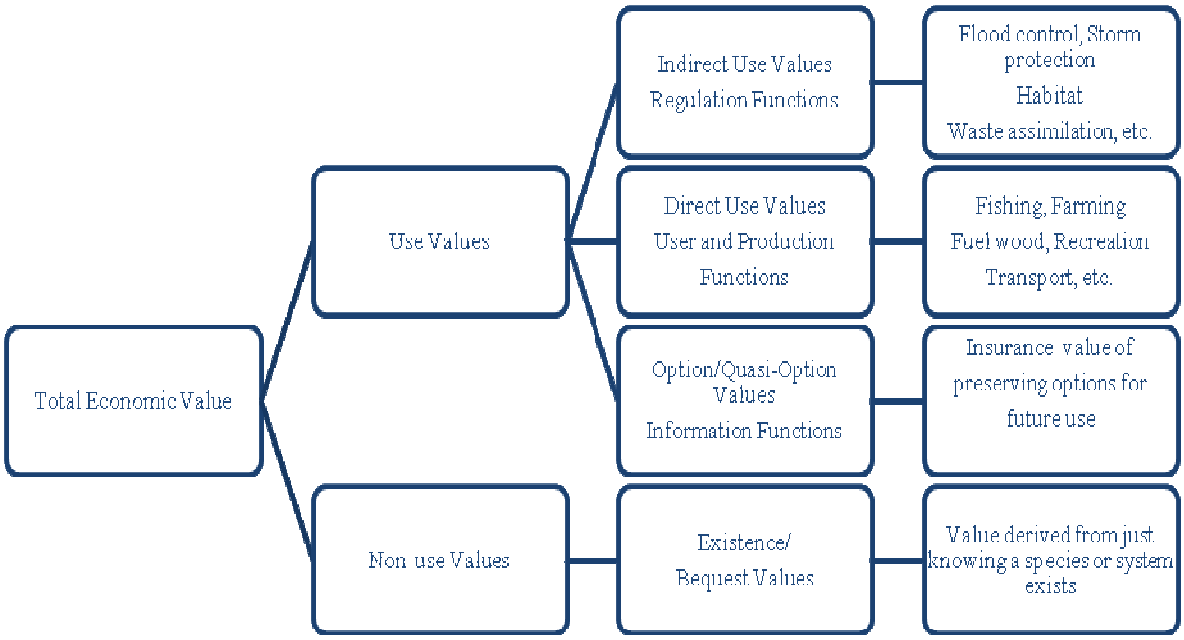


**Figure 1:** Values of the coastal ecosystem (Constanza et al., 1997)

The increase in urbanization near the coast has serious environmental consequences. Worldwide, more than 600 million people are living in coastal zones which are less than 10 meters in elevation; of which 360 million reside in urban areas (McGranahan et al., 2007). Urban systems drastically affect the flow of water and energy near the coast, it is found that one-third of coastal mangrove forests and one-fifth of coral reefs have already been lost. In many parts of the world, coastal fish population has declined considerably. Especially major harbours of Asian cities have exhibited drastic fishery declines as well as numerous other environmental problems. Global capture of fishery production in 2008 was about 90 million tonnes, with an estimated first-sale value of US$93.9 billion, comprising about 80 million tonnes from marine waters and a record 10 million tonnes from inland waters (FAO, 2010). World capture fishery production was relatively stable in the past decade. The fishery sector is a major source of income and livelihood for millions of people around the world. Employment in the fishery sector has grown faster (with an average rate of increase of 3.6 percent per year since 1980) than the world's population and employment in traditional agriculture (FAO, 2010). The number of people directly or indirectly supported by marine fishery is about 540 million or nearly 8% of the world's population (FAO, 2010).

## 2.1 SLR and other climate change events

Global climate change brings additional pressure on degraded coastal ecosystems. Climate change will have enormous effect on the physical, biological and biogeochemical characteristics of the oceans and coasts by modifying the ecological structure and functions. Coasts are highly vulnerable to extreme events, such as storms, which impose substantial costs on coastal communities. Nearly 120 million people in the World are exposed to tropical cyclones annually, which killed 2, 50,000 people from 1980 to 2000. Through the 20th century, global rise of sea level contributed to increase in coastal inundation, erosion and ecosystem losses, but with considerable local and regional variations (IPCC, 2007).

The change in sea level (mean sea level) at the coast is defined as the height of the sea with respect to a local land benchmark, averaged over a period of time, such as a month or a year, long enough so that fluctuations caused by waves and tides are largely removed (IPCC, 2001). Measurements of present-day sea level change rely on two different techniques: tide gauges and satellite altimetry. Changes in mean sea level as measured by coastal tide gauges are called "relative sea level changes". From 1961 to 2003, the average rate of SLR was 1.8 ± 0.5 mm/yr. For the 20th century, the average rate was 1.7 ± 0.5 mm/yr (IPCC, 2001). The projected rise from 1990 to 2100 is 9–88 cm with a mid-estimate of 48 cm (IPCC, 2001). Recent study shows that rise in sea level is much greater than the earlier estimation in the IPCC and other scientific studies (Pycroft et al., 2014). Based on revised estimates the sea-level rise until 2100 will be between 1.0 and 2.0 m, compared with 0.4 and 1.0 m estimated earlier. During 1901 to 2010 the mean rate of global averaged sea level rise was 1.7 [1.5 to 1.9] mm/yr, and 2.0 [1.7 to 2.3] mm/yr between 1971 and 2010, and 3.2 [2.8 to 3.6] mm/yr between 1993 and 2010 (IPCC, 2013). Besides SLR, storms and tropical cyclones also lead to significant effects at the coast, directly through changes in extreme winds, and indirectly by causing storm surges and large waves (Nicholls and Lowe, 2004).

However, there is uncertainty regarding the scenarios used in the scientific studies for measuring future sea level changes. Recent research and expert opinion indicate that significant SLR may occur earlier than previously thought. And there will be variations in the regional sea levels. The regional and local sea levels will not necessarily be the same as the global average change. Regionally and locally, vertical land movements can be quite large, even on the decadal time scale. There are dynamic effects resulting from oceanic circulation, wind and pressure patterns, which along with ocean-water density cause variations in the level of the sea surface (IPCC, 2001).

## 2.2 Vulnerability and socio-economic impacts

The rise in sea level has a number of biophysical and socio economic impacts. These include loss of property and coastal habitats, damage to infrastructure, increased flood risk and potential loss of life, loss of tourism, recreation and transportation functions, impacts on agriculture and aquaculture through decline in soil and water quality and inundation (Nicholls and Lowe, 2004). Degradation of coastal ecosystems, especially wetlands and coral reefs, also has serious implications for the well-being of the societies dependent on the coastal ecosystems for goods and services. Increased flooding and degradation of freshwater, fishery and other resources could impact hundreds of millions of people, and the socio economic costs on coasts will escalate as a result of climate change.

The potential impacts of SLR are estimated for different countries (developed, and developing) considering a 1-5metre rise in sea levels (TERI, 1996). Few other studies are also attempted to assess the regional level estimates (Nicholls and Mimura, 1998; Darwin and Tol, 2001; Dasgupta et al., 2007). These studies considered a number of different indicators for estimating the impacts like land loss, population affect, total capital loss and wetlands loss etc. In a study by Dasgupta et al. (2007), six indicators are chosen; these are land, population, GDP, urban extent, agricultural extent and wetlands. The study estimates the impact for 84 developing countries situated in the coastal region by grouping them into five world regions (Latin America and the Caribbean countries; Middle East and North Africa; Sub-Saharan Africa; East Asia and South Asia). The most affected regions due to SLR are East Asia and South East Asia.

The comparison of the relative magnitude of impacts across countries or regions is very difficult because of the different subsets of indicators or regions used in different studies. Further, most of these impacts derived in general are linearly related to SLR, the only exception being wetland loss that is more strongly related to the rate of SLR, rather than the absolute change (Nicholls and Lowe, 2004). Nicholls (2004) in a study measured the impact of SLR considering coastal flooding and wetland loss under the IPCC SRES scenarios. Under the A2 (Self-reliance and preservation of local identity, high population) scenario, coastal flooding remains a problem through 2080s. In West Africa, East Africa, South Asia and South East Asia, more than 80% of the population will be affected by floods. On the other hand, Hitz and Smith (2004) found that adverse impacts of climate change will increase with the rise in temperature and sea level, and it is difficult to determine whether the relationship between impacts and SLR is a straight line or exponential. However, these global projections of SLR only provide a generalized view of what the magnitude of SLR might be, whereas the impact would more likely to be felt locally. The low-income settlements, and poor income groups within all settlements, tend to be the most vulnerable to these changes.

Many coastal communities in the developing world are described as fragile. They depend highly on a severely depleted and overfished natural resource base and on badly degraded coastal ecosystems. Climate change will further complicate the challenges by affecting the productivity and thereby livelihood of marine fishery dependent communities. The changes in water temperature, precipitation and oceanographic variables like, wind velocity, wave action and SLR, can bring significant ecological and biological changes to coastal ecosystems. The direct and indirect pathways through which climate change will affect marine fishery are analysed by researchers like (Allison et al., 2005: Vivekanandan, 2006: Allison et al., 2009: Badjeck et al., 2010: Sumaila et al., 2011).

The IPCC has already issued a warning regarding the seriousness of the impact of climate change on fish distribution. However, it is challenging to derive the relationship between climatic factors and fish production. One of the major problems in assessing the impact is the complexity of segregating the climate-induced changes in fish population from other human–induced changes such as over fishing (Vivekanandan, 2006). The record of fish catches are often influenced by economic factors such as the relative price paid for different types of fish. These non-climatic factors therefore over/underestimate the climate related trends in fish catch. But there is no doubt that climate change will add to the problems in fishery sector that is already characterized by stagnating catches, full utilization of resources, large overcapacity and conflicts among fishers.

The following points show different types of effect of climate change on fishery.

The ecological impacts of climate change on fishery include:

1. Change in ecosystem processes, change in yield i.e. fish stocks and production, change in species distribution i.e. fish migration, increased variability of catches, changes in seasonality of production i.e. decrease in fishing season

The direct impacts of climate change on fishery livelihood include:

2. Damage to infrastructure, damage to fishing gears, increased danger at sea, loss/gain of navigation routes, flooding in the living areas of fishing villages.

The socio-economic impacts of climate change on fishery include

3. Economic drain on fishermen, rehabilitation, increase in fuel costs, reduced health due to diseases.

Vulnerability of 132 countries to the potential impacts of climate change on fish catch is derived using an indicator-based approach (Allison et al., 2009). The study considers vulnerability as the function of exposure, sensitivity and adaptive capacity. The indicators of exposure include water temperatures and other climatic exposure like precipitation, salinity, ocean circulation and mixing, river flow, nutrient levels, sea and lake levels, ice cover, glacial melt, storm frequency and intensity, and flooding. Sensitivity is derived through a composite indicator comprising fishery production (landings), and the contributions of fishery to employment, export income and dietary protein. Adaptive capacity comprises elements such as levels of social capital, human capital and the appropriateness and effectiveness of governance structures. Here vulnerability $V = f([E, S] - AC)$ is considered as a direct function of exposure (E) and sensitivity (S) but indirect function of adaptive capacity (AC) that also measures the potential impacts of climate change. The result of the study shows that countries in Central and Western Africa (e.g. Malawi, Guinea, Senegal, and Uganda), Peru and Colombia in north-western South America, and four tropical Asian countries (Bangladesh, Cambodia, Pakistan, and Yemen) are more vulnerable.

Climate change has already altered ocean conditions, particularly water temperature and biogeochemistry. These observed changes along with future projections are expected to impact fishery production, distribution and composition. Further, this will affect fishing operations, the allocation of catch shares and the effectiveness of fishery management measures. The economic consequences of climate change are losses in terms of revenues due to changes in the price and value of catches, fishing costs, earnings to fishing companies and household incomes in many regions, as well as throughout the global economy. Capital costs, that is, the cost of vessels, fishing gear, processing plants and so on, would also be affected by climate change (by involving additional capital for fishing and processing operations to adapt to climate change impacts on the quantity, composition and distribution). Changes in migratory routes and fish distribution would also affect travel time, which can lead to increase or decrease in fuel and storage costs depending on catch levels and patterns, and also the management regime in place (Sumaila et al., 2011).

## 3. Coastal ecosystem in India

### 3.1 Geographic and physical profile

Vulnerability of coastal zone depends on underlying physical and socio-economic characteristics of coastal areas. The 8118 km long coastline of India is comprised of eastern and western coast line. The eastern coast line includes 4 States, West Bengal, Odisha, Andhra Pradesh and Tamil Nadu. The west coast line includes 5 states, Gujarat, Maharashtra, Goa, Karnataka and Kerala. The other Union territories of coastal India include Pondicherry, Andaman and Nicobar Islands on the east coast, while Daman Diu and Lakshadweep Islands are on the west coast. Total area under the 9 coastal states constute about 42% of the total area in India and includes 66 coastal districts. The two coasts are different in many aspects. The east coast is known for flat terrain dotted with beaches, rich in coral reefs, coastal sand bars-dunes, river basins, backwaters, deltas, lakes (Chilika Lake), saltpans, mangrove and mudflats (it constitutes 7% of total worlds mangrove area). On the other hand the western coast has narrow rolling plains, estuaries (Western Ghats), creeks, few sandy beaches and plenty of natural inlets coupled with rocky outcrops. Along with this variety of natural and physical structures, both the coasts have a greater differentiation in terms of economic activities, population, industry and Infrastructure.

**Table 1:** Features of coastal states and union territories

| State/ Uts | Length of Coast line (kms) | Population in coastal districts (in millions) | Population density (p/km$^2$) |
|---|---|---|---|
| Andhra Pradesh | 974 | 33.6 | 308 |
| Goa | 104 | 1.46 | 394 |
| Gujarat | 1600 | 39.89 | 308 |
| Karnataka | 300 | 4.70 | 319 |
| Kerala | 590 | 27.46 | 859 |
| Maharashtra | 720 | 28.63 | 365 |
| Odisha | 480 | 11.62 | 269 |
| Tamil Nadu | 1076 | 33.38 | 555 |
| West Bengal | 158 | 29.28 | 1029 |
| Andaman and Nicobar Islands | 1912 | 0.378 | 46 |
| Daman and Diu | 27 | 0.242 | 2169 |
| Lakshadweep | 132 | 0.064 | 2013 |
| Puducherry | 45 | 1.24 | 2598 |

Source: Census, 2011

### 3.2 Demographic profile

More than 250 million people in India live within 50km of the coastline; a majority of them consist of urban population. According to Census (2011), 17% of the total population in India belongs to the 66 coastal districts of the 9 coastal states (Table 1). There are 77 cities in the coastal region of India, including some of the largest and most dense urban agglomerations like; Mumbai, Kolkata, Chennai, Kochi and Visakhapatnam. The population density per $km^2$ in most of the districts is higher than the density of the respective state and country. The high population density increases the risks and vulnerability of the coastal states, as more people become vulnerable to climate change issue. Historically coastal zones are home to a large number of fishing communities. The fishing communities have a traditional way of living. But the current pressure from urbanization is pushing them to poverty. The well being and livelihood of fishing communities is linked to the state of coastal ecosystems.

### 3.3 Economic profile

The coasts of India are of enormous socio-economic importance, which inherits highly productive ecosystem, a rich marine biological diversity and the largest number of commercial fish species in the world. The major activities undertaken along the Indian coastal zone are traditional activities like; fishing, tourism, agricultural activities, oil exploration, commercial and residential development. Fishing activities not only provides important source of food but also provides employment, income and foreign exchange for India. The new types of resources include using new technologies such as ocean thermal energy, wave energy, offshore mineral deposits, etc. Importance of the industrial sector in the Indian economy has risen. Currently coastal states in India together represent more than 60% of FDI inflow and 68% of total factories with the highest productivity in Tamil Nadu followed by Maharashtra. The GDP contribution to the Indian economy is higher from the mega cities like Mumbai, Kolkata, and Chennai which are situated along the India's coastline. Both the coasts (East and West) are important trading centres from ancient times. India has eleven major sea ports along the coastal regions. The high economic value of these areas and its relative fragility and vulnerability to natural hazards, SLR and anthropogenic activities make the preservation and the management of coastal zone resources to be of enormous economic importance. The major activities carried out along the coastal areas of India are given in the following table (Table 2).

### 3.4 Climate change issues and concerns

Climate change issues are of major concerns for coastal regions of India mainly because of the vulnerability of poor to climate changes and because of large spatial and temporal variations in the climate. India has been identified as one amongst the 27 countries which are the most vulnerable to the impacts of global warming related accelerated sea level rise (UNEP, 1989). Observations suggest that the sea level has risen at a rate of 2.5 mm per year along the Indian coastline since 1950s. A mean SLR of between 15 and 38 cm is projected by the mid- $21^{st}$ century along India's coast. Added to this, a 15% projected increase in intensity of tropical cyclones would significantly enhance the vulnerability of population living in cyclone prone coastal regions of India (Aggarwal and Lal 2008).

The SLR is likely to result in loss of land due to submergence of coastal areas, inland extension of saline intrusion and ground water contamination and may have wide economic, cultural and ecological repercussions. The high degree of vulnerability of Indian coast can also be characterized by an extensive low-laying coastal area, high population density, frequent occurrence of cyclones and storms, and a high rate of coastal environmental degradation. Further, scientists predicted that changes in average temperatures, rainfall patterns and monsoon timings will affect India's entire environment in the coming years, and will adversely affect nation's water resources, sea-levels and biodiversity. A significant proportion of the population in coastal areas in India also lives in poverty. The rapid economic growth, without adequate considerations for equity, fuelled by the pressures of liberalization and globalization, has led to the unregulated expansion of economic activities in coastal areas.

**Table 2:** Major activities along the Indian coastal zone

| | | |
|---|---|---|
| **Land Based** | | |
| I. | Coast dependent | Ports and Harbours |
| | | Oil Terminals |
| | | Paper and Pulp mills |
| | | Metallurgical Plants |
| | | Fish Processing |
| | | Power Plants |
| II. | Coast preferring | Urban, commercial and residential development |
| | | Tourism and beach recreation |
| | | Agriculture |
| III. | Coast independent | Defence |
| **Water Based** | | |
| | | Offshore Oil and Gas |
| | | Offshore Placer Mining |
| | | Navigation |
| | | Naval Defence |
| | | Water Sports |
| | | Fishing |
| | | Dredging and Land Reclamation |

Source: The State of Environment (Ministry of Environment and Forests)

The coastal regions in India are in immense pressure from both natural as well as anthropogenic activities. The latter occurs either due to overexploitation of coastal and marine resources or due to the use of the coastal and marine environment as sinks for pollutants and other wastes arising as by-products of development activities. There are various sources of marine pollution, and their impact varies as per the nature of the pollutant.

## 4. Sea level rise along coastal India

The estimation of mean SLR for various ports in India is available on the basis of past tide gauge data. Among these, the estimates for Mumbai, Kochi and Vishakhapatnam showed a SLR of 0.78, 1.14 and 0.75 mm/year respectively, where as the estimates for Chennai showed a decrease in sea level (-0.65 mm/year) (Unnikrishnan et al., 2006). In another study Unnikrishnan and Shankar (2007) estimated SLR for the northern part of Indian Ocean. The estimated trend in stations like Mumbai, Kochi in the Arabian Sea and Vishakhapatnam in the Bay of Bengal is between 1.06 -1.75mm/yr, with an average rise of 1.29mm/yr. Their estimation results are also found consistent with the global estimates of Inter Governmental Panel on Climate Change (IPCC). This shows that the SLR trends in northern Indian Ocean are comparable to global estimates.

Vulnerability of Indian coastal region to the consequences of the estimated SLR due to green house effect shows the region most vulnerable to SLR is the low-lying areas of Lakshadweep Island and the east coast region (Sathaye et al., 2006). The east coast region is more vulnerable to the frequency of storms. The physical impacts of 1 metre SLR is estimated for the nine coastal states and 38 coastal districts (TERI, 1996). It is found that 5763 $km^2$ (or 0.41%) combined area of the coastal states will be directly affected by such changes. A total of 7.1 million people are found to be at risk, representing 4.6% of the total coastal population. Gujarat and West Bengal are the most affected states in terms of land area loss to 1 metre SLR, similarly in terms of population, Tamil Nadu and Maharashtra are the most affected because of their high density of coastal population (Table 3). In terms of land use, cultivated land is the most affected in West Bengal, Odisha, and Maharashtra. In terms of settlement land, Maharashtra and Gujarat are the most vulnerable states (TERI, 1996). Considering the impact at district level, Mumbai is found to be highly vulnerable to land loss with a consequent affect on its population. However, the extent of vulnerability not only depends on mere exposure to SLR and population living close to the sea, but also depends on the levels of economic activity in the region, land use, coastal infrastructure and investment. The estimated economic costs for the same ranges from Rs 2287 billion in the case of Mumbai to Rs 3.6 billion for Baleshwar district of Odisha where the impacts are likely to be less (TERI, 1996).

**Table 3:** Potential effects of 1mt sea level rise on India's coastal area and population

| State/Union teritories | Coastal area (million hectares) | | | Population (millions) | | |
|---|---|---|---|---|---|---|
| | 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 | 4.34 | 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 |
| Odisha | 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 |
| India | 139.594 | 0.571 | 0.41 | 416.74 | 7.1 | 1.68 |

Source: TERI (1996)

According to Dwivedi and Sharma (2005), one of the most significant and direct impact of SLR is the shoreline retreat and the loss of the coastal wetland as a result of the inundation of the low land. Using mean SLR data from various stations in India, they estimated 2100 $km^2$ of wetland loss in West Bengal out of a total of 3604 $km^2$ if the current sea level trend continues for the next 100 years. The maximum loss of coastal wetland projected for Gujarat approximately 8453 $km^2$ out of a total of 25083$km^2$. The loss in the coastal wetlands will further harm the biological diversity of flora and fauna and productivity of the wetland systems. Therefore necessary measures must be taken towards maintaining sustainability and the health of wetlands which are important sources of freshwater, besides being sources of livelihood to rural population.

### 4.1 Flood, cyclones and other events

Increased flooding and salt-water intrusion have direct effect on coastal agriculture, fisheries, aquaculture, freshwater resources, human settlements and tourism. The impact of climate change can also be related to the loss of biodiversity in coastal areas. The vulnerability atlas of India (BMTPC, 2006) shows 8.5% of total land in India is vulnerable to cyclones, 5% of land is vulnerable to floods and 1 million houses are vulnerable to other allied damage annually. Between 1877-2005 total 283 cyclones (among those 106 severe cyclones) occurred in a 50 km wide strip on the east coast whereas comparatively less severe cyclones occurred on west coast (total 35 cyclones). In 19 severe cyclonic storms death toll was greater than 10,000. The super-cyclone of 1999 wreaked havoc in coastal Odisha claiming more than 30,000 human lives. Similarly in July 2005, the city of Mumbai received an unprecedented 944 millimetres of rainfall in a 24-hour period, resulting in the most devastating floods in recent history leaving more than 500 people dead, mostly in slum settlements.

While the vulnerability varies from region to region, a large part of the country is exposed to such natural hazards which often turn into disasters causing significant disruption of the socioeconomic life of communities (BMTPC, 2006). Storm surges are also the major cause of coastal flooding along the east coast of India. The projected rise in the sea level due to greenhouse warming may affect the storm surges and consequently the coastal flooding in the east coast. The mangroves along the coastal regions of India including Andaman and Nicobar Islands act as barriers against cyclones, avoid coastal erosion and serve as habitat for a number of aquatic lives specially fish, prawns and crabs.

Besides anthropogenic disruptions Climate changes will further disturb the delicate balance of the mangrove ecosystems and hence can bring out visible changes in them (Dash et al., 2007). Table 4 shows the recent figures of damaged (human lives lost, cattle lost, houses damaged and crop area affected) due to cyclones, heavy rains, floods along the coastal states of India.

Impacts of climate related natural hazards in the coastal zone, particularly tropical cyclones studied by Patwardhan et al. (2003). A number of indices (housing, population) are constructed based on various indicators such as population density, housing materials from secondary sources at district level. The cyclone specific data like; number and frequency of tropical cyclones, human mortality, livestock morality, damaged house and damaged crop are collected and an impact index is generated. Overall impacts of climate change and vulnerable districts are derived with the help of cluster analysis. The number of vulnerable districts in east coast is found to be more in comparison to west coast because the frequency and magnitude of tropical cyclone is more in east coast. Kumar and Tholkappian (2006) also estimated the relative vulnerability of coastal districts in India using composite index. They used demographic (population density, annual population growth), physical (coast length, insularity, frequency of cyclones, probable maximum surge heights), economic (agricultural dependency, income), and social (literacy, spread of institutional set up) indicators to construct the indexes. Composite indexes are calculated by taking the averages of all the standardized observations of each district over all the components. Like the above study this study also found that the number of vulnerable districts on the east coast regions of India is more than in the west coast region.

**Table 4:** Damage due to Cyclonic Storms/Heavy Rains /Flash Floods/Landslides in coastal states of India (2010-2011 and 2011-2012)

| States/UTs | 2010-2011 | | | | 2011-2012 (P) | | | |
|---|---|---|---|---|---|---|---|---|
| | No. of Human Lives Lost | No. of Cattle Lost | No. of Houses Damaged | Cropped Area Affected (Lakh Hectare) | No. of Human Lives Lost | No. of Cattle Lost | No. of Houses Damaged | Cropped Area Affected (Lakh Hectare) |
| Andhra Pradesh | 171 | 17230 | 38152 | 20.86 | - | - | - | - |
| Gujarat | 232 | 541 | 4735 | 0.67 | 53 | 175 | 4734 | - |
| Goa | 1 | 1 | 101 | - | 1 | - | 134 | - |
| Karnataka | 82 | 215 | 14400 | 0.1 | 84 | 51 | 419 | - |
| Kerala | 103 | 87 | 15328 | 0.03 | 133 | 525 | 11737 | 0.88 |
| Maharashtra | 8 | 5 | 9 | - | 106 | - | - | - |
| Odisha | 10 | 260 | 5339 | 0.3 | 87 | 1493 | 290780 | 4.19 |
| Tamil Nadu | 203 | 5436 | 325080 | 4.17 | - | - | - | - |
| West Bengal | 112 | 7 | 180374 | 0.3 | 77 | 33 | 317481 | 0.09 |
| Andaman and Nicobar Islands | 6 | - | - | - | - | - | - | - |
| Puducherry | - | - | 346 | 0.01 | - | - | 4 | 0.0049 |
| India | 2310 | 48778 | 1338619 | 45.75 | 1430 | 6266 | 684901 | 1628 |

Source: Indiastat.com

## 5. Discussion and conclusion

Studies analyzed in this paper are mostly based on estimating vulnerability at macro level. Studies have considered the country as a whole or, coastal states or coastal districts as the units of analysis. However, India is a vast country having geographic, economic, cultural diversity. The coastal fishing communities living close to the sea are always vulnerable to climate change and other related impacts. The fisheries sector makes important contributions to local development in coastal regions, provides huge employment and diverse livelihood. Fishing livelihood also provide useful platforms to study adaptation to climate change because fishing community is well known for being reactive to changes in environment, markets, and an unpredictable resource base (Coulthard, 2008). Fishing community depends mostly on natural resources for their livelihood whose distribution and productivity are known to be influenced by climate dynamics. Climate change will impact fisheries through a diversity of direct and indirect pathways (Badjeck et al., 2010). Hence there is a need for local level studies focusing on fishing communities and their livelihood aspects.

## 6. References

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