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Review Article

SEA LEVEL RISE AND COASTAL VULNERABILITY ASSESSMENT: A REVIEW

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ABSTRACT
The coastal zones are highly resourceful and dynamic. The coastal zones are facing many natural hazards such as coastal erosion, Storm surge, Tsunami, coastal flooding and sea level rise. It is obvious that the future sea level rise due to human induced global warming is the main threat to the coastal zone. The global mean sea level is continuing to rise during the 21st century. In this regards, coastal vulnerability assessment due to sea level rise is needed. Globally, there are many coastal vulnerability assessment tools and techniques such as CM (Common Methodology), SURVAS (Synthesis and Up scaling of Sea Level Rise Vulnerability Assessment Studies), DIVA (Dynamic Interactive Vulnerability Assessment) and CVI (Coastal Vulnerability Index). In the present paper discuss the various aspects of sea level rise and coastal vulnerability index assessment in details.

Key Words: *Sea Level Rise, Coastal Zone, Coastal Vulnerability, Coastal Vulnerability Index*

INTRODUCTION
Sorenson and McCreary (1990) defined 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 that is an area in which processes depending on the interaction between the land and sea are most intense." However, the extent of coastal zone is varies rim due to daily tides, seasonally with astronomic forces, and sporadically with sea storms and great river floods etc. Coastal zone is a physiographic unit. The total global coastlines have above 1.6 million kilometres and coastal ecosystems occurred in 123 countries around the world (Burke *et al.,* 2001). The narrow strip of coastal zone covers less than 5% of Earth's land surface area (Rashid *et al.,* 2009). Coastal zone are the most fragile, dynamic and productive ecosystem and it is under pressure from both anthropogenic activities and natural processes. The coastal environment is a unique because mangroves forest, coral reefs, sea beaches, sea weeds, tidal flats and daily tide, waves etc. are found only at the coast. 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. It contains a wide range of natural resources, productive and valuable habitat of the biosphere such as mangroves, coral reefs, saltpans, salt-marsh, creeks, estuary, beach, sand dune estuary, lagoons, coastal wetlands and mud-flat etc. It also provides important services such protecting shoreline and absorbing flood water as filtering of pollution, retaining nutrients, maintaining water quality. Due to its unique location benefited environment, fertile lowland, abundant marine resources, water transportation, aesthetic beauty etc., people are attracted to live, to commerce, to military and to a variety of industries from ancient time to the present. It is an area of high economic significance due to faster economic development, large population migrations and urban development. It is estimated that 1.2 billion people, or approximately 23 % of the world's population, lives within 100 m of sea level and 100 km from the coast (Nicholls and Small, 2002; Nicholls, 2003). 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 on the coast (Crooks and Turner, 1999). But the coastal zones are facing a lot of problems. They are landfill, dredging, and pollution caused by urban, industrial and agricultural development, coastal erosion, loss of coastal habitat, storm surge, tsunami and the global warming induced sea level rise etc.

Human activities such as industrial activities, agricultural practice and destruction of forest, development of transport system are major causes of increasing emissions of greenhouse gasses like co2, methane, CFCS into the atmosphere. IPCC 2001 estimated that the atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have grown by about 31%, 151% and 17%, respectively, between 1750 and 2000 year. The globally averaged temperature near the Earth's surface rose by 0.74 ± 0.18 °C over the period 1906–2005 (IPCC 4th assessment report). According to the IPCC 4th report, the rate of warming over the last half of that period was almost doubles that for the period as a whole (0.13 ± 0.03 °C per decade, versus 0.07 °C ± 0.02 °C per decade; whereas Hansen *et al.,* 2001 and Trenberth *et al.,* (2007) reported that the Earth warmed from ~1900 to 1940, cooled slightly from ~1940 to 1965–1970 and then warmed markedly from ~1970 onward. The evidences of global warming are found in the three major ice repositories in the world. The Greenland ice is melting at a rate of 239±23 km^3 per year (Chen *et al.,* 2006). The extent of Arctic sea ice has been decreasing by almost 8% per decade since the middle of last century (Stroeve *et al.,* 2007). Perhaps the most alarming is the widespread loss of ice in West Antarctica (Rignot *et al.,* 2008) contributing to global sea level rise of ~0.36 mm/year (Chen *et al.,* 2008). On the whole, the climate change-induced rise in global sea level is estimated to be 1–3 mm/year (Pielke *et al.,* 2007). Even if the global temperatures are levelled off at this stage, the sea level continues to rise over the 21 century (Meehl *et al.,* 2005). The global warming causes significant upward shift in species optimum elevation (Lenoir *et al.,* 2008); increase the food prices all over the world (Parry *et al.,* 2008), public health problems such as the alarming spread of malaria in Africa and elsewhere (Hoyle, 2008). According to the Warren *et al.,* (2013), More than half of common plants and one third of the animals could see a dramatic decline this century due to climate change and Plants, reptiles and particularly amphibians are expected to be at highest risk. Perhaps the most commonly recognized impact of global warming is the eustatic rise in sea level (Allen and Komar, 2006) due to thermal expansion of seawater and addition of ice-melt water (Meehl *et al.,* 2005). According to Piontek *et al.,* (2013), one out of 10 people on Earth are likely to live in a climate impact hotspot by the end of this century, if greenhouse gas emissions continue unabated.

1.1 Sea Level Rise Measurement

Sea Level means the height of the sea measured relative to a mark on the nearby land called the Tide Gauge Benchmark. Mean Sea Level 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). 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 120meters lower than today. Compared with those of previous millennia, the changes in global sea level occurring today are tiny. The global sea level increased by about 120m as a result of the deglaication 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.

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 increased (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 (Lambeck *et al.,* 2002; Gehrels *et al.,* 2006; Kemp *et al.,* 2009). The global sea level rise over the 20th century is 1.7 +/- 0.5mm/year (IPCC, 2007). According to Holgate 2007, "the rate of sea level change was found to be larger in the early part of the last century (2.03 ±0.35mm/yr., for the period of 1904 to 1953 year), in comparison with the later part (1.45 ±0.34 mm/yr. for the period of 1954-2003 year). The highest decadal rate of rise occurred in the decade centred on 1980 (5.31 mm/yr.) with the lowest rate of rise occurring in the decade centred on 1964 (-1.49mm/yr.). Over the entire century the mean rate of change was 1.74±0.16mm /yr". A detailed analysis of sea level rise was carried out by Church and White (2006) and they reconstructed global sea level from a variety of data sources back to 1870. From 1870 to 2004 (135yr.) the total global sea level rise was 195mm, an average of 1.44mm/yr. for the 20th century; the rise was about 160mm (1.7±0.3mm/yr.) indicating a slight acceleration during the 20th century. Leuliette *et al.*, (2004), estimate that the global average sea level has been rising at a rate of 2.8± 0.4mm/yr. Based on the advent of high-accuracy satellite altimetry since about 1993, Cazenave *et al.*, (2008) found that the GRACE-based Ocean mass has increased at an average rate of 1.91+/ -0.1 mm/yr. over the period of 2003–2008. According to IPCC 5th assessment report, 2013, the rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia. Over the period 1901–2010, global mean sea level rose by 0.19 [0.17 to 0.21] m. They also predicted that the global mean sea level will continue to rise during the 21st century due to increased ocean warming and increased loss of mass from glaciers and ice sheets.

1.2 Sea Level Observation in Indian Scenario

Sea level change study of Indian coast has been carried out by many researchers and scientists in India such as Emery and Aubrey (1989); Douglas (1991), Das and Radhakrishna (1993) Unnikrishnan *et al.*, 2006; Unnikrishnan *et al.*, (2007). Das and Radhakrishna 1993 reported that the average sea level rise for India region was 2.5 mm/year since the 1950. According to Shankar *et al.*, (2001), the mean sea level is higher in bay Bengal in comparing to the Arabian sea due to the wind forced coastal circulation and the salinity gradient along the coast . Mean sea level rise at selected stations along the Indian coast namely Mumbai, Kochi, Chennai and Vishakhapatnam, have 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 estimate of sea level rise needs to be corrected using the rates of vertical land movements. In the next year, Unnikrishnan *et al.*, 2007 estimates that the mean sea-level-rise along the Indian coasts are in between 1.06– 1.75 mm/year, with a regional average of 1.29 mm/yr, after correction of global isostatic adjustment (GIA) using model data.

1.3 Prediction of Sea Level Rise

The range of sea level rise at the end of 21st century as presented in the Intergovernmental Panel on Climate Change (IPCC) second assessment report, 1996 was 0.13 to 0.94 metres based on the IS92 scenarios. IPCC (2000) was published a report called "The **Special Report on Emissions Scenarios** (SRES)" which describe the greenhouse gas emissions scenarios. These SRES scenarios have been used to make projections of possible future climate change. The SRES scenarios were used in the IPCC Third Assessment Report (TAR), published in 2001, and in the IPCC Fourth Assessment Report (AR4), published in 2007. The SRES scenarios were designed to improve upon some aspects of the IS92 scenarios. The global mean sea level is projected to rise at the end of 21st Century by 0.09 to 0.88 metres for the full range of SRES scenarios (IPCC, third assessment report, 2001). This is due primarily to thermal expansion and loss of mass from glaciers and ice caps. IPCC (2007) had given sea level rise estimates that range between 18 and 59 cm up to the end of the next century (excluding future rapid dynamical changes in ice flow for each scenario family). For the Fifth Assessment Report of IPCC, the scientific community has defined a set of four new scenarios, denoted Representative Concentration Pathways (RCP). These four RCPs include one mitigation scenario leading to a very low forcing level (RCP2.6), two stabilization scenarios (RCP4.5 and RCP6), and one scenario with very high greenhouse gas emissions (RCP8.5). The RCPs can thus represent a range of 21st century climate policies, as compared with the no-climate-policy of the Special Report on Emissions Scenarios (SRES) used in the Third Assessment Report and the Fourth Assessment Report. The last assessment report of the IPCC-Intergovernmental Panel on Climate Change (IPCC AR5, 2013) has given new estimates of sea level rise for different Representative Concentration Pathways (RCPs) scenario. These are shown in table.1. Some published papers give new estimates on global sea level rise. Rahmstorf (2007) gives an estimate of 50-140 cm, later corrected to 75-190 cm (Vermeer and Rahmstorf, 2009). Horton *et al.*, (2008) estimate 54-89 cm (acknowledging that this could be a lower limit), and Jevrejeva *et al.*, (2010) estimate the sea level rise between 60 and 160 cm. It can be noticed that all estimates are substantially higher than the estimate of AR4. Jevrejeva *et al.*, (2011), use a physically reasonable sea level model constrained by observations, and forced with four new Representative Concentration Pathways (RCP) radioactive forcing scenarios (Moss *et al.*, 2010) to project median sea level rises of 0.57 for the lowest forcing and 1.10 m for the highest forcing by 2100 which rise to 1.84 and 5.49 m respectively by 2500. 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 (Josh *et al.*, 2010).

Table 1: Global sea level rise projection based on various RCP scenarios (IPCC fifth assessment report, 2013)

		2046-2065		2081-2100	
Variable	Scenario	Mean	Likely range	Mean	Likely range
Global Mean Sea Level Rise (m)	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to .63
	RCP6.0	0.25	0.18 to 0.32	0.47	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.63 to 0.82

1.4 Impacts of Sea Level Rise

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 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.*, 2000). 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 (Tanh and Furukawa, 2007) face the danger of being displaced. Ultimately, this may lead to the displacement of millions of people, significant damage to property and infrastructure, and a considerable loss of coastal ecosystems by the end of the 21st Century (Nicholls and Lowe, 2004). Protection of life, property and coastal environment along the coast are major causes of concern.

2. Coastal Vulnerability

The term "vulnerability" is used among a wide range of scientific discipline and policymakers from different aspects (Zou and Thomalla, 2008). The Intergovernmental Panel on Climate Change (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. So 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). According to Blaikie *et al.*, 1994, vulnerability means: "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 hazard (an extreme natural event or process)". 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.

Review Article

Table 2: Summary of coastal vulnerability indices, their geographical application and the variables needed to implement them (Modified from Abuodha and Woodroffe, 2007). International approaches

Index	Geographical application	Variable considered	Reference
Coastal vulnerability index (CVI)	USA	Relief, rock type, landform, vertical land movement, shoreline displacement, wave energy, tidal range	Gornitz and Kanciruk, 1989; Gornitz, 1991; Gornitz *et al.*, 1991
Coastal vulnerability index (CVI)	USA	Historic shoreline erosion rates, geomorphology, relative rates of sea-level rise, coastal slope, wave height , tidal range	Thieler and Hammer, 1999
Coastal vulnerability index (CVI)	USA	Geomorphology, regional coastal slope, rate of relative sea-level rise, historical shoreline change rates, mean tidal range and mean significant wave height.	Pendleton *et al.*, 2004
Coastal vulnerability index (CVI)	Greece	Coastal slope, displacement, geomorphology, wave height and tidal range	Doukakis, 2005
Social vulnerability index (SoVI)	USA	Principal components analysis of Census-derived social data	Boruff *et al.*, 2005
Coastal vulnerability Index	Coast of the Buenos Aires Province, Argentina	Elevation, Geology, Geomorphology, Shoreline erosion/accretion, Mean tide range, and mean wave height.	Diez *et al.*, 2007
Coastal social vulnerability score (CSoVI)	USA	Combination of CVI and SoVI	Boruff *et al.*, 2005
Sensitivity index (SI)	Canada	Relief, sea-level trend, geology, coastal landform, shoreline displacement, wave energy, tidal range	Shaw *et al.*, 1998
Erosion hazard index	Canada	As SI, plus exposure, storm surge water level, slope	Forbes *et al.*, 2003
Risk matrix	South Africa	Location, infrastructure (economic value), hazard	Hughes and Brundrit, 1992
Sustainable capacity index (SCI)	South Africa	Vulnerability and resilience of natural, cultural, institutional, infrastructural, economic and human factors	Yamada *et al.*, 1995
Sensitivity index	Ireland	Shoreface slope, coastal features, coastal structures, access, land use	Carter, 1990

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

1. The susceptibility of a coastal area to the physical and ecological changes imposed by sea-level rise;
2. The potential impacts of these natural systems changes on the socioeconomic system;
3. The capacity to cope with the impacts, including the possibilities to prevent or reduce impacts via adaptation measures. (This last factor is often termed 'adaptive capacity').

The more suitable definition given by IPCC Fourth Assessment Report 2007, in relation with climate change and sea level rise, as: "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2007)". Hence, vulnerability is a function of exposure, sensitivity and adaptive capacity (figure 1). Stockholm Environment Institute defined vulnerability as the degree to which an exposure unit (e.g. social group or ecosystem) is susceptible to harm due to exposure to a perturbation or stress, and the ability (or lack thereof) of the exposure unit to cope, recover, or adapt (Zou and Thomalla, 2008). The present study considers vulnerability is the degree of loss resulting from the occurrence of the phenomena and vulnerability mapping is basically an estimation of coastal landforms which are vulnerable to predict the sea level rise.

2.1 Tools and Techniques of Coastal Vulnerability Assessment

The extensive research has been carried out in the past two decades by many researchers on potential and observed impacts of climate change on natural and social systems (McCarthy *et al.*, 2001). Its major focus is coastal zone particularly impacts and adaptation of climate change and sea level rise as well as the sustainable coastal management. Several international approaches have been developed to assess the vulnerability of coastal zone due to climate change and sea level rise (Abuodha *et al.*, 2006). These are follows:

1. IPCC Common Methodology (CM)
2. Coastal vulnerability index
3. Global Vulnerability Assessment (GVA)
4. Bruun rule
5. The Synthesis and Upscaling of Sea-level Rise Vulnerability Assessment (SURVAS)
6. Land and wetland loss assessment
7. Dynamic Interactive Vulnerability Assessment (DIVA)
8. Simulator of Climate Change Risks and Adaptation Initiatives (SimCLIM)
9. Community Vulnerability Assessment Tool (CVAT)
10. Coastal Zone Simulation Model (COSMO)
11. South Pacific Island Methodology (SPIM)
12. Shoreline Management Planning (SMP).

Coastal vulnerability index assessment has been discussed in details.

2.2 Coastal Vulnerability Index Assessment

A coastal vulnerability index (CVI) was used to map the relative vulnerability of the different segment of the coast due to sea-level rise. The CVI ranks the variable consider under study. The rankings for each variable were combined and an index value calculated. The CVI method yields numerical data that cannot be linked directly with particular physical effects but it highlights those coastal segments where the effects of sea-level rise might be the greatest, i.e. where there is the greatest chance that physical changes will occur as sea-level rises.

The simplest of these are assessments of the physical vulnerability of the coast, while the more complex also examine aspects of economic and social vulnerability. The advantages of using CVI method are simple, hasty and reliable. A summary of various indices applied in international and national are shown in Table1 & Table2.

2.3 International Approach

The Coastal Vulnerability Index (CVI) was first developed by Gornitz and Kanciruk (1989) to climate change, particularly sea-level rise for United States coastal considering inundation, flooding and susceptibility to erosion. Many coastal vulnerability index (CVI) or coastal sensitivity index (CSI) has been developed with modifications to the original CVI of Gornitz and Kanciruk (1989) (Abuodha and Woodroffe, 2006). Gornitz (1991) had included seven parameters in the vulnerability of U.S west coastline. They are (1) Coastal geomorphology, (2) Coastal relief (m), (3) Shoreline change (m/yr), (4) Mean tidal range (m), (5) mean wave height (m), (6) Sea level change (mm/yr) and (7) Rock type. In 1991, Gornitz also suggested that CVI could be applied on a global scale and could be improved by using the variables of storm frequency, how much population at risk. Coastal sensitivity index (CSI) calculated by Carter *et al.,* (1990) for Ireland coast considering shore face slope, features, coastal structures, access and land use. Carter's approach has been followed by Shaw *et al.,* (1998) to calculate a coastal sensitivity index for the coast of Canada. Manson *et al.,* (2005), applied sensitivity index for western Canadian Arctic coast. A similar approach has been applied by Rachold *et al.,* (2000) for Arctic coastal dynamic project. The distinction between CVI and CSI was done by Abuodha *et al.,* (2010). They said that CSI is assessing only physical aspects of the coast and not socio-economic variables, such as population. Vulnerability is understood in terms of people being vulnerable and so needs socio-economic variable. Apart from the difference in terminology, both CSI and CVI use same methodology. Thieler and Hammer-Klose (1999) developed a coastal vulnerability index for USA coast using historic shoreline erosion rates, geomorphology, relative rates of sea level rise, coastal slope, wave height, tidal range. Pendleton *et al.,* (2004) had considered the above parameter to assess the CVI of USA coast. Similar parameters had been used by Dukakis (2005) for CVI calculation of western pelleponese in Grece coast. Deiz *et al.,* (2007) had considered elevation (instead of slope) but he did not consider sea level change as a vulnerable factor. Erosion hazards index has been developed by Forbes *et al.,* (2003) for Canadian coast using sensitivity index and plus exposure, storm surge water level, slope variable. Hughes and Brundrit (1992) calculated Risk matrix for South Africa coast using location, infrasture (economic value) and hazard. Yamada *et al.,* (1995) used vulnerability and resilience of natural, cultural, institutional, infrasture, economic and human factor for sustainable capacity index (SCI) for South Africa coast. Boruff *et al.,* (2005) assessed the social vulnerability index (SoVI) using principal components analysis (PCA) of socio-economic variables on a coastal area USA. He also developed coastal vulnerability score (CSoVI) for USA coast by combine of CVI and SoVI. Abuodha *et al.,* (2010) calculated Coastal sensitivity index (CSI) of Illawarra coast, southeast Australia, using nine variables, namely (a) rock type, (b) coastal slope (c) geomorphology (d) barrier type (e) shoreline exposure (f) shoreline change (g) relative sea level rise (h) mean wave height and (j) mean tide range. The municipality-wide vulnerability map of Aveiro's Lagoon was prepared by Alves *et al.,* (2011) using GIS techniques considering nine parameters.

These are distance to the shoreline, topographic elevation, geology, geomorphology, land cover, wave height, tide levels, past occurrences of erosion/accretion and artificialization due to anthropogenic actions. Papanastassiou *et al.,* classified the coast of the Argolikos Gulf according to its vulnerability to an anticipated future sea-level rise, using the Coastal Vulnerability Index and utilizing GIS technology considering six physical variables: geomorphology, coastal slope, relative sea-level rise rate, shoreline erosion or accretion rate, mean tidal range and mean wave height. Palmer *et al.,* (2011) used five physical parameters namely: beach width, dune width, percentage rocky outcrop, distance (width) of vegetation behind the back beach and distance to the 20m isobaths for assessing the relative coastal vulnerability of the KwaZulu-Natal coast, South Africa.

A GIS based coastal vulnerability index for wave-induced erosion in Northern Ireland has been developed by McLaughlin *et al.,* (2002) incorporating of socioeconomic variables. The overall index constitutes of the sum of three sub-indexes such as coastal characteristics, coastal forcing and socio-economic sub-index. The variables of socio-economic sub-index were Population, Cultural heritage, Roads, Railways, Land use, Conservation status.

2.4 National Approach

The vulnerability of the Indian coastal region to the consequences of the estimated sea level rise due to the greenhouse effect is studied by Shetye *et al.,* (1990), Diksha *et al.*, and Belperio *et al.*, (2001) considered elevation, exposure, aspect, and slope as the physical parameters for assessing the coastal vulnerability to sea-level rise and concluded that coastal vulnerability is strongly correlated with elevation and exposure.

Table 3: Summary of coastal vulnerability indices, their geographical application and the variables needed to implement them. National approaches

Coastal vulnerability index (CVI)	Udupi coast in Karnataka state, along the west coast of India,	Shore-line change rate, sea-level change rate, coastal slope, mean tidal range, coastal geomorphology.	Dwarakish *et al.*, 2009
Coastal vulnerability index (CVI)	Chennai , India	a) Shoreline Change Rate (m/yr); b) Mean Sea Level Change Rate (mm/yr); c) Significant Wave Height (m); d) Mean Tidal Range (m); e) Coastal Regional Elevation; f) Near-shore Bathymetry; g) Geomorphic units; h) Strom Surges (m).	Arun and Pravin, 2012
Coastal vulnerability index (CVI)	Orissa coast, India	Geomorphology, coastal slope, shoreline change, mean tidal range, significant wave height, tsunami run up, coastal regional elevation, sea level change.	Srinivasa *et al.*, 2010
Coastal vulnerability index (CVI)	Andhra Pradesh, India	Geomorphology, coastal slope, shoreline change, mean tidal range, significant wave height,	Rao *et al.*, 2008
Coastal vulnerability index (CVI)	Cuddalore – Villupuram, east coast of India	shore-line change rate, sea-level change rate, coastal slope, tidal range, coastal regional elevation, storm surge	Mahendra *et al.*, 2011
Coastal vulnerability index (CVI)	Mangalore coast, India.	Geomorphology, regional coastal slope, shoreline change rates, and population.	Hegde and Raju, 2007
Coastal vulnerability index (Physical vulnerability index (PVI) as well as the Socio-economic vulnerability index (SVI))	Puducherry coast. India	physical-geological parameters (slope, geomorphology, elevation, shoreline change, sea level rise, significant wave height and tidal range) and four socio-economic factors (population, Land-use/Land-cover (LU/LC), roads and location of tourist places	Murali *et al.*, 2013

To identify the potential vulnerable coastal stretch of cochin, south west India for sea level rise has been studied by Dinesh *et al.*, (2006) and Rajawat *et al.*, (2006) delineated the hazard line along the Indian coast using data on coastline displacement, tide, waves, and elevation. Coastal vulnerability index (CVI) has been calculated by Hegde and Raju (2007) to understand the relative vulnerability of the various segments of the Mangalore coast to coastal erosion hazards considering geomorphology, regional coastal slope, shoreline change rates, and population. However, they also suggested that the CVI could be improved by adding more parameters such as wave height, tidal range, and probability of the storm. Coastal vulnerability index CVI of Andhra Pradesh coast have been developed by Rao *et al.*, (2008) using (1) Coastal geomorphology, (2) Coastal slope (%), (3) Shoreline change (m/y), (4) Mean spring tide range (m), and (5) Significant wave height (m). Rao *et al.*, (2008) considered coastal slope to be a better variable than elevation in vulnerability studies since the elevation refers to point where as slope refer to an area. Dwarakish *et al.*, (2009) calculated CVI for Udupi coastal zone of Karnataka from shoreline change rate, sea-level change rate, coastal slope, mean tidal range, coastal geomorphology. Srinivasa Kumar *et al.*, (2010) has been assessed the coastal vulnerability index for Orissa coast using eight variables; where tsunami run up, coastal regional elevation and sea level change were included along with the above 5 variables. The multi-hazard coastal vulnerability along the Cuddalore-Villupuram, east coast of India has been calculated by Mahendra *et al.*, (2011) using geospatial techniques and considering the parameters: shoreline change rate, sea-level change rate, coastal slope, tidal range, coastal regional elevation, storm surge etc. Arun *et al.*, (2012) developed Coastal Vulnerability Index (CVI) for Chennai coast using eight relative risk variables to know the high and low vulnerable areas, area of inundation due to future SLR, and land loss due to coastal erosion. These variable are a) Shoreline Change Rate (m/yr); b) Mean Sea Level Change Rate (mm/yr); c) Significant Wave Height (m); d) Mean Tidal Range (m); e) Coastal Regional Elevation; f) Near-shore Bathymetry; g) Geomorphic units; h) Strom Surges (m). An Analytical Hierarchical Process (AHP) based approach to calculate the coastal vulnerability index along the Puducherry coast has been studied by Murali *et al.*, (2013). Seven physical-geological parameters such as slope, geomorphology, elevation, shoreline change, sea level rise, significant wave height and tidal range) and four socio-economic factors such as population, Land-use/Land-cover (LU/LC), roads and location of tourist places) are considered to measure the Physical Vulnerability Index (PVI) as well as the Socio-economic Vulnerability Index (SVI). Based on the weights and scores derived using AHP, vulnerability maps are prepared to demarcate areas with very low, medium and high vulnerability. The coastal vulnerability index (CVI) has been calculated by combining of both PVI and SVI values.

CONCLUSION

The present day the sea level rise a great topic of discussion because of its acceleration and have potential of huge impacts on the low lying coastal zone, because of the coastal zone is highly resourceful, dynamic and highly densely populated. So, it needs the proper management of coastal areas, keeping in mind the climate change and global warming induced accelerating sea level rise. The coastal vulnerability index highlights those coastal segments where the effects of sea-level rise might be the greatest, i.e. where there is the greatest chance that physical changes will occur as sea-level rises. Hence, the coastal vulnerability assessment is a primary step in coastal zone management.

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