ASSESSMENT OF CLIMATE-INDUCED SEA-LEVEL RISE SCENARIOS AND ITS INUNDATION IN COASTAL ODISHA, INDIA

KHRISTODAS, P. M.[1] – PALANIVELU, K.[1] – RAMACHANDRAN, A.[1*] – ANUSHIYA, J.[1] – PRUSTY, B. A. K.[2] – GUGANESH, S.[1]

[1]*Centre for Climate Change and Disaster Management, Anna University, Chennai, India*
(e-mail: punya.khristodas@gmail.com)

[2]*Department of Environment Studies, Berhampur University, Berhampur-760007, Odisha, India*
(e-mail: anjaneia@gmail.com)

**Corresponding author*
e-mail: andimuthu.ramachandran@gmail.com

(Received 8th Feb 2022; accepted 20th Jun 2022)

Abstract. Climate-induced Sea levels rise (SLR) has been one of the major concerns of the world community in recent decades. The present work attempts to find the current and future SLR and its inundation magnitude in the coastal districts of Odisha, India. Long-term monthly sea level data were used to assess the recent sea-level rise. The SLR projections were generated under different IPCC's Representative Concentration Pathway (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) scenarios using the site-specific SLR scenario generator tool 'SimCLIM'. At last, the coastal area, which would be inundated for 0.5 m and 1 m SLR, was estimated and geospatially mapped using the ArcGIS tool. The observed SLR trend along the coast is 0.19 cm/yr from 1966 to 2015, equivalent to a change of 19.50 cm/100 years. The future SLR would be in the range of 4.15 to 9.09 cm for 2040, 13.71 to 37.73 cm for 2070, and 20.20 to 76.74 cm for 2100. Approximately 992.7 km^2 area would be inundated due to 0.5 m SLR and 1720.1 km^2 for 1 m SLR. This visible stress will pose a severe threat to the coastal natural resource base of Odisha.
Keywords: *coastal resilience, digital elevation model, representative concentration pathways, sea level rise projections, SimCLIM climate software*

Introduction

Sea level rise (SLR) is one of the most noticeable distresses of climate change and its extremities. Recent Intergovernmental Panel on Climate Change (IPCC) 2021 report alarms that there is a 0.20 m rise in global mean sea level from 1901 to 2018. The average rate of SLR was 0.13 cm/yr (1901-1971) and rose by 0.37 cm/yr (2006-2018), and it would continue to rise to 2 m by the end of the Century under a very high emissions scenario (SSP5-85 low confidence) (IPCC, 2021). The significant threats of SLR include inundation of low-lying areas, increasing coastal flooding, increasing salinity, loss of wetlands, loss of biodiversity and shoreline change, etc. (IPCC, 2007; Carrasco et al., 2015). Eventually, these will have huge imprints on river deltas, coastal areas with high population density, and infrastructure (Nicholls et al., 2007; McGranahan et al., 2007). People are becoming more vulnerable to SLR and climatic extremities with increasing developmental activities in coastal areas. As almost 600 million people live at mean sea level or below 10 m it leads to the generation of around US$1 trillion in global wealth, while the environmental and socio-economic consequences of recurrent coastal flooding can be devastating (Kirezci et al., 2020). If civilization does not adapt to sea-level rise; in that case, coastal areas will experience more regular and severe floods, costing trillions of dollars, harming hundreds of millions of people throughout the world and putting their lives and livelihoods in danger (Hinkel et al., 2014; Neumann et al., 2015; Kulp and Strauss, 2019). Coastal populations are in jeopardy due to the effects of SLR on their socio-economic conditions. These factors influence physical habitats, fish stocks, coastal ecosystems, infrastructures, and marine and inland fishing practices (Allison et al., 2008; Shah et al., 2013). Nicholls et al. (1999) estimated that a 38 cm rise in global sea level would lead to an approximate loss of 22% of coastal wetlands and that a 1 m SLR would yield a loss of 46% of the coastal wetlands.

Predictions of changes in coastal habitat boundaries due to expected relative SLR allow for advanced preparation for particular parts of the coastline to mitigate and offset anticipated losses and reduce risks to coastal growth and human safety (Gilman et al., 2007). Thus, a better understanding of SLR and its impacts is needed to anticipate risks associated with SLR. The first move in such direction will be to project SLR at the local level at various time scales and scenarios formulated by the IPCC (Ramachandran et al., 2017). These projections will facilitate more efficient coastal planning and management of natural resources and develop adaptation strategies for the coastal communities. Long-term datasets on climate change variables are a prerequisite for projection studies, and in recent times, computer-based climate models/tools have supported the research community by providing scenarios. Various models for coastal studies are available for climate change projection, such as Bathtub, BTELSS, DIVA, SimCLIM, etc. The SimCLIM model has been hailed as a helpful tool for determining the risk-based influences of climate change at the local level (Warrick, 2009).

Study area

The current work aims to provide sea-level rise projections for the Odisha state of India at the local scale. Odisha state is situated along the eastern coast of India with a 480 km long coastline stretching from Baleshwar on the north to Ganjam on the south (17°48’ to 22°34’ N and 81°24’ to 87°29’E). The state has six coastal districts: Baleshwar, Bhadrak, Kendrapara, Jagatsingpur, Puri, and Ganjam (*Fig. 1*). These coastal districts have predominant agricultural landscapes. Farming and related practices are the mainstays of the locals’ livelihoods. The coastal stretch of the state is bestowed with unique landforms such as lagoons, sandy (nesting) beaches, dunes, wetlands and estuaries. Asia’s largest brackish water lagoon, Chilika Lake, is located along the Odisha coast. Bhitarkanika national park, India’s second-largest mangrove forest after Sundarbans of West Bengal and Gahirmatha- the world’s largest nesting beach for the Olive Ridley sea turtle Odisha (Mohanty et al., 2008; Kumar et al., 2010; Hauer, 2016). In contrast, the coast of Odisha is subject to extreme tidal variations, strong littoral drift, frequent cyclones, and flooding. Tropical storms that originate in the Bay of Bengal regularly inflict deaths and significant damage in the coastal districts (Das et al., 1983; Murty et al., 1986; Dube et al., 1994, 1997, 2000; Chittibabu et al., 2002; Kumar et al., 2010). In addition to cyclones, Odisha has a history of rigorous flood hazards due to storm surges produced in the Bay of Bengal, floods from the rivers, and substantial rainfall related to tropical hurricanes and monsoon depressions (Chittibabu et al., 2002). Severe flooding caused by storm surges devastated the lives and property of thousands of people living along the coast. Tourism hotels and resorts, fishing communities, and townships have already been vulnerable to frequent storm surge disasters (Kumar et al., 2010).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_33933409

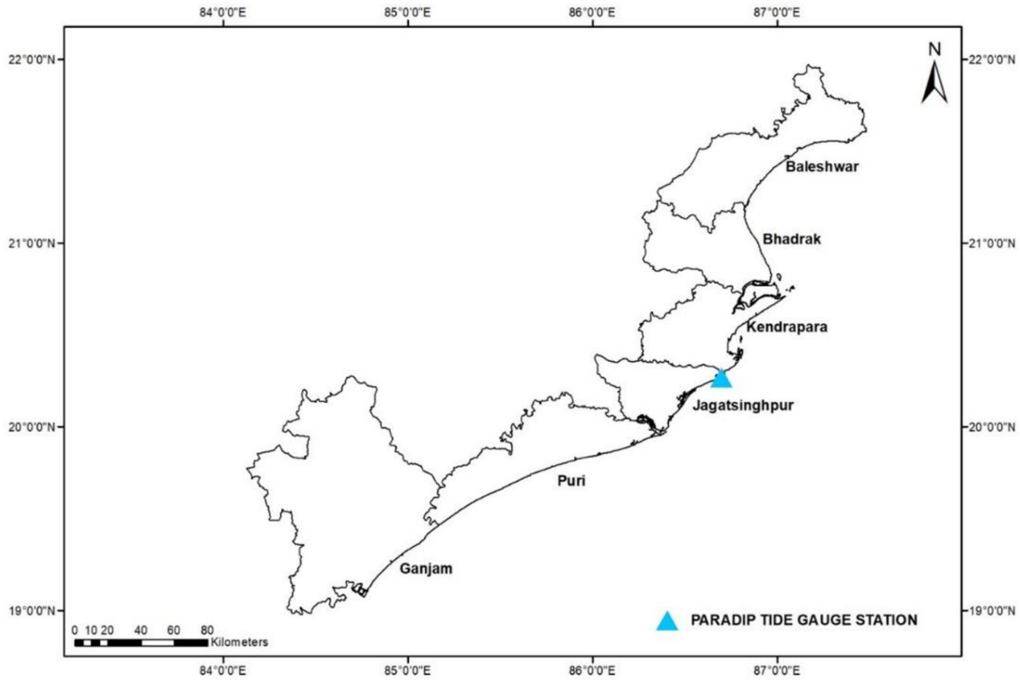

Figure 1. *Study area: coastal districts of Odisha*

Additionally, coastal areas of Odisha are at risk of rapid erosion (Ramesh et al., 2011). In recent decades, the native population has begun to migrate to other cities, searching for better livelihood support systems and income opportunities (Velan and Mohanty, 2015). Furthermore, the increase in sea level will also pose a significant threat to Odisha's coastal stretch. Thus, it is necessary to assess the sea-level rise and its effects along the coastline stretch of Odisha.

The current research has three objectives: (i) to analyze the observed sea-level rise in Odisha's coast and (ii) to provide future SLR projections for Odisha under IPCC AR5 based for Representative Concentration Pathways (RCP) RCP2.6, RCP4.5, RCP6.0, and RCP8.5 scenarios and (iii) to assess the magnitude of inundation and portray the area of inundation for the two SLR scenarios, i.e., of 0.5 m and 1 m. This study is the first attempt to project SLR for the coast of Odisha, India.

Methods

In this work, IPCC criteria for assessing the SLR were followed. The detailed methods of determining past sea-level changes along the coast using historical data projection of sea-level rise were generated under different IPCC's Representative Concentration Pathway (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) scenarios and estimation of inundation area under future SLR are as follows:

Assessing past sea-level changes

Many studies use monthly mean sea-level values to estimate past sea-level rise (Unnikrishnan et al., 2006, 2015; Ramachandran et al., 2017). The monthly mean sea level data are available in Permanent Service for Mean Sea Level (PSMSL) archives at

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_33933409

http://www.psmsl.org. PSMSL is a global data bank for long-term sea-level change information from tide gauges and bottom pressure records, which contains monthly and annual mean values of sea level from over 1800 tide gauge stations across the globe. Paradip tide gauge station is the only tide gauge station of Odisha available in the PSMSL archive (Station ID: 1161). This station lay in 20.26 N and 86.7 E and owned tide gauge data from 1966 till 2015 with 77% completeness. The monthly mean sea level data of Paradip tide gauge station were downloaded and analyzed to observe the changes in sea level and its trend along the coast of Odisha.

Developing SLR projections using IPCC scenario

Future SLR projections were developed as per IPCC's RCP scenarios using the SimCLIM tool. SimCLIM, a user-friendly tool, includes a scenario generator that uses pattern-scaling approaches at essential scales (Warrick, 2009). It deals with different patterns of climate change from complex global climate models (GCM) that display time-variant global climate change predictions (Amin et al., 2018). In recent years, the majority of the studies have neglected the calculation of regional assessments of fluctuations in sea level, owing to the lack of technological knowledge (Mary et al., 2021). SimCLIM software is developed to provide solutions to this problem by re-gridding the pattern scaling system to a 720 × 360 grid (i.e., 0.5°×0.5°) using a bilinear interpolation method (Yin et al., 2013). SimCLIM version 4.0, a site-specific scenario generator tool, was used to calculate the SLR projection for the six coastal districts of Odisha. The observed MSL trend of the Paradip tide gauge station was given as a reference datum in the scenario generator to project future SLR. The model has 28 global climate models (GCMs) (*Table 1*). GCMs were organized hierarchically based on normalized GCM values (pattern scaling) by SimCLIM to perform the sensitivity analysis. The measure of the central tendency was calculated based on the median value of the constructed ensemble (SimCLIM, 2011). All the 28 GCMs were selected to construct an ensemble, and the central tendency was calculated as follows:

$$\text{Median value} = (n-1) \times 50\% + 1 \qquad \text{(Eq.1)}$$

where 'n' denotes the number of GCMs chosen, which, in this case, is 28.

$$\text{Median Value} = (28-1) \times 50\% + 1 = 14.5$$

with the value in the 14^{th} and 15^{th} places in terms of magnitude selected as the median value (SimCLIM, 2011).

The contributions from the components at the global, regional, and local scales were considered when computing the SLR projection for a specific location, and it is expressed as follows (Nicholls et al., 2011):

$$\Delta RSL = \Delta SL_G + \Delta SL_{RM} + \Delta SL_{RG} + \Delta SL_{VLM} \qquad \text{(Eq.2)}$$

where ΔRSL stands for relative sea-level change, ΔSL_G stands for global mean sea-level change, ΔSL_{RM} stands for regional variation in sea level from the global mean due to metero-oceanographic factors, ΔSL_{RG} stands for regional variation in sea level due to changes in the earth's gravitational field, and ΔSL_{VLM} stands for change in sea level due to vertical land movement.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_33933409

The tool has a unique facility of considering climate sensitivity range to project sea-level change. The SLR changes of low, medium and high range for all RCP scenarios were considered (SimCLIM, 2011). Then, future SLR projections were generated under different IPCC's Representative Concentration Pathway RCP2.6, RCP4.5, RCP6.0, and RCP8.5 scenarios for three time slices 2040, 2070, and 2100.

Table 1. *Available GCMs with sea-level rise variables in CMIP5*

S. No.	GCM	S. No.	GCM
1	ACCESS1-0	15	GISS-E2-R-CC
2	ACCESS1-3	16	HadGEM2-CC
3	bcc-csm1-1	17	HadGEM2-ES
4	bcc-csm1-1-m	18	inmcm4
5	CanESM2	19	IPSL-CM5A-LR
6	CCSM4	20	IPSL-CM5A-MR
7	CMCC-CM	21	MIROC5
8	CMCC-CMS	22	MIROC-ESM
9	CNRM-CM5	23	MIROC-ESM-CHEM
10	CSIRO-Mk3-6-0	24	MPI-ESM-LR
11	GFDL-CM3	25	MPI-ESM-MR
12	GFDL-ESM2G	26	MRI-CGCM3
13	GFDL-ESM2M	27	NorESM1-M
14	GISS-E2-R	28	NorESM1-ME

Estimating inundation area and mapping

Due to future SLR along the coast, the inundation area was estimated using inundation mapping in the ArcGIS 10.5 tool (Malik and Abdalla, 2016). The Cartosat-1 (30 m resolution) digital elevation model (DEM) from National Remote Sensing Centre (NRSC), Hyderabad, India, was used in this study. Eight CartoDEM tiles, which cover coastal districts of Odisha, were downloaded from the Bhuvan portal on 22/04/2021 (*Table 2*). These eight tiles are combined into a single DEM file. The CartoDEM was post-processed for geoid correction, and the null values were removed. The processed DEM was clipped with Odisha's coastal district shapefile. Then the inundation area for 0.5 m and 1 m SLR scenarios were calculated and mapped using the Raster Calculator tool in ArcGIS. Finally, the raster output was transformed into a polygon, and the inundation area was measured for each district.

Table 2. *Details of CartoDEM tiles representing the coastal Odisha*

Sl. No.	Tile number	Bounding box
1	F45P	87E21N – 88E22N
2	F45O	86E21N – 87E22N
3	F45U	86E20N – 87E21N
4	F45T	85E20N – 86E21N
5	E45C	86E19N – 87E20N
6	E45B	85E19N – 86E20N
7	E45A	84E19N – 85E20N
8	E45G	84E18N – 85E19N

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_33933409

Results

The observed sea-level change from 1966 to 2015, the SLR projections for the six coastal districts for four different scenarios at three-time scales, and district-wise inundation areas due to future SLR are presented here.

Observed sea-level changes from 1966 to 2015

The monthly mean sea-level data from 1966 to 2015 were analyzed to see the changes along the coast. This 50-year-long monthly data from the Paradip tide gauge station shows that the sea level along Odisha's coast has increased steadily (*Fig. 2*). The observed relative sea level trend is 0.19 cm per year with a 95% confidence interval of +/- 0.09 cm per year, comparable to a change of 19.50 cm in 100 years.

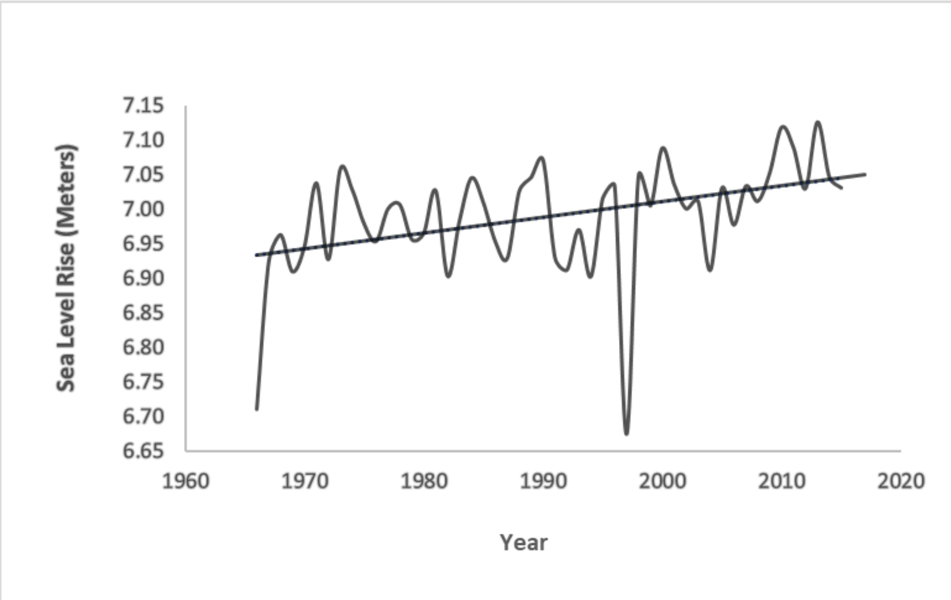

Figure 2. *The observed SLR projection for Paradip (Odisha) tide gauge station*

Future IPCC scenarios of SLR for Odisha

SLR projections (low, medium, and high) of IPCC RCPs 2.6, 4.5, 6.0, and 8.5 were made for three different timescales with an interval of 30 years, i.e., for 2040, 2070, and 2100. The detailed projections for each timescale are described below:

SLR scenarios for the year 2040

The estimated SLR projections would be between 4.28 to 9.25 cm for the RCP2.6 scenario; 4.35 to 9.18 cm for the RCP4.5 scenario; 4.15 to 9.09 cm under the RCP6.0, and 4.65 to 9.51 cm for the RCP8.5 scenario. The SLR would be 4.15 to 4.94 cm (low), 6.35 to 7.18 cm (medium) and 8.50 to 9. 51 cm (high) sensitivity. The district-wise SLR projections for RCP2.6, RCP4.5, RCP6.0, and RCP8.5 are listed in *Table 3*. The SLR projections of the Baleshwar district are 4.29 to 4.81 cm (low), 6.54 to 6.99 cm (medium) and 8.63 to 9.26 cm (high) range. For the Bhadrak district, the projected SLR levels are 4.39 to 4.94 cm, 6.69 to 7.18 cm and 8.84 to 9.51 cm, respectively, for low, medium and high ranges, respectively. For the Kendrapara district, the projected SLR

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_33933409

levels are 4.25 to 4.76 cm (low), 6.49 to 6.94 cm (medium) and 8.57 to 9.19 cm (high) range. For Jatatsinghpur district, SLR would be 4.48 to 4.89 cm (low), 6.89 to 7.11 cm (medium) and 9.17 to 9.42 cm (high). For Puri and Ganjam districts, the projected SLR levels would be 4.15 to 4.65 cm and 4.17 to 4.68 cm, 6.35 to 6.79 cm and 6.37 to 6.82 cm, 8.40 to 9.00 cm and 8.43 to 9.04 cm under low, medium and high sensitivity, respectively.

Table 3. *District wise SLR projections for the year 2040*

Scenario	RCP2.6			RCP4.5			RCP6.0			RCP8.5		
Districts \ Range	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Baleshwar	4.43	6.80	9.05	4.49	6.96	8.96	4.29	6.54	8.63	4.81	6.99	9.26
Bhadrak	4.62	6.95	9.25	4.61	6.93	9.18	4.39	6.69	8.84	4.94	7.18	9.51
Kendrapara	4.38	6.75	8.98	4.45	6.71	8.89	4.25	6.49	8.57	4.76	6.94	9.19
Jagatsinghpur	4.48	6.89	9.17	4.56	6.86	9.09	4.56	6.86	9.09	4.89	7.11	9.42
Puri	4.28	6.60	8.80	4.35	6.57	8.71	4.15	6.35	8.40	4.65	6.79	9.00
Ganjam	4.31	6.63	8.83	4.37	6.60	9.00	4.17	6.37	8.43	4.68	6.82	9.04

SLR scenarios for the year 2070

The SLR projections of Odisha for 2070 have been estimated as 13.71 to 30.30 cm for the RCP2.6; 15.76 to 32.45 cm for RCP4.5; 15.01 to 31.16 cm under the RCP6.0, and 19.52 to 37.73 cm for the RCP8.5 scenario. While the SLR would be between 13.71 to 20.09 cm, 21.84 to 28.63 cm and 29.49 to 37.73 cm under the low, medium and high range, respectively. The SLR projections under IPCC RCP2.6, RCP4.5, RCP6.0, and RCP8.5 scenarios for all the districts are given in *Table 4*.

Table 4. *Sea Level Rise projection for the year 2070*

Scenario	RCP2.6			RCP4.5			RCP6.0			RCP8.5		
Districts \ Range	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Baleshwar	14.15	22.46	30.30	16.25	24.25	32.45	15.48	23.31	31.16	20.09	28.63	37.73
Bhadrak	14.08	22.37	30.17	16.17	24.15	32.32	15.41	23.21	31.04	20.00	28.51	37.58
Kendrapara	14.03	22.29	30.08	16.11	24.07	32.22	15.35	23.13	30.94	19.93	28.42	37.46
Jagatsinghpur	13.93	22.16	29.90	16.01	23.92	32.03	16.01	23.92	32.03	19.81	28.25	37.25
Puri	13.71	21.84	29.49	15.76	23.58	31.59	15.01	22.67	30.34	19.52	27.86	36.75
Ganjam	13.77	21.93	29.60	15.83	23.68	31.71	15.08	22.76	30.45	19.60	27.78	36.66

SLR scenarios for the year 2100

The SLR projections for 2100 have been estimated as 20.20 to 49.64 cm for the RCP2.6; 25.92 to 57.36 cm for RCP4.5; 26.32 to 57.62 cm under the RCP6.0 and 38.69 to 76.74 cm for the RCP8.5. While the SLR would be between 20.20 to 39.77 cm (low), 33.92 to 57.04 cm (medium), and 48.33 to 76.74 cm (high) range, respectively. The SLR projections under RCP2.6, RCP4.5, RCP6.0, and RCP8.5 scenarios for all the districts such as Baleshwar, Bhadrak, Kendrapara, Jagatsinghpur, Puri, and Ganjam are listed in *Table 5*.

Overall, the projected SLR is high in the Baleshwar district, followed by Bhadrak, Kendrapara, Jagatsinghpur, Ganjam and Puri districts. Puri district would have a low

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_33933409

SLR compared to other districts. The SLR projection for the Baleshwar district would be 20.84 to 39.77 cm under low sensitivity; 34.89 to 57.04 cm under medium sensitivity; 49.64 to 76.74 cm under high sensitivity for the period 2100. Puri district would have a low SLR compared to other districts. The SLR projection for the Puri district would be 20.20 to 38.69 cm under low sensitivity; 33.92 to 55.56 cm under medium sensitivity; 48.51 to 75.08 cm under high sensitivity for 2100.

Table 5. *Sea level rise projection for the year 2100*

Scenario	RCP2.6			RCP4.5			RCP6.0			RCP8.5		
Range / Districts	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Baleshwar	20.84	34.89	49.64	26.70	41.60	57.36	27.36	42.11	57.62	39.77	57.04	76.74
Bhadrak	20.75	34.74	49.44	26.58	41.43	57.13	27.24	41.94	57.39	39.60	56.82	76.45
Kendrapara	20.67	34.62	49.28	26.49	41.29	56.95	27.15	41.80	57.21	39.47	56.64	76.21
Jagatsinghpur	20.53	34.41	48.99	26.32	41.05	56.63	26.32	41.05	56.63	39.23	56.31	75.79
Puri	20.20	33.92	48.33	25.92	40.48	55.87	26.57	40.98	56.12	38.69	55.56	74.81
Ganjam	20.29	34.06	48.51	26.03	40.64	56.08	26.68	41.14	56.33	38.84	55.77	75.08

Coastal inundation due to future SLR

The inundation model using ArcGIS indicates that nearly 992.7 km^2 (4.48%) area would be under the threat of inundation for 0.5 m SLR (*Fig. 3*). An approximate area of 1720.1 km^2 (7.77%) would be under the threat of inundation for 1 m SLR (*Fig. 3*). The district-wise inundated area for 0.5 m and 1 m SLR is listed in *Table 6*. The results reveal that the Kendrapara district is highly vulnerable to SLR risks, followed by Puri, Bhadrak, Jagatsinghpur, Baleshwar and Ganjam district. Nearly 492.9 km^2 area would be inundated for 0.5 m SLR and 770.69 km^2 for 1 m SLR in Kendrapara district. In Puri district, around 314.12 km^2 area would be inundated for 0.5 m SLR and 557.9 km^2 for 1 m SLR. There would be about 98.63 km^2 inundated area for 0.5 m SLR and 327.79 km^2 for 1 m SLR in Bhadrak district. In the Jagatsinghpur district, around 65.97 km^2 area would be inundated for 0.5 m SLR and 107.75 km^2 area would be inundated for 1 m SLR followed by Baleshwar (14.33 and 42.95 km^2) and Ganjam (5.7 and 11.29 km^2) for 0.5 m and 1 m SLR, respectively.

Discussion

The observed and projected SLR of the State and its pact with national and international studies, the significance of district wise SLR projections and its inundation through the lens of its ecological importance are elaborately discussed below.

The monthly mean sea level data of Paradip tide gauge station shows that the sea level along the coast of Odisha is increasing steadily from 1966 to 2015 with a 0.19 cm/yr rise. Globally, Sea levels are rising because of the continental ice melt and thermal expansion of ocean water due to global warming. The global mean sea level rose to 20 cm from 1901 to 2018, and the average rate of SLR was 0.13 cm/yr (1901-1971) and rose by 0.37 cm/yr (2006-2018) (IPCC, 2021). While SLR in the Indian Ocean is non-uniform, the rate of north Indian Ocean rise was 0.10-0.17 cm/yr from 1874 to 2004 and 0.33 cm/yr from 1993 to 2015 (Swapna et al., 2020). The estimated relative sea-level trend of Odisha's coast agrees well with the Indian scenario of SLR.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_33933409

Table 6. *District-wise area of inundation in Odisha*

S. No.	Districts	Total area of the district (km^2)	Inundation area (km^2)		% Inundation area (%)	
			0.5 m SLR	1 m SLR	0.5 m SLR	1 m SLR
1	Baleshwar	3,634	14.33	42.95	0.39	1.18
2	Bhadrak	2,505	98.63	327.79	3.93	13.08
3	Ganjam	8,071	5.7	11.29	0.07	0.13
4	Puri	3,479	314.12	457.9	9.02	13.16
5	Kendrapara	2,644	492.82	770.69	18.63	29.14
6	Jagatsinghpur	1,759	65.97	107.75	3.75	6.12

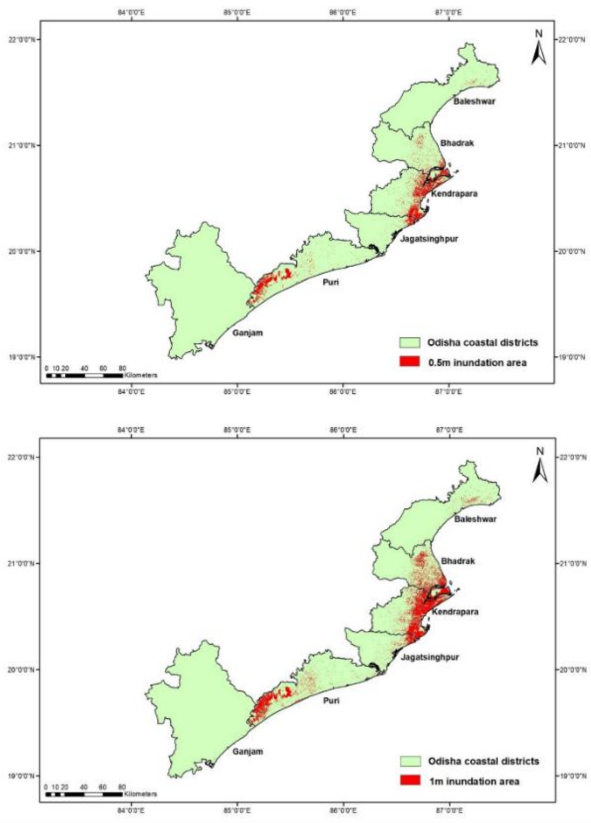

Figure 3. *Map showing area of inundation due to 0.5 m SLR (left) and map showing area of inundation due to 1 m SLR (right)*

The projected SLR of Odisha's coast indicated a 20.20 to 39.77 cm increase under low emission scenarios, 33.92 to 57.04 cm under medium emission scenarios and 48.33 to 76.74 cm under high emission scenarios for the year 2100. The global mean sea level rise is expected to be 19 cm in 2050 and 44 cm by 2100 under a low emission scenario. The very high emission scenario is expected to be 23 cm in 2050 and 77 cm in 2100 (IPCC, 2021). At the same time, the steric sea level in the north Indian Ocean is projected to rise by approximately 30 cm relative to the average over 1986–2005 under the RCP4.5 scenario at the end of the twenty-first Century, with the corresponding projection for the global mean rise being approximately 18 cm (Krishnan et al., 2020).

Earlier, Unnikrishnan et al. (2015) also estimated the increasing trend of SLR reaching the values close to the global mean SLR trends (0.32 cm/yr) from 1993-2012. The present study findings agree with the other regional SLR studies in India (Unnikrishnan et al., 2006; Khan, 2013; Ramachandran et al., 2017). The results of the present research slightly deviate from the global mean SLR. For RCP8.5, the global mean SLR for 2081–2100 compared to 1986–2005 would likely be in the range of 45–82 cm, whereas the SLR forecast for the Odisha coast range from 48.33 to 76.74 cm. These ranges were calculated using CMIP5 climate forecasts, process-based models, and a literature review of glacier and ice sheet contributions (IPCC, 2013). Under ocean circulation, regional differences in ocean density, and atmospheric pressure, local sea levels generally differ from the global mean (Khan, 2013). Climate model forecasts for the twenty-first Century indicate that, in addition to global mean sea level rises, the large-scale spatial pattern may also alter, potentially affecting local SLR (Pardaens et al., 2010). To validate the total trend SLR projections based on GCM performances; this research compared the observed tide gauge data from 1966 to 2015. However, the future predictions of the estimates of total trend SLR by SimCLIM are depends on the performance of the multi-model ensemble, which is made up of 28 GCMs, arranged hierarchically based on the normalized GCMs values by the pattern scaling method.

Regardless of the exact extent of the rise, a rise in sea level is unavoidable in the next decades. Nuisance floods will become more common and more substantial as sea levels rise, converting a once-in-a-lifetime event into a common and potentially damaging problem due to road closures, inundated storm drains, and infrastructural compromises (Chisholm et al., 2021). The estimated projected SLR in this study will pose a series of threats to the sensitive coastal Odisha. Even though the cumulative areas of inundation in all the six coastal districts are 4.48% and 7.77% of the total area to 0.5 m and 1 m SLR, the towns, human settlements, infrastructures, and habitats are located along the coast will be under severe threat. According to IPCC (2001), a 1 m rise in sea-level rise in India could render nearly 7 million people homeless. In the next three decades, Odisha will be one of the worst affected states due to sea-level rise, with the entire stretch from Baleshwar to Ganjam at risk of flooding and inundation by 2050 (Climate Central, 2019). The coast of Odisha is gifted with rich wetlands and ecosystems, which support a diverse range of habitats and provide various ecological goods and services. Nearly 114,238 marine fisherfolk families depend on the Odisha coast for their livelihood (Kumar and Pattnaik, 2014). Major Biodiversity in wetlands includes Subarnarekha, Baitarina, Gahirmatha, Bhitarkanika, Mahanadi, Devi, Chilika Lake, and Rusikulya River, hotspots with high ecological importance are lying in these coastal districts. The environmental significance of the study area and probable SLR impacts in each district are elaborately discussed below:

Kendrapara, the high prone district to SLR, has 35.82 km of coastal length. Approximately 18.63% area of Kendrapara district would be inundated to 0.5 m SLR and 29.14% area for 1 m SLR in Kendrapara district. This district has India’s 2nd largest existing mangrove ecosystem, the ‘Bhitarkanika Mangroves’. This mangrove ecosystem has ecological, geomorphological, and biological significance, including mangrove forests, rivers, creeks, estuaries, backwaters, accreted lands, and mudflats. Further, the ecosystem has high faunal importance, including the occurrence of a sizeable population of estuarine crocodiles (*Crocodylus porosus*). Besides this, the sanctuary is rich in other reptiles, birds and mammals, and people. Apart from this, these mangrove forests are moral habitat for king cobra, Indian python and water monitor lizards (Gopi

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_33933409

and Pandav, 2007). The district also has a forest cover of 305 km^2 (ISFR, 2017) and a 1350 km^2 agriculture area (Government of Odisha, 2015). Increasing SLR poses a significant threat to this district's mangrove ecosystems, forest and agriculture areas. Inundation stress, salinity increase, and sediment erosion at landward zones would be significant risks in this region.

Puri is identified as the second most vulnerable district to SLR risks. Even though the estimated SLR projection is low among other districts, the inundation vulnerability is high due to its topography. Nearly 9.02% area of Puri district would be inundated for 0.5 m SLR, and around 13.16% area would be inundated for 1 m SLR. The district covers 214 km^2 of forest land (ISFR, 2017) and 1340 km^2 of agricultural land (Government of Odisha, 2015). The famous Chilika Lake hosts a diverse environment that includes marine, brackish, and freshwater ecosystems. This lake is home to the Irrawaddy dolphin (Sutaria, 2007), critically endangered. It is one of the main wintering areas for migratory birds on the Indian subcontinent, with over 225 species at various phases of their life cycles. More than 0.2 million fishermen rely on the rich fish fauna (Mohanty et al., 2018), including roughly 317 species (Mohanty et al., 2015). Sea level rise also pushes native species from the area, searching for healthier habitats and allowing invasive species to dominate (Varela et al., 2018). Olive Ridley turtles use the vast sandy beaches of Odisha as nesting habitat (Chattopadhyay et al., 2018).

The third vulnerable district to SLR is Bhadrak district, with nearly 1700 km^2 of agriculture area and 75 km^2 of forest cover. Out of this, almost 3.93% of the district area would be inundated for 0.5 m SLR, and around 13.08% area would be inundated for 1 m SLR, followed by the Jagatsinghpur district. Nearly 3.75% of the district area would be inundated for 0.5 m SLR, and 6.12% area would be inundated for 1 m SLR. Jagatsinghpur district has the Gahirmatha rookery, home to huge sea turtles, casuarina trees and mangrove patches along the mainland shore. Natural disasters, such as cyclones and oceanic pressures and shifting riverine discharge have caused noticeable alterations in the study region, particularly in the segments used most for nestings, such as the sand spit and the islets (Prusty et al., 2007). The rising sea levels resulting from climate change threaten these nesting sites (National Research Council, 1990; Leatherman et al., 2000; Garcia et al., 2015; Grases et al., 2020). This district covers 136 km^2 (ISFR, 2017) of forestland and 900 km^2 of agricultural land (Government of Odisha, 2015). Already the Jagatsinghpur district has experienced major floods during the last two decades, causing extensive damage through loss of livestock, human life, and property and the inundation of agricultural lands, waterlogging, salt-water intrusion, and tidal inundation (Jena, 2018).

The fifth vulnerable district to SLR is the Baleshwar district. An approximately 0.39% area would be inundated for 0.5 m SLR, and around 1.18% area would be inundated for 1 m SLR in the Baleshwar district. Agriculture is a principal activity of the district. Nearly 1910 km^2 are net sown area (Government of Odisha, 2015). The forest covers 380 km^2 (ISFR, 2017) of Ganjam, the least vulnerable district to SLR, which has Rushikulya rookery - the third-largest rookeries in the world. Thousands of turtles congregate in the nearshore water of the study area every winter for reproduction. Marine turtle species are vulnerable to climate change-induced SLR (Fuentes et al., 2013). Ganjam has a coastal length of 62.90 km with 3890 km^2 of agriculture area (Government of Odisha, 2015) and 2103 km^2 of forest cover (ISFR, 2017). Low-lying coastal areas are more vulnerable to rising sea levels because they face submergence or salt-water intrusion (Kakani et al., 2011). Seawater intrusion will

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_33933409

stress plants and animals and may even cause the disappearance of certain species when the salinity level reaches above their tolerance. Consequently, SLR would affect farmlands due to land flooding and seawater intrusion. Thereby, agriculture in low-lying coastal areas or adjacent to deltas could be severely impacted by SLR (Rosenzwig and Hillel, 1995; Nicholls et al., 2007; Kibria et al., 2010).

Furthermore, the Ministry of Environment, Forest & Climate of India (2015) has declared the Bhitarkanika Wildlife Sanctuary, Bhitarkanika National Park and Gahirmatha (Marine) Wildlife Sanctuary in Odisha as an example Eco-Sensitive Zone (ESZ). Nearly 45 villages in the Bhadrak district and 157 villages in Kendrapara come under the ESZ. Thus, rising sea levels will severely affect coastal Odisha and its rich Biodiversity.

Climate uncertainty can affect habitats such as mangroves and coral reefs, fisheries, and tourism (IPCC, 2007). The coastline of Odisha, endowed with natural ecosystems, lagoons, olive ridley rookeries, and beaches, attracts more tourism activities in this region and has generated better employment opportunities, thereby sustaining livelihood. Carrasco et al. (2015) indicated that these coastal landforms are also not an exemption from the impacts of SLR. Odisha is particularly vulnerable to cyclones, floods, and droughts, causing widespread damage to the fishing community (DoF, 2014). The findings indicate that sea-level rise is a major concern on the coast of Odisha, along with already evidenced cyclones, storm surges, coastal erosion, and tsunamis, among other disasters. The coastal areas of Odisha, which provide numerous ecological socio-economic benefits to the citizens, will be under threat due to SLR. Even with adopting strategies to stabilize climate forcing by 2050, SLR is predicted to accelerate during the next Century. Therefore, an integrated strategic adaptation plan is needed urgently for this coastal area to reduce SLR vulnerability. The projected SLR and inundation area map of the coastal stretch of Odisha would be a valuable resource for policymakers and planners in developing adaptation strategies. The vulnerable coastal areas, natural resources, and dependent societies at risk demand immediate action to increase their resilience.

Conclusions

This work analyzes sea-level changes during past decades and projects future SLR at the local level at various time scales (2040, 2070, and 2100) under all four IPCC AR5 emission scenarios. The inundation area due to future SLR is also estimated and geospatially mapped. The specifics of this study are:

- An increasing trend of 0.19 cm/yr SLR was observed along the coast of Odisha from 1966 to 2015.
- SLR will continue to rise till the end of the Century under all emission scenarios. The projected SLR of Odisha’s coast indicated a 48.33 to 76.74 cm under high emission scenarios for the year 2100.
- Ganjam district, which has 3890 km^2 of agriculture area and 2103 km^2 of forest cover, is alarming to note that these two considerable areas will be inundated shortly.
- The biological and ecological hotspots of Odisha, such as Bhitarkanika wildlife sanctuary, Chilika Lagoon, and Gahirmatha Olive Ridley rookery, which lies along the coast, would be at risk of rising sea level.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_33933409

- Even though the highest SLR projection is observed for the Bhadrak district, the Kendrapara district is highly vulnerable to SLR scenarios. Nearly 18.63% (492.82 km^2) area would be inundated for 0.5 m SLR and 29.69% (770.69 km^2) area for 1 m SLR in Kendrapara district, followed by Puri and Bhadrak.
- The current study uses CARTOSAT-1 (30 m) DEM data and climate scenarios from GCM data. The significant difference would be observed with higher resolutions DEM data and future climate scenarios.
- The outputs will help decision-makers to develop synergetic adaptation strategies to reduce the risks in the coastal districts of Odisha.
- The study urges to frame SLR inclusive planning in coastal zone management in the state.

Acknowledgements. The author Mr. Punya Murthy Khristodas is thankful to the University Grants Commission (UGC), Government of India, for funding this project under (Maulana Azad National Fellowship)-scheme- 2016-2021 (ref. no.: F1-17.1/2014-2015-CHR-ORI-42755, February 2017). All authors of this research work are indeed grateful to all the colleagues of the Center for Climate Change and Disaster Management (CCCDM), Anna University, Chennai, for their technical support.

REFERENCES

[1] Allison, E. H., Perry, L. A., Badjeck, M. C., Adger, W. N., Brown, K., Conway, D., Halls, A. S., Pilling, G. M., Reynolds, J. D., Andrew, N. L. (2008): Vulnerability of National Economies to the Impacts of Climate Change on Fisheries. – Fish 10(2): 173-196.

[2] Amin, A., Nasim, W., Mubeen, M., Sarwar, S., Urich, P., Ahmad, A., Wajid, A., Khaliq, T., Rasul, F., Hammad, H. M., et al. (2018): Regional climate assessment of precipitation and temperature in Southern Punjab (Pakistan) using SimCLIM climate model for different temporal scales. – Theoretical and Applied Climatology 131(1-2): 121-131.

[3] Carrasco, A. R., Ferreira, Ó., Roelvink, D. J. A. (2015): Coastal lagoons and rising sea level: A review. – Earth Science Reviews 154: 356-368.

[4] Chattopadhyay, N. R., Chetia, A., Machahary, K. Q., Dupak, O. (2018): Assessment of Conservation Measures for Olive Ridley Sea Turtle (Lepidochelys Olivacea) Along Rushikulya Rookery, Ganjam District, Odisha, India. – International Journal of Marine Biology Research 3(1): 1-9.

[5] Chisholm, L., Talbot, T., Appleby, W., Tam, B., Rong, R. (2021): Projected changes to air temperature, sea-level rise, and storms for the Gulf of Maine region in 2050. – Elementa: Science of the Anthropocene 9(1): 1-14.

[6] Chittibabu, P., Dube, S. K., Sinha, P. C., Rao, A. D., Murty, T. S. (2002): Numerical Simulation of Extreme Sea Levels for the Tamil Nadu (India) and Sri Lankan Coasts. – Marine Geodesy 25(3): 235-244.

[7] Climate Central (2019): Flooded Future: Global Vulnerability to Sea Level Rise Worse than Previously Understood. – Climate Central, Princeton, NJ, pp 1-12.

[8] Das, P. K., Dube, S. K., Mohanty, U. C., Sinha, P. C., Rao, A. D. (1983): Numerical simulation of the surge generated by the June 1982 Orissa cyclone. – Mausam 34(4): 359-366.

[9] DoF (2014): Disaster Management Plan of Fisheries Department. – Directorate of Fisheries, Cuttack, Odisha.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_33933409

[10] Dube, S. K., Rao, A. D., Sinha, P. C., Chittibabu, P. (1994): A real time storm surge prediction system: An application to east coast of India. – Proceedings of the Indian National Science Academy 60: 157-170.
[11] Dube, S. K., Rao, A. D., Sinha, P. C., Murty, T. S., Bahulayan, N. (1997): Storm surge in the Bay of Bengal and Arabian Sea: The problem and its prediction. – Mausam 48(2): 283-304.
[12] Dube, S. K., Chittibabu, P., Rao, A. D., Sinha, P. C., Murty, T. S. (2000): Extreme sea levels associated with severe tropical cyclones hitting Orissa coast of India. – Marine Geodesy 23(2): 75-90.
[13] Fuentes, M. M. P. B., Pike, D. A., Dimatteo, A., Wallace, B. P. (2013): Resilience of marine turtle regional management units to climate change. – Global Change Biology 19(5): 1399-1406.
[14] Garcia, Y. C., Ramírez-Herrerac, M. T., Delgado-Trejod, C., Legorreta-Pauline, G., Coronaf, N. (2015): Modeling sea-level change, inundation scenarios, and their effect on the Colola Beach Reserve - a nesting-habitat of the black sea turtle, Michoacán, Mexico. – Geofísica Internacional 54(2): 179-190.
[15] Gilman, E., Ellison, J., Coleman, R. (2007): Assessment of mangrove response to projected relative sea-level rise and recent historical reconstruction of shoreline position. – Environmental Monitoring and Assessment 124: 105-130.
[16] Gopi, G. V., Pandav, B. (2007): Conservation of Avifauna of Bhitarkanika Mangroves, India. – Zoosprint 22: 2839-2847.
[17] Government of Odisha (2015): Odisha Agricultural Statistics 2013-14. – Directorate of Agriculture and Food Production, Bhubaneswar.
[18] Grases, A., Vicente, G., Manuel, G., Jue, L., Joan, P. S. (2020): Coastal flooding and erosion under a changing climate: implications at a low-lying coast (Ebro Delta). – Water 12(2): 1-26.
[19] Hauer, M. E., Evans, J. M., Mishra, D. R. (2016): Millions projected to be at risk from sea-level rise in the continental United States. – Nature Climate Change 6(7): 691-695.
[20] Hinkel, J., Lincke, D., Vafeidis, A., Perrette, M., Nicholls, R., Tol, R., Marzeion, B., Fettweis, X., Ionescu, C., and Levermann, A. (2014): Coastal flood damage and adaptation costs under 21st Century sea-level rise. – Proceedings of the National Academy of Science USA 111(9): 3292-3297.
[21] IPCC (2001): Climate Change 2001. The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (TAR-IPCC). – Cambridge University Press, Cambridge.
[22] IPCC (2007): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate. – Cambridge University Press, Cambridge, pp. 385-432.
[23] IPCC (2013): Summary for Policymakers. – In: Stocker, T. F., Qin, D., Plattner, G. K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P. M. Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
[24] IPCC (2021): Summary for Policymakers. – In: Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M. I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J. B. R., Maycock, T. K., Waterfield, T., Yelekçi, O., Yu, R., Zhou, B. (eds.) Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
[25] ISFR (2017): India State of Forest Report. – Forest Survey of India, Dehradun, Ministry of Environment, Forests and Climate Change. Government of India. https://www.fsi.nic.in/forest-report-2017.

[26] Jena, P. P. (2018): Climate change and its worst effect on coastal Odisha-an overview of its impact in Jagatsinghpur District. – Journal of Humanities and Social Science 23(1): 1-15.
[27] Kakani, N. R., Subraelu, P., Kommireddi, V. N. K., Malini, B. H., Ramakrishnan, R., Rajawat, A. S., Ajai (2011): Climate change and sea-level rise: impact on agriculture along Andhra Pradesh coast—a geomatics analysis. – Journal of the Indian Society of Remote Sensing 39: 415-422.
[28] Khan, A. S. (2013): Climate change induced sea level rise projection and its predicted impact on the Tamil Nadu coast, India: Framing ecosystem and community based adaptation strategies. – Ph. D. Thesis, Anna University, Chennai, India.
[29] Kibria, G., Haroon, A. K. Y., Nugegoda, D., Rose, G. (2010): Climate Change and Chemicals: Environmental and Biological Aspects. – New India Publishing Agency, New Delhi, India**.**
[30] Kirezci, E., Young, I., Ranasinghe, R., Muis, S., Nicholls, R., Lincke, D., Hinkel, J. (2020): Projections of global-scale extreme sea levels and resulting episodic coastal flooding over the 21st century. – Scientific Reports 10(1): 11629.
[31] Krishnan, R., Sanjay, J., Gnanaseelan, C., Mujumdar, M., Kulkarni, A., Chakraborty, S. (2020): Assessment of Climate Change over the Indian Region. – A Report of the Ministry of Earth Sciences (MoES), Government of India, New Delhi.
[32] Kulp, S. A., Strauss, B. H. (2019): New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. – Nature Communications 10(1): 1-12.
[33] Kumar, S. T., Patnaik, S. (2014): Marine fisheries; its current status, sustainable management and socio economic status of the marine fishers of Odisha, through Indian marine policy: a case study. – Research Journal of Animal, Veterinary and Fishery Sciences 2(7): 10-19.
[34] Kumar, T., Mahendra, R. S., Nayak, S., Radhakrishnan, K., Sahu, K. (2010): Coastal vulnerability assessment for Orissa State, East Coast of India. – Journal of Coastal Research 26: 523-534.
[35] Leatherman, S., Zhang, K., Douglas, B. (2000): Sea level rise shown to drive coastal erosion. EOS. – Transactions American Geophysics Union 81(6): 55-57.
[36] Malik, A., Abdalla, R. (2016): Geospatial modeling of the impact of sea level rise on coastal communities: application of Richmond, British Columbia, Canada. – Modelling Earth System and Environment 2(3): 146.
[37] Mary, O. O., Williams, A. B., Benson, N. U. (2021): Simulated sea-level rise under future climate scenarios for the Atlantic Barrier lagoon coast of Nigeria using SimCLIM. – IOP Conference Series: Earth and Environmental Science 665: 012068.
[38] McGranahan, G., Balk D., Anderson, B. (2007): The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. – Environment & Urbanization 19(1): 17-37.
[39] Mohanty, P., Pal, S. R., Mishra, P. (2008): Monitoring and management of environmental changes along the Orissa coast. – Journal of Coastal Research 24(2B): 13-27.
[40] Mohanty, S., Mishra, S., Mohanty, R., Mohapatra, A., Pattanaik, A. (2015): Ichthyofaunal diversity of Chilika Lake, Odisha, India: an inventory, assessment of biodiversity status and comprehensive systematic checklist (1916-2014). – Check List 11(6): 1-19.
[41] Mohanty, S. K., Bhatta, K., Nanda, S. (2018): Bibliography of Publications: Research and Investigations in Chilika Lake (1872-2017). – Chilika Development Authority, Bhubaneswar.
[42] Murty, T. S., Flather, R. A., Henry, R. F. (1986): The storm surge problem in the Bay of Bengal. – Progress in Oceanography 16(4): 195-233.
[43] National Research Council. (1990): Decline of the Sea Turtles: Causes and Prevention. – National Academy Press, Washington.

[44] Neumann, A. T., Vafeidis, J., Zimmermann, R., Nicholls, J. (2015): Future coastal population growth and exposure to sea-level rise and coastal flooding—A global assessment. – PloS One 10(3): e0118571.
[45] Nicholls, R. J., Hoozemans, F., Marchand, M. (1999): Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. – Global Environmental Change - Human and Policy Dimensions 9(1): 69-87.
[46] Nicholls, R. J., Wong, P. P., Burkett, V. R., Codignotto, J. O., Hay, J. E., McLean, R. F., Ragoonaden, S., Woodroffe, C. D. (2007): Coastal Systems and Low-Lying Areas. – In: Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J., Hanson, C. E. (eds.) Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Parry. Cambridge University Press, Cambridge, pp. 315-356.
[47] Nicholls, R. J., Hanson, S. E., Lowe, J. A., Warrick, R. A., Lu, X., Long, A. J., Carter, T. R. (2011): Constructing sea level scenarios for impact and adaptation assessment of coastal areas: a guidance document. – Technical Guidelines of the Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA) of the Intergovernmental Panel on Climate Change. IPCC, Geneva.
[48] Pardaens, A. K., Gregory, J. M., Lowe, J. A. (2010): A model study of factors influencing projected changes in regional sea level over the twenty-first Century. – Clim Dyn 36(9-10): 2015-2033.
[49] Prusty, G., Dash, S., Singh, M. P. (2007): Spatio-temporal analysis of multi-date IRS imageries for turtle habitat dynamics characterization at Gahirmatha coast, India. – International Journal of Remote Sensing 28: 871-883**.**
[50] Ramachandran, A., Khan, A. S., Palanivelu, K., Prasannavenkatesh, R., Jayanthi, N. (2017): Projection of climate change-induced sea-level rise for the coasts of Tamil Nadu and Puducherry, India using SimCLIM: a first step towards planning adaptation policies. – Journal of Coastal Conservation 21(23): 1-12.
[51] Ramesh, R., Purvaja, R., Senthilvel, A. (2011): National assessment of shoreline change: Odisha coast. – NCSCM/MoEF Report, 2011-01.
[52] Rosenzweig, C., Hillel, D. (1995): Potential impacts of climate change on agriculture and food supply. – Consequence 1(2): 23-32.
[53] Shah, K. U., Dulal, H. B., Johnson, C., Baptiste, A. (2013): Understanding livelihood vulnerability to climate change: applying the livelihood vulnerability index in Trinidad and Tobago. – Geoforum 47: 125-137.
[54] SimCLIM (2011): SimCLIM Essentials: Training Book 1, Version 2.0. – Climsystems, Hamilton.
[55] Sutaria, D. (2007): Irrawaddy Dolphin – India. – Whale and Dolphin Conservation Society. http://www.wdcs.org/submissionsbin/consprojectirr.pdf. Accessed: 25 Dec 2008.
[56] Swapna, P., Ravichandran, M., Nidheesh, G., Jyoti, J., Sandeep, N., Deepa, J. S., Unnikrishnan, A. S. (2020): Sea-Level Rise. Assessment of Climate Change over the Indian Region. – Springer, Singapore, pp. 175-189.
[57] Unnikrishnan, A. S., Shankar, D. (2006): Are sea-level-rise trends along the coasts of the north Indian Ocean consistent with global estimates? – Global and Planetary Change 57(3): 301-307.
[58] Unnikrishnan, A., Gangan, N., Lengaigne, M. (2015): Sea-level-rise trends off the Indian coasts during the last two decades. – Current Science 108(5): 966-971.
[59] Varela, M. R., Patricio, A. R., Anderson, K., Godley, B. J. (2018): Assessing climate change associated sea level rise impacts on sea turtle nesting beaches using drones, photogrammetry and a novel GPS system. – Global Change Biology 25(2): 753-762.
[60] Velan, N., Mohanty, R. K. (2015): Gender Wise Rural-to-Urban Migration in Orissa, India: An Adaptation Strategy to Climate Change. – In: Delgado-Ramos, G. C. (ed.) Inequality and Climate Change: Perspectives from the South. CODESRIA, Dakar, pp. 137-170.

[61] Warrick, R. A. (2009): Using SimCLIM for modeling the impacts of climate extremes in a changing climate: a preliminary case study of household water harvesting in Southeast Queensland. – 18th World IMACS/MODSIM Congress, Cairns, Australia, pp. 2583-2589.
[62] Yin, C., Li, Y., Urich, P. (2013): SimCLIM 2013 Data Manual. —CLIM Systems Ltd., Hamilton.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_33933409