IDRiM (2024) 14 (1) **ISSN: 2185-8322**
DOI10.5595/001c. 119011

Journal of Integrated Disaster Risk Management

Regular Article

Cyclone Vulnerability Assessment of Coastal Odisha: A Sub-district Level Analysis

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Received: 12/01/2024 / Accepted: 03/05/2024 / Published online: 28/06/2024

Abstract Tropical cyclones have the potential of unleashing havoc on ecosystems, infrastructure, and even individuals. Situated in the eastern region of India, Odisha, an Indian constituent state, shares its eastern border with the Bay of Bengal. Owing to its extensive coastline of more than 450 kms, the state is vulnerable to cyclones. Conducting a comprehensive vulnerability assessment in the coastal districts as well as Community Development (CD) blocks of Odisha would help ascertain the level of vulnerability and provide a deeper understanding of households' capacity to adjust to this extreme event. With quick advancements in a variety of data availability and processing techniques, the use of remote sensing and spatial analysis has risen dramatically to control the effects of catastrophic disasters on the ground. Existing coastal vulnerability and sensitivity indices generally concur that incorporating socioeconomic indicators will facilitate the identification of vulnerable locations. Hence, the present study seeks to construct an integrated coastal risk assessment index for coastal Odisha, taking into account both physical and socioeconomic attributes both at district as well as sub-district (block) level. The study encompasses 103 blocks distributed over 9 districts of the coastal region of Odisha. Ten parameters were chosen based on the criteria of physical and social vulnerability. A vulnerability map is created to identify zones with very low, low, moderate, and high vulnerability based on the weights and scores obtained using the Analytic Hierarchy Process (AHP). Findings reveal that around 32% of the whole study area, which amounts to 9820 km^2, is classified as the highly vulnerable zone. The majority of the blocks are classified as the moderately vulnerable zone, encompassing around 15,000 km^2, or 48% of the total area. The area with the lowest danger, which covers only 235 km^2 (0.78% of the total), is classified as a very low- or no-risk zone. The findings could be valuable for policymakers in developing and executing proactive strategies to mitigate cyclone impacts. The findings of this study endorse the notion that communities living in such areas should be

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provided with interventions that target the reduction of susceptibility and the adoption of appropriate adaptive strategies.

Keywords: Tropical cyclone, Vulnerability assessment, Coastal Odisha, Analytic Hierarchy Process (AHP), Sub-district analysis

1. INTRODUCTION

1.1 Background of the Study

A cyclone is a natural disaster that poses a threat to human life, causes destruction of property, and damages infrastructure. India has consistently experienced and survived tropical cyclones (Garge et al., 2015). The Bay of Bengal in the southeast, the Arabian Sea in the south-west, and the Laccadive Sea in the south encircle the nation on three sides. Tropical cyclones, tsunamis, storm surges, river floods, high tides, and other meteorological disasters have all hit India's 7516-km-long coastal region (Yadav & Barve, 2017). In the Bay of Bengal region, cyclone intensity has grown during the past decade. Higher winds spread across a greater area have raised the risk and coastal vulnerability (Murty et al., 2016). Cyclones and other meteorological hazards have a significant impact on country's coastal industries, which include agriculture, forestry, salt production, and fisheries. When it comes to cyclones, Odisha is one of India's most vulnerable states. The stakeholders involved in disaster management for tropical cyclones considerably benefit from categorising the region's susceptibility.

Odisha is very susceptible to disasters as a result of its geographical and socioeconomic circumstances. Its location on India's east coast makes it one of the world's six most cyclone-prone places, with the coast of Odisha having the highest risk in terms of cyclone landfall (OSDMA, 2017). Although Odisha's coastline constitutes only 17% of the Indian east coast, it has seen around 35% of all cyclonic and severe cyclonic storms that have traversed the east coast. Additionally, it has regularly faced concomitant storm surges that have flooded significant areas of coastal districts (Revenue & Disaster Management Department, 2018). Several cyclones, including Phailin (2013), Hudhud (2014), Titli (2018), Fani (2019), Bulbul (2019), Amphan (2020), Yaas (2021), Gulab (2021), and Jawad (2021), have damaged and destroyed a wide range of commercial, infrastructural, and private assets in Odisha’s coastal belts. If private losses are not included, the overall damage and loss caused by storm Fani in 2019 is assessed at INR 29,315 crore, whereas INR 2779.32 crore was spent for the restoration of damages created by Cyclone Titli in 2018 (Revenue & Disaster Management Department, 2018). The Rapid Damage and Need Assessment Report (RDNA) calculated the financial impact of Cyclone Phailin's destruction and losses in the year 2013 to be at INR 89,020 million, equivalent to nearly US$1,450 million. The majority of the reconstruction expenditures, as shown by a combined report of Government of Odisha, Asian Development bank , United Nations and The World Bank (2013), are allocated to agriculture and livestock (30%) and housing (33%).

The term 'Vulnerability' refers to the extent to which individuals, resources, and environments are prone to the impacts of particular hazards, as determined by physical, social, economic, and environmental factors (UNDRR, 2009). According to the Intergovernmental Panel on Climate Change (IPCC), vulnerability is the extent to which a system is susceptible to or unable to cope with adverse effects of climate change, including climate variability and extremes, and it depends on the type, magnitude, and rate of climate variation to which a system is exposed, as well as the system's sensitivity and its capacity for adaptation. (van Ypersele, 2001). The likelihood of a cyclone hitting a specific location is determined on the basis of various factors, including the magnitude of the risk, the extent of the population's exposure to it, the level of poverty, and the level of government involvement (Field et al., 2012). While it is not possible to completely prevent natural catastrophes, it is possible to assess and develop solutions to reduce their destructive impact on coasts (Malehmir et al., 2016; Pratiwi et al., 2023). Taking adequate mitigation measures can help lessen the loss and damage of devastating tropical cyclones. A comprehensive tropical cyclone vulnerability assessment can provide enough data to support effective mitigation strategies. Satellite remote sensing and geographic analysis can be utilised to aid risk management strategies by evaluating cyclone dangers, vulnerability, and capacity for mitigation. This can be achieved by the assessment and modelling of these factors under projected future climate conditions (Li & Li, 2013). Utilising remote sensing and spatial analysis techniques can be advantageous for predicting the hazards associated with tropical cyclones. Planners can utilise the maps produced by vulnerability assessments to devise innovative strategies that prioritise prevention and mitigation (Hoque et al., 2018). The integration of remote sensing data with spatial analysis provides a highly effective approach for evaluating the geographical vulnerability to tropical cyclones.

The main objective of the present paper is to provide a comprehensive approach for assessing the risk associated with tropical cyclones, considering both physical and social vulnerability factors. The research is conducted at both district and sub-district (community development block or block) levels. As far as administrative hierarchy is concerned, blocks are the next lower order administrative units after districts. The micro-level (block level) study is useful in preparing effective strategies for reducing the impacts of cyclones. The block-level vulnerability assessment allows for a thorough analysis of infrastructure variation, significantly improving the reliability of the assessment results for decision-making purposes (Yarveysi et al., 2023). The proposed methodology examines the spatial distribution of vulnerability to tropical cyclones in the coastal region of Odisha.

1.2 Study Area

Odisha is situated in the eastern part of India and is flanked by the Bay of Bengal to the east. It boasts a coastline that stretches approximately 480 kms. Nine districts have been selected, all of which are in close proximity to the Bay of Bengal and frequently encounter tropical cyclones. The frequent visit of tropical cyclone leads to detrimental effects on the economy, infrastructure, and human life. Therefore, the study is limited to a total of 103 blocks, which are sub-district administrative units, encompassing all nine districts of the state.

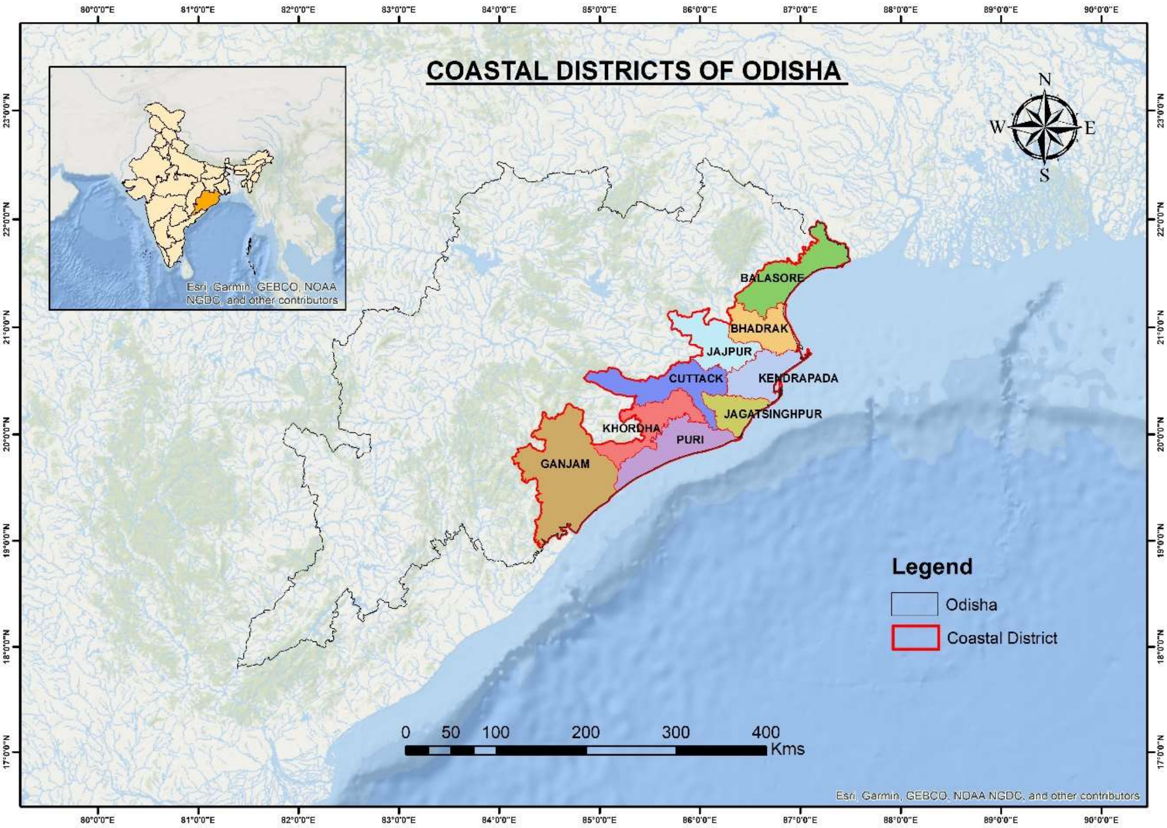

Figure 1. Study area

2. DATABASE AND METHODOLOGY

2.1 Data Sources

A set of crucial criteria were selected to evaluate areas prone to cyclones on a block-by-block basis. The data for these criteria was obtained from a diverse range of sources.

Table 1. Database and its use/application

Sl. No.	Data	Use/Application	Source
1	Sentinel (10m resolution)	Land use & Landcover	Copernicus
2	SRTM Digital Elevation Model (DEM) 30 m resolution	Slope, Proximity to coastline	Shuttle Radar Topography (SRTM) Open Topography
3	Cyclone Tracks (1980-2020)	Proximity to Cyclone Track	International Best Track Archive for Climate Stewardship (IBTrACS)
4	Social Parameters	Population density, Women, Children, Literacy, Agricultural Dependent Population, Kutcha Houses	Census of India (2011)

The sources of data along with their use are displayed in table 1. Observations of the same region may be made often because to Sentinel-2's high return frequency. Even in situations with dense plant coverings, the SRTM can see and locate the hidden subsurface through the interpretation of digital elevation models (DEMs). For tropical cyclones, the most comprehensive worldwide collection is provided by the International Best Track Archive for Climate Stewardship (IBTrACS) project. The 2021 Census of India, which was scheduled to be conducted in 2021, has been delayed due to the COVID-19 pandemic. Therefore, in regard to socially susceptible criteria, the 2011 census is utilised. Finding an optimal dataset proves challenging due to the multitude of sources that may provide the numerous data required for cyclone disaster management (Li & Padgett, 2013).

2.2 Methodology

Figure 2 shows a comprehensive methodological flowchart that was employed to achieve the objective. Twelve sub-criteria were chosen for the study based on the literature review and their impact on the vulnerability of tropical cyclones. The two broad categories of parameters or criteria were: physical vulnerability and social vulnerability.

DOI10.5595/001c. 119011

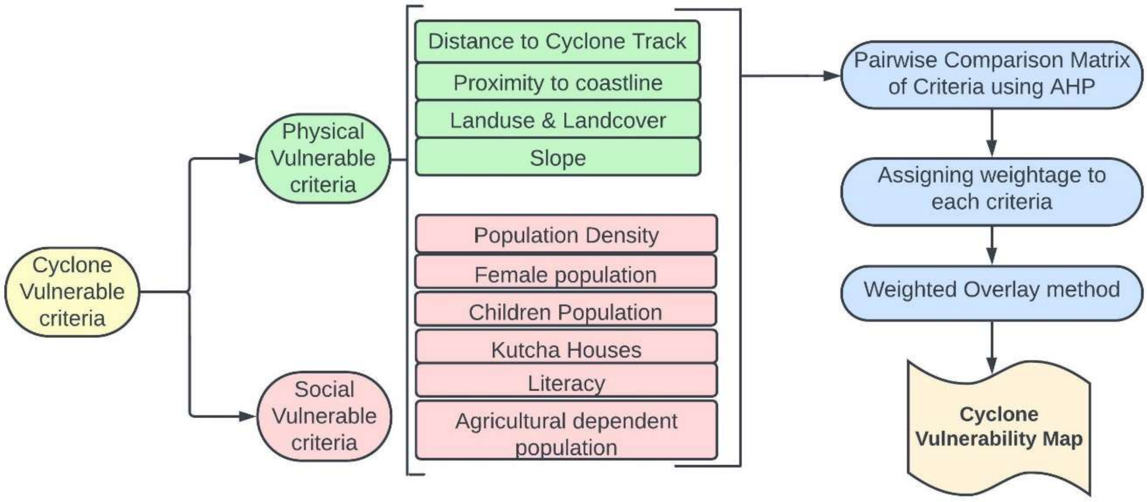

Figure 2. A framework for identifying regions vulnerable to cyclones in the coastal Odisha

For the assessment of cyclone-vulnerable areas, the multi-criterion decision analysis approach of the Analytic Hierarchy Process (AHP) is used. The analytic hierarchy process (AHP) is a mathematical and logical strategy for organising, computing, and analysing complex decisions. It is a frequently used structured strategy for analysing parameters in a study based on their priority and making judgements by assigning weights to parameters. To derive the weight for each parameter, the parameters are compared pairwise and written in matrix form (Saaty, 1977).

Each sub-criteria layer was processed in ArcGIS 10.8 and resampled with a cell size of 30m x 30m. AHP is used to find weights for each criterion, which are then used in the weighted overlay technique to make the final cyclone susceptibility map with and without mitigation capacity criteria.

3. RESULTS AND DISCUSSION

Important physical and socially vulnerable criteria that play a key role in identifying the risk zones are picked in order to access the coastal areas of Odisha that are prone to cyclones.

3.1 Criteria for Determining Physical Vulnerability

Physical vulnerability criteria include Landuse and Land Cover, slope, proximity to the coast, cyclone tracks. These factors are crucial in the assessment of physical vulnerability.

3.1.1 Landuse and Landcover

Land cover is divided into six categories: waterbodies, vegetation, built-up areas, active floodplains, agricultural, and arid lands. The agricultural area covers the largest area with around 16,600 km^2, followed by vegetation with 6,700 km^2. Ranks to each category has been provided for the analysis to be done using AHP. The built-up and agricultural areas are ranked highest due to their heightened vulnerability to cyclones. Then the active flood plains, vegetation, and water bodies are assigned subsequent ranks. Landuse and landcover are ascertained through the application of supervised classification on Sentinel-10 m resolution data. (Figure 3a).

3.1.2 Slope

Cyclones are more likely to occur on flat terrain rather than on steep slopes. Majority of the surface in the coastal region of Odisha has slope of less than 5 degrees (Figure 3b). Slope with less than 5.5 degrees covers an area of around 13,500 km^2, whereas an area of approximately 9,500 km^2 is characterized by slope ranging from 10.5 to 15.5 degree. The interior parts of districts such as Ganjam, Cuttack, and Jajpur have steeper slopes and higher elevation, rendering them less vulnerable to cyclones.

3.1.3 Proximity to Coastline

Tropical cyclones consistently pose a threat to coastal regions due to their highest intensity being observed over the ocean. As we venture further into the continent, various obstacles such as buildings, trees, and elevated areas affect the intensity of the cyclone, restricting its ability to advance. A buffer zone is delineated extending 80 kms or more from the coast of Odisha towards the landmass. Further, it is divided into five zones: 0–20 kms, 20–40 kms, 40–60 kms, 60–80 kms, and 80 kms and beyond (Figure 3c).

3.1.4 Proximity to Cyclone Track

Individuals and assets located along previous paths of cyclones and the shoreline face a significant level of vulnerability to tropical storms (Alam & Dominey-Howes, 2015). The International Best Track Archive for Climate Stewardship (IBTrACS) has been utilised to ascertain the trajectories of cyclones spanning from 1980 to 2020 (Figure 3d). Buffer analysis is employed to draw buffers at 2 kms intervals from the previous cyclone tracks, extending up to distances of 8 kms and beyond.

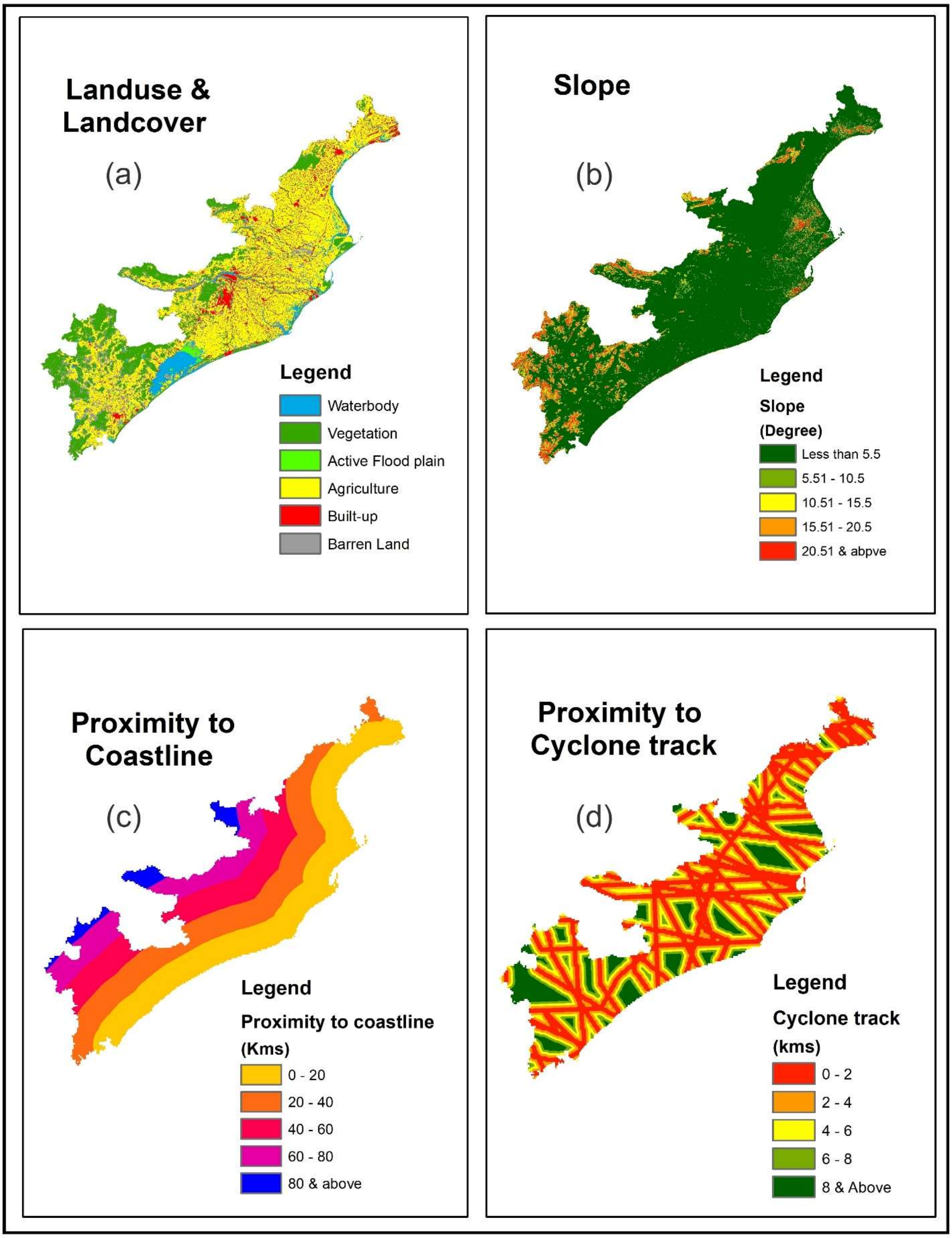

Figure 3. Criteria for physical vulnerability: (a) Landuse and Landcover (b) Slope (c) Proximity to coastline (d) Proximity to cyclone track

3.2 Criteria for Determining Social Vulnerability

A multitude of societal elements are extremely susceptible to tropical cyclones.; therefore, the vulnerability to cyclones is not just determined by physical factors. Population density, child and female populations, literacy, agricultural dependency, and kutcha houses are the social factors used in the study.

3.2.1 Population Density

Places with dense populations are likely to be more vulnerable to cyclones. One of the key variables in identifying social vulnerability is considered to be population density (Dewan, 2013). At all levels of the decision hierarchy, the population density indication is therefore given a higher priority. It was computed by dividing the total population of a census tract by the tract's area (in km^2). In this study area, Odisha's capital, Bhubaneswar (Khordha), Cuttack (Cuttack), Puri Sadar (Puri), Raghunathpur (Jagatsinghpur), and Kendrapara (Kendrapara) are some of the highly densely populated areas (Figure 4a).

3.2.2 Kutcha House

Kutcha houses are most negatively impacted by cyclones. Wood, plastic, polyethene, thatch, and other materials are used to make them. The people living there are left utterly homeless since these materials lack the ability to hold a house upright during cyclones and are completely destroyed by storms. 2011 Census of India data was used to compile information for the kutcha dwelling. Some blocks with the highest percentage of kutcha houses are Soro (Balasore), Bhadrak (Bhadrak), Rajnagar (Kendrapara), Banki (Cuttack), Satyabadi (Puri), Rangelunda (Ganjam), Tangi (Khordha), etc (Figure 4 b).

3.2.3 Children Population

Children are particularly affected by tropical cyclones because they are less able to follow and use evacuation procedures efficiently on their own (Hoque et al., 2018). Nilagiri and Oupada (Balasore), Danagadi and Sukinda (Jajpur), Rajnagar (Kendrapada), Nuagaon (Jagatsingpur), Beguniapada, and Surada (Ganjam) are some of the blocks with the highest percentage of children (Figure 4 c).

DOI10.5595/001c. 119011

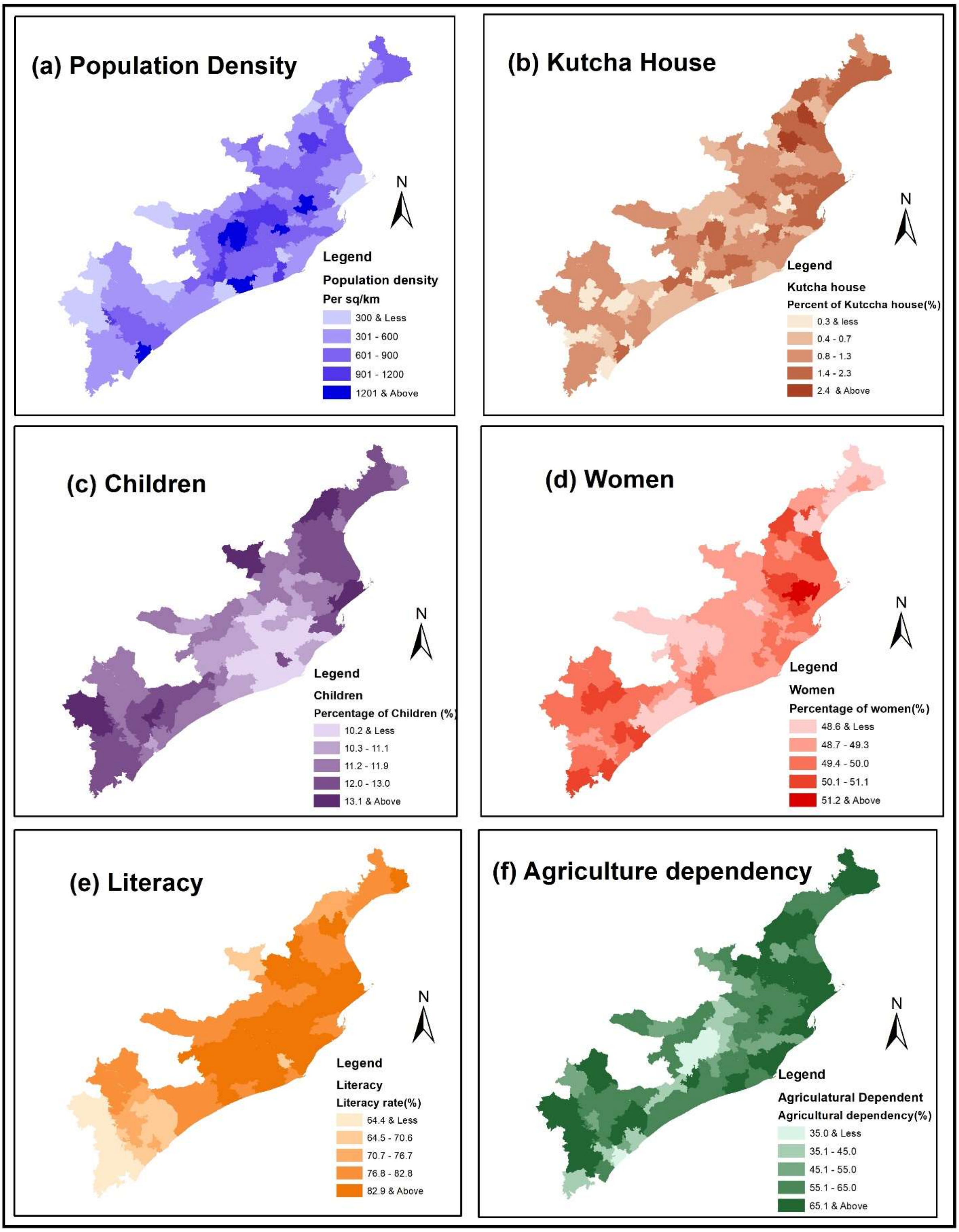

Figure 4. Criteria for Social vulnerability: (a) Population density (b) Kutcha house (c) Children (d) Women (e) Literacy (f) Agricultural dependency

3.2.4 Women Population

In many places, particularly in rural areas and some urban areas, women are dependent on their male counterparts to take any decision, making them dependent and more vulnerable to cyclones (Hossain et al., 2017). Women are more vulnerable during the pre-disaster period than men are, and they often experience greater hardship during the post-disaster crisis. Many blocks in coastal Odisha have a large number of females, including Rajkanika and Ali (Kendrapada), most blocks of Bhadrak, Balasore, Ganjam, *etc.* (Figure 4 d). Women are considered to be more vulnerable than men due to their lack of mobility and independence.

3.2.5 Level of Literacy

The literacy rate has a big impact on social vulnerability to cyclone disasters. Literate people are better aware of the effects of cyclones and more inclined to heed evacuation instructions and take other precautions to lessen the effects that are likely to occur (Muttarak & Lutz, 2014). Education improves preparedness and hastens recovery after catastrophes for people and societies. In the case of literacy, many blocks have achieved more than 80 percent literacy. Very few blocks in Ganjam districts show the lowest level of literacy, ranging between 55 percent and 65 percent.

3.2.6 Agricultural Dependency

Storm surges, strong winds, and heavy rain damage agricultural crops. As a result, agricultural dependent people suffer a huge loss of income due to the effects of tropical cyclones (Hoque et al., 2016). The information regarding agricultural dependency is derived from the 2011 Census of India at the block level. The total number of main workers and marginal workers employed as cultivators and agricultural labourers is considered. Rivers like the Mahanadi, Brahmani, Subarnarekha, and Rusikuliya, among others, make the land sufficiently rich to support productive agriculture. The majority of the coastal blocks, including Balasore, Bhadrak, Kendrapara, and Jagatsinghpur, have populations that are mostly dependent on agriculture, making them more vulnerable.

3.3 Evaluation of Vulnerability Assessment Using Analytic Hierarchy Process(AHP)

In order to enhance priority setting and better decision-making when the phenomena being examined comprise both the quantitative and qualitative parts of a choice, the Analytic Hierarchy Process (AHP) is used. Thomas L. Saaty originally created the AHP. The AHP is built on multiple criteria that, in order to make the optimal choice, prioritise the criteria identified by various parties (stakeholders and experts) participating in the decision-making process. Additionally, it aids in defending the wisdom of the choice (Saaty, 1977, 1980). AHP chooses the optimal options. For the assessment of cyclone risk locations, several studies have employed AHP and consider AHP to be more advantageous in the event of a multi-index integrated evaluation (Murali et al., 2013; Subbarayan et al., 2023; Mansour et al., 2021). In this study, the weights for each of the selected criteria are calculated according to a standard process.

3.3.1 Construction of Matrix

All components are compared pair-wise, and the matrix is completed by assigning scores depending on the relative weight of each element. Each factor is compared to each other in a pair-wise comparison matrix by giving the corresponding cell a relative dominating value between 1 and 9. The table 2 shows the scale of Saaty (1–9) and its relative importance.

Table 2. Saaty's rating scale

Scale	Importance / Description
1	Equal Importance
2	Equal to Moderate importance
3	Moderate importance
4	Moderate to Strong Importance
5	Strong Importance
6	Strong to Very Strong Importance
7	Very Strong Importance
8	Very to Extremely Strong Importance
9	Extremely Importance

A score of 1 indicates equal significance, a score of 3 signifies a mild preference, a score of 5 denotes a clear preference, and a score of 7 indicates a strong preference. When a substitute for the odd numbers is needed, the even numbers—specifically, 2, 4, 6, and 8—are employed. Table 3 presents the outcome of the suitability analysis and the ranking of sub-criteria based on their relative importance.

Table 3. Suitability analysis and ranking of sub-criteria according to relative importance

Component	Criteria	Not suitable (1)	Less suitable (2)	Moderately suitable (3)	Suitable (4)	Highly Suitable (5)
Physical vulnerability	Slope (in degrees)	20.5 & above	15.5-20.5	10.5-15.5	5.5-10.5	Less than-5.5
	Proximity to Coastline (kms)	80 & above	60-80	40-60	20-40	0-20
	Proximity to Cyclone track(kms)	8 & above	6-8	4-6	2-4	0-2
	Landuse and Landcover	Water body	Active flood plain	Barren land	Vegetation cover	Built-up, Agriculture
Social Vulnerability	Population Density	Less than 300	300-600	600-900	900-1200	1200 & above
	Kutcha houses (%)	Less than 0.3	0.3 – 0.7	0.7 – 1.3	1.3-2.3	2.3 & above
	Children population (%)	Less than 10.2	10.2 – 11.1	11.1 – 12.0	12.0- 13.0	13.0 & above
	Women population (%)	Less than 48.5	48.5 – 49.5	49.5 - 50.5	50.5 – 51.5	51.5 & above
	Level of literacy (%)	82 & above	76 – 82	70 - 76	64 - 70	Less than 64
	Agricultural dependency population (%)	Less than 22	35 – 45	45 - 55	55 - 65	65 & above

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3.3.2 Evaluation of Matrix

The AHP demands a consistency check of the pairwise comparison matrix, which was done by computing the consistency ratio (CR), because the choices made about the prioritisation of the criteria may not be ideal.

CR = CI/RI ……………………………………….(1)

where CI is Consistency Index & RI is Random Index. The CI is calculated using the equation:

CI = (λ max-n)/(n-1)……………………………(2)

where n is the order of the matrix, and λ max is its biggest or primary Eigen value. The random index (RI) is defined as the average of the resultant consistency index, according to the order of the matrix (table 4) that Saaty provided in 1977. In general, relevance is defined as a consistency ratio (CR) of 0.10 or below. The values must be adjusted once more if the supplied result is not less than or equal to 0.10. (Saaty, 1977).

The CR for this study was 0.01031, which is less than 0.10, meaning that the relative weights given to each criterion may be utilised for further processing.

Table 4. Random Index (RI) (Saaty, 1980)

Matrix size	1	2	3	4	5	6	7	8	9	10
Random Consistency Index (RI)	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

3.3.3 Pairwise Comparison Matrix

For the evaluation and identification of the susceptible regions of coastal Odisha, a total of ten parameters, including population density, closeness to the shoreline, proximity to the cyclone track, Kutcha houses, women's and children's populations, agricultural dependency population, level of literacy, slope, and LULC, were taken into account. The table 5 shows the pair-wise matrix along with the weight of each criterion after applying AHP. Layers representing each parameter were created in the ArcGIS 10.8 programme, then transformed to raster files and resampled to a cell size of 30 m x 30 m. The weighting of each layer was adjusted in accordance with the pairwise comparison matrix in the weighted overlay analysis, and the result was the generation of the cyclone susceptible map, which was classified into four categories (high, moderate, low, and very low) based on natural breaks.

 ISSN: 2185-8322
DOI10.5595/001c. 119011

Table 5. Pair-wise comparison matrix for each parameter along with weightage

Parameters	Population density	Proximity to Coastline	Proximity to Cyclone	Kutcha House	Women Population	Children Population	Agricultural dependency	Level of Literacy	Slope	LULC	Weightage	Weightage in Percent
Population density	1	1	3	5	5	5	7	7	8	9	0.29	28.7
Proximity to Coastline	1	1	2	5	4	5	5	7	8	9	0.26	25.81
Proximity to Cyclone track	0.3	0.5	1	2	3	3	3	4	5	7	0.14	14.33
Kutcha House	0.2	0.2	0.5	1	1	1	1	1	2	3	0.06	5.65
Women Population	0.2	0.25	0.33	1	1	1	1	1	2	3	0.06	5.55
Children Population	0.2	0.2	0.33	1	1	1	1	1	2	2	0.05	5.18
Agricultural dependency	0.14	0.2	0.33	1	1	1	1	1	1	2	0.05	4.7
Literacy	0.14	0.14	0.25	1	1	1	1	1	1	2	0.04	4.44
Slope	0.13	0.13	0.20	0.5	0.5	0.5	1	1	1	1	0.03	3.22
LULC	0.11	0.11	0.14	0.33	0.33	0.5	0.5	0.5	1	1	0.02	2.43
											1	100

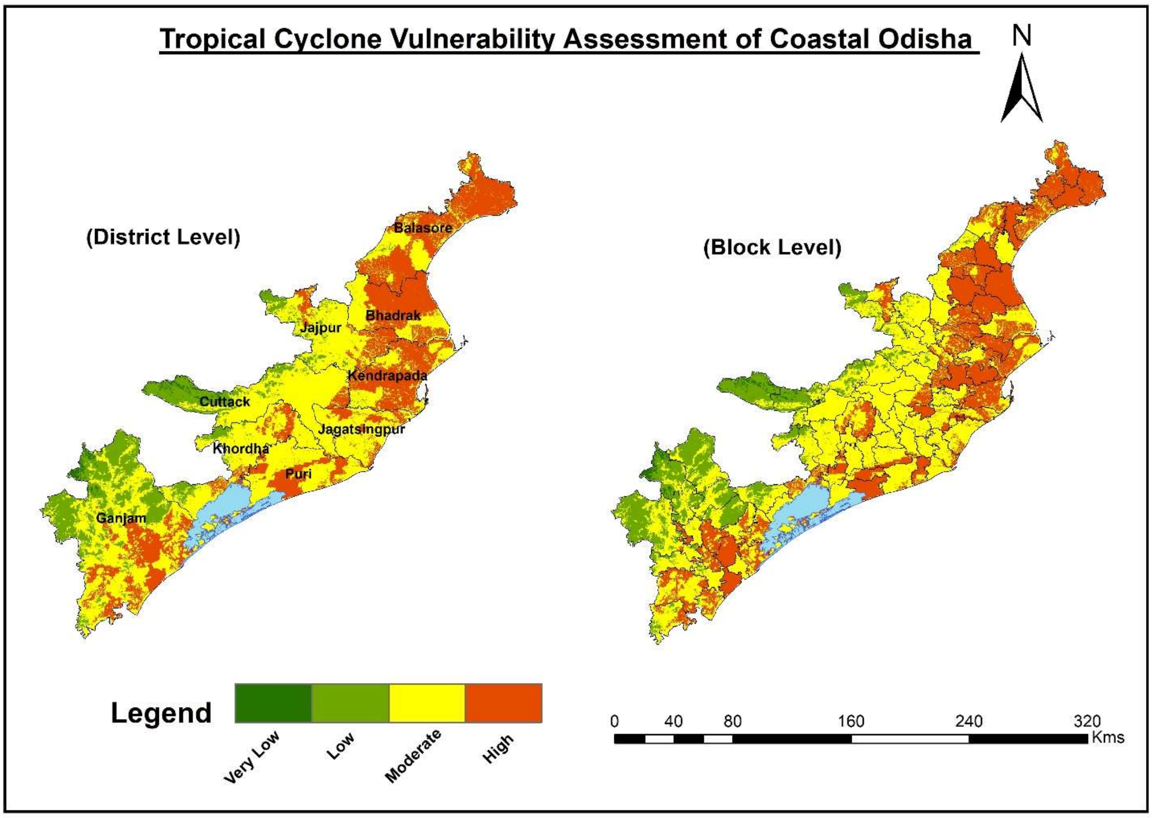

Figure 5. Tropical cyclone vulnerability assessment of Coastal Odisha at district and block level

The research area consists of regions with varying levels of vulnerability: very high vulnerability (32.40%), moderate vulnerability (48.88%), low vulnerability (17.95%), and extremely low or no risk zones, which account for 0.78% of the total area. The resulting map (Figure 5) shows that about 9820 km^2, or 32.40 percent area of the study area are extremely vulnerable to cyclones. Block level analysis reveals that the northern coastal blocks of Balasore (Jaleswar, Bhogarai, Baliapal, Basta, Remuna, Baleswar Sadar, Soro, Khaira, Simila and Nilagiri), Bhadrak (Bhadrak, Basudebpur, Tihiri and Dhamnagar), and Kendrapara (Kendrapada, Patamundai and Mahakalparha) are all very vulnerable to cyclones. The primary factors contributing to this circumstance, are the dense population and the propensity for cyclone paths to traverse this region. In addition to this, blocks in the Ganjam district, such as Purusottampur, Chhatrapur, Rangelunda, Chitiki, Kabisuryanagar, Khalikot, and portions of Digapahandi, have significant vulnerability. The high percentage of women and children, poor literacy rate, and population dependence on agriculture contribute to high vulnerability in the Ganjam district. The vulnerability of some blocks in Puri (Kakatpur, Puri-Sadar, Satyabadi, and Kanas), Jagatsinghpur (Raghunathpur, Tirtol, and Kujanga), Eastern Jajpur (Dashrathpur, Binjharpur, and Bari), parts of Khordha (outside Bhubaneswar and Tangi), and Eastern Cuttack, *i.e.*, Nishchintakoli and southern Niali, is also greater.

Approximately 49% of the land in the nine chosen districts is classified as moderate zones. Moderate vulnerability is observed in considerable areas of Cuttack, Jagatsinghpur, Khordha, Jajpur, and Ganjam. Moderate vulnerability is equivalent to severe vulnerability in terms of severity and harm. These blocks exhibit higher literacy rates, a population with less dependence on agriculture, a modest number of Kutcha dwellings, and comparatively steeper slope. The moderate zones stretch beyond 20 kms or more inland.

About 17.95 percent, equivalent to 5439.42 km^2 of the study area falls within the low vulnerability area. The vulnerability to the cyclones decreases as elevation increases, and this zone forms the interior parts of districts, such as Cuttack, Khordha, Ganjam, and Jajpur. Areas with low vulnerability are located at a distance more than 40 to 60 kms from the shore. Further, just a mere 235.31 km^2, accounting for only 0.78% of the total area, are classified as zones with an extremely low or non-existent level of danger. This zone is part of northern portions of Bhanjanagar block of Ganjam district, Narashingpur, and Badamba blocks of Cuttack. These areas are located in the interior parts of the districts and have greater elevations. High levels of vegetation can be seen in terms of the land cover.

When it comes to cyclone susceptibility at the district level, Balasore, Bhadrak, and Kendrapara are considered to be extremely sensitive areas. Such susceptibility is attributed to a higher proportion of Kutcha homes, a higher proportion of children, and a population that depends heavily on agriculture. It is also more vulnerable to the intensity of cyclones due to its low height, slope, and proximity to the cyclone tracks. The districts of Puri, Jagatsinghpur, Khordha, Jajpur, and Cuttack are primarily considered to be moderately sensitive, while there are also some indications of high susceptibility in these places. The proportion of women and children is lower than in other places, and these moderately susceptible zones also have high literacy rates. Western parts of Khordha, Cuttack, Jajpur, and Ganjam are the districts with low and very low susceptible zones. The high altitude and lower population density in these districts are the primary causes of their reduced susceptibility and vulnerability.

Table 6. Area of vulnerable zones

Vulnerable Zone	Area (km^2)	Percentage (%)
High	9819.46	32.40
Moderate	14816.52	48.88
Low	5439.42	17.95
Very Low	235.31	0.78

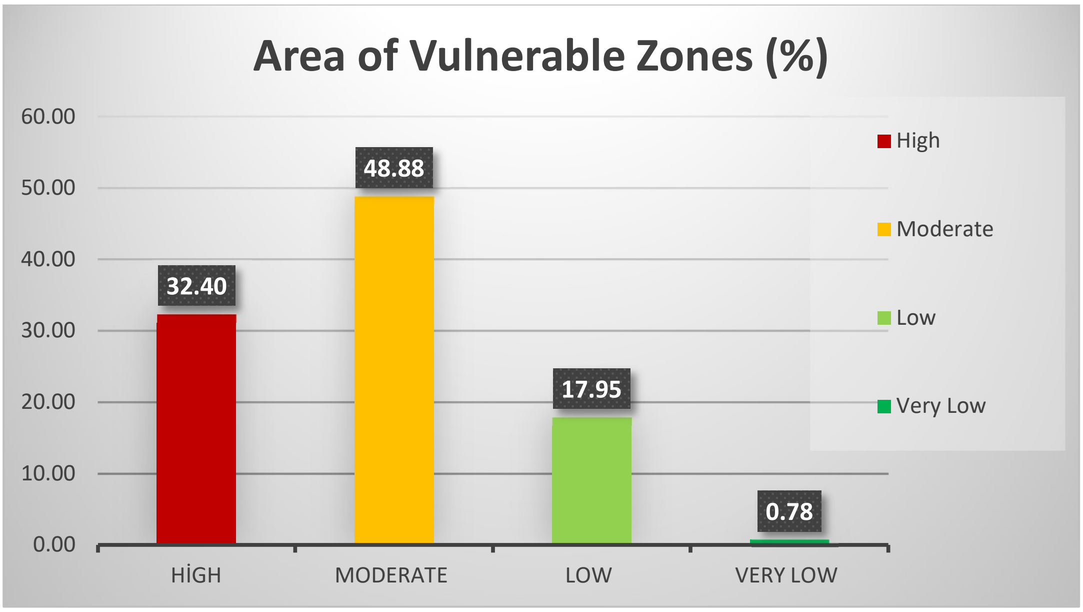

Figure 6. Graph showing the percentage of area under each zone

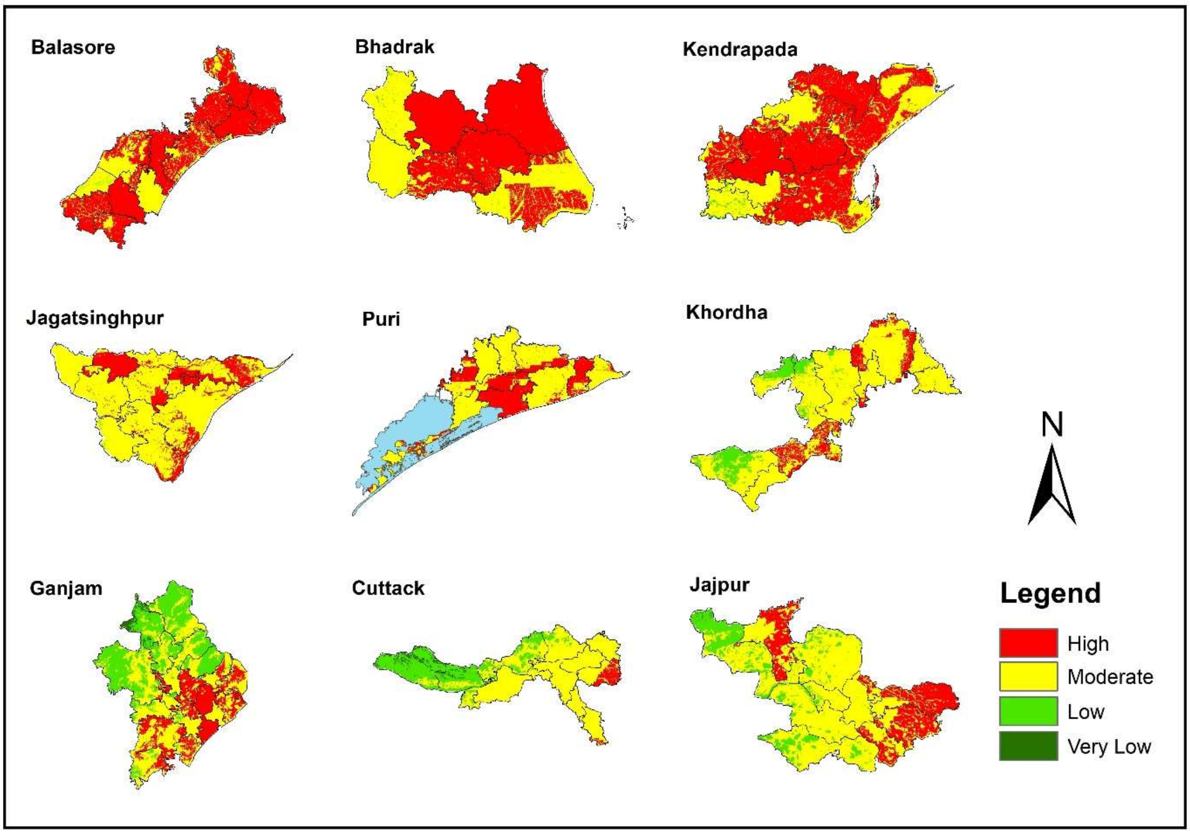

Figure 7. Block-wise tropical cyclone vulnerability in each coastal district of Odisha

Table 7. Blocks that are highly vulnerable and moderately vulnerable by tropical cyclone in eastern Odisha

Sl.no.	District	Blocks (Highly vulnerable)	Blocks (Moderately Vulnerable)
1	**Baleswar**	Jaleswar Bhogarai Baliapal Basta Remuna Baleswar Sadar Soro Khaira Simila Nilagiri	Oupada Bahanaga
2	**Bhadrak**	Bhadrak Basudebpur Tihiri Dhamnagar Chandabali	Banta Bhandaripokhari
3	**Kendrapada**	Kendrapada Patamundai Mahakalparha Rajkanika Rajnagar Derabis	Ali Marshaghat Garadapur
4	**Jagatsinghpur**	Raghunathpur Tirtol	Birirhi Jagatsingpur

DOI10.5595/001c. 119011

		Kujanga	Nuagan Balikuda Ersama
5	**Puri**	Kakatpur Puri-Sadar Satyabadi Kanas Southern Nimapda Krushnaprashad	Pipili Delanga Brahmagiri Gop Astarang
6	**Khordha**	Tangi Bhubaneswar	Balianta Balipatana Jatani Khordha Begunia Southern Bolagarh Chilika
7	**Ganjam**	Ganjam Purusottampur Rangelunda Chitiki Kabisuryanagar Khalikot Parts of Digapahandi Parts of Beguniapada	Chhatrapur Sanakhemundi Surada Aska Seragad
8	**Jajpur**	Danagadi Dasarthpur	Korai Sukinda

		Binjipur Bari	Dharmasala Rasulpur Jajpur Sadar Badachana
9	**Cuttack**	Nischintakoili Southern Niali	Cuttack Sadar Kantapda Barang Salepur Mahanga Choudwar Banki-Dampada Banki Parts of Athgard

4. POLICY RESPONSE AND WAY FORWARD

Since 1999, when the Super cyclone devastated Odisha's coastal region and claimed over 10,000 lives, the Government of Odisha, in partnership with the Union Government of India, has continuously put efforts and resources into safeguarding its inhabitants against cyclones. Odisha became the first state in India to form a disaster management authority in 1999, following the Super Cyclone. The efficient disaster management of the cyclones Phailin and Fani, which affected the coastal areas of Odisha in 2013 and 2019, respectively, made the state's consistent intervention fairly evident (Jena & Kouamé, 2023). The United Nations (UN) commended the Odisha government's management of both cyclones, Fani and Phailin (Senapati, 2013; Jena & Kouamé, 2023).

The State Disaster Management Plan, 2019, provides a range of structural and non-structural mitigation strategies for various departments and directorates, such as drinking water, Panchayat Raj, MSME, excise, health and family welfare, factories and boilers, and animal husbandry and veterinary services. As per the report, the primary approach to disaster management has shifted from relief and restoration to a culture of readiness and mitigation (OSDMA 2019:59). Resilient communities and infrastructure are necessary for managing disasters, particularly cyclones, in an efficient manner. Indeed, a multitude of initiatives and plans are in place to enhance the overall welfare of individuals possessing immense potential to establish robust infrastructure and communities resilient to cyclones.

The Mahatma Gandhi Rural Employment Guarantee Scheme (MGNREGS) aims to provide employment opportunities and social security for disadvantaged people. The P*radhan Mantri Awaas Yojana (PMAY)-Gramin* (Prime Minister's Rural Housing Scheme) is being implemented to provide pucca dwellings to all the households that are homeless or living in run-down houses. The Government of Odisha also provides assistance on housing through the schemes of *Biju Pucca Ghara Yojana* (BPGY), *Matsyajivi Basagruha Yojna* (MBY) for the fisher folk community, *Nirman Shramik Pucca Ghara Yojna* (NSPGY) for construction workers, and *Pucca Ghara Yojna* for mining workers (Government of Odisha, Asian Bank of Development, The United Nations, and The World Bank ,2019). Road connection is essential for prompt evacuations, improved communications, and linking every hamlet with hospitals, shelters, and other resources during the post-disaster period. This is why the *Pradhan Mantri Gram Sadak Yojana* (PMGSY) is a programme that is being undertaken to improve the road connectivity. Pre-, during-, and post-disaster health care facilities that are equal, accessible, and reasonably priced are the goals of the National Health Mission (NHM). *Samagra Shiksha Abhiyan* (SSA) guarantees that every kid attends elementary school for five years. The goal of the National Rural Drinking Water Programme (NRDWP) is to guarantee that everyone has access to enough safe drinking water at all times (OSDMA, 2019) Despite the considerable potential of these initiatives to reduce the effects of cyclones, they have fallen short of achieving the anticipated level of effectiveness during the cyclone disaster management process. Therefore, all the schemes should have clear guidelines with regard to their interface in the disaster management process. For example, all homes constructed under the PMAY should follow disaster-resistant housing designs. The provision of special assistance should also be extended to the beneficiaries for this purpose.

Despite the support for all major projects and plans, the post-disaster recovery period remains chaotic. The most recent and devastating disaster to strike Odisha, which has an impact on both human and physical wellbeing, was Cyclone Fani in 2019. The Damage, Loss, and Need Assessment (DLNA) report states that the cyclone affected about 14 districts of Odisha. The cyclone completely, substantially, or partially affected 3,61,743 residential properties (both rural and urban), including kutcha and pucca homes. Despite their composition of brick, concrete, and other materials, pucca homes occasionally collapse due to the weight of several trees and other structures falling upon them. The severe gusting wind caused damage to 69% of rural homes in Puri alone, according to the assessment. The severe gusting wind seriously impacted over half of the slums (829 out of 1508) in the urban areas of Puri, Khordha, and Cuttack. After further evaluation, the DLNA study concluded that the recovery costs for home, land, and settlement alone were INR 8996 crore. In addition to the significant damage and loss to housing and settlement, other social sectors, including health and education, as well as the supply of water, electricity, and other services, also suffered losses and damages (Government of Odisha, Asian Development Bank, The United Nation & The World Bank, 2019).

Notwithstanding the Odisha government's persistent recognition for its proactive efforts towards safeguarding public safety, such as the implementation of informed evacuation strategies, the enormous costs accrued by other social and physical sectors cannot be disregarded. Needless to say, despite numerous structural mitigation plans—including the construction of 800 multipurpose cyclone shelters, evacuation routes along the state's entire coastline, and embankments—being implemented to establish cyclone resilience, much remains to be done to attain the overarching objective of 'zero-human casualties'. In an effort to minimize susceptibility to cyclones, forthcoming disaster mitigation strategies for cyclones ought to explore the subsequent aspects.

- It is well known that forests, particularly mangroves, protect coastal regions by acting as an effective barrier against strong, windy cyclonic winds. During Cyclone "*Bulbul*" in 2019, the mangroves in the Sundarbans slowed down the destructive winds to a far greater extent before they could enter the locality (IFRC, 2019). But all along the coast of Odisha, the mangroves are in danger because of the dense population living there and the competing need for land for prawn farming and agriculture (Forest & Environment Department Odisha, 2023). Frequently subjected to strong winds and surges from tropical storms, mangrove ecosystems frequently recover over time and continue to offer a plethora of social advantages following storm occurrences (Krauss & Osland, 2019). Thus, it becomes necessary to protect the existing cover and increase the quantity of these ecosystems in coastal areas.

- Houses, either pucca or kutcha, bear the maximum damage and recovery costs. In places with higher to moderate susceptibility, a general code and conduct for building "cyclone-resistant houses" should be stated and followed. Officials should oversee and maintain strict scientific rules for building construction to minimise loss and recovery expenses after the event of a cyclone. Regular monitoring and inspection are necessary for the house's location, elevation, and material quality.

- Often, the inundation of saline water brought by tidal surges destroys agricultural fields and harms people, animals, homes, and agricultural areas. Saline embankments aid in preventing storm surges and salty water inundation. More such embankments are needed to contain the storm surges.

- Prompt and quick recovery is important, as the DLND report states that the suffering in the case of Cyclone *Fani* persisted for too long in spite of a highly effective evacuation and quick response. Despite the government of Odisha's declaration that the welfare of its most vulnerable communities was a top concern, the tardy recovery of the electricity, water, and communication networks caused significant deprivations for these groups (Government of Odisha, Asian Development Bank, The United Nation & The World Bank, 2019). Thus, it is crucial to recover from the cyclone as soon as possible in order to rebuild resilience and stand tall.

- Women are considered among the worst sufferers, as they were not given enough privacy in the shelter houses, which had a negative impact on them and occasionally made them feel unsafe (Government of Odisha, Asian Development Bank, The United Nation & The World Bank, 2019). Therefore, when constructing a multipurpose shelter house, it is crucial to prioritize the safety and privacy of women.

5. CONCLUSION

There has been an increase in the frequency of cyclones in Odisha in recent years. Both the physical and socio-economic parameters contribute to the susceptibility of a place to cyclonic impact. The coastal areas of Odisha are experiencing significant impacts from cyclone-induced storms and floods (Chittibabu et al., 2004). The vulnerability mapping at both the district and block levels indicates that the majority of the most vulnerable places are located in agricultural, built up, and densely populated areas. Further, though the pockets of high vulnerability are observed in different parts of the region, the majority of extremely vulnerable areas are situated in the northern coastal plains, specifically in the districts of Baleswar, Bhadrak, Kendrapara, and Jagatshingpur. Due the longer distance from the coast, and high literacy rate, Cuttack and Jajpur districts have moderate level of vulnerability. Similarly, due to relatively high literacy rates in Puri and Khordha, the vulnerability gradually reduces to a moderate extent. Furthermore, these places demonstrate reduced levels of reliance on agriculture, relative lower share of children in the population, and low sex ratio. The eastern part of Ganjam district, has a mix of high and moderate level of vulnerability pockets. However, cyclones do not pose a threat to the western coastal region; blocks located in the western parts of Ganjam, Cuttack and Jajpur face less risk of damage from cyclones. Nevertheless, it is evident that the most parts of coastal region of Odisha is vulnerable to the detrimental effects of tropical cyclones, specifically in regards to infrastructure and agriculture. There is a great extent of spatial heterogeneity in the degree of vulnerability to cyclones in the region. Decision-makers may use the results of this study to make sure that the mitigation strategies are both effective and efficient in various spatial contexts, with the aim of reducing the impact of cyclones. The analysis is limited by its reliance on the 2011 census data for social indicators, which represents the most recent available data. The enumeration for the 2021 census was postponed because to the COVID-19 epidemic. It goes without saying that over the past two decades, effective state intervention in disaster management has significantly contributed to the mitigation of cyclone impacts. In order to lessen the vulnerability to cyclones, it is necessary to develop more innovative strategies for creating robust communities and infrastructure in the vulnerable areas.

REFERENCES

Alam, E. & Dominey-Howes, D. (2014). A new catalogue of tropical cyclones of the northern Bay of Bengal and the distribution and effects of selected landfalling events in Bangladesh. *International Journal of Climatology, 35*(6), 801-835. https://doi.org/10.1002/joc.4035

Chittibabu, P., Dube, S., Macnabb, J., Murty, T., Rao, A. D., Mohanty, U. C. & Sinha, P. (2004). Mitigation of Flooding and Cyclone Hazard in Orissa, India. *Natural Hazards, 31*, 455-485. https://doi.org/10.1023/B:NHAZ.0000023362.26409.22

Dewan, A. (2013). Flood in a Megacity: Geospatial Techniques in Assessing Hazards, Risk and Vulnerability. 10.1007/978-94-007-5875-9

Field, C. ,Barros V., & Stocker, T. (2012). *Managing the risks of extreme events and disasters to advance climate change adaptation.* Special report of the Intergovernmental Panel on Climate Change (IPCC).

Forest & Environment Department – Government of Odisha. (2023). *Mangroves of Odisha-A pictorial Guide.* https://odishaforest.in/admin/data/documents/publication_file_1950704990.pdf

Garge, R.N., Ha, H., Khoo, S. (2015). Disaster Risk Management and the Role of the Armed Forces: Critical Analysis of Reactive Disaster Management in India. In: Ha, H., Fernando, R., Mahmood, A. (eds) Strategic Disaster Risk Management in Asia. *Springer, New Delhi*. https://doi.org/10.1007/978-81-322-2373-3_5

Government of Odisha, Asian Development Bank & The World Bank (2013). *India Cyclone Phailin in Odisha, October 2013: Rapid Damage and Needs Assessment Report*. https://ncrmp.gov.in/wp-content/uploads/2014/03/Odisha-Phailin-report-Final.pdf

Government of Odisha, Asian Development Bank, The United Nation & The World Bank (2019). *Cyclone Fani Damage, Loss and Need Assessment: Rapid Damage and Needs Assessment Report.* https://www.osdma.org/publication/cyclone-fani-2019-dlna-report/#gsc.tab=0

Pratiwi, P. H., Dwiningrum, S. I. A., & Sumunar, D. R. S. (2023). Integrated Disaster Risk Management in the Education Process in Schools. *IDRiM Journal, 13*(1), 172–192. https://doi.org/10.5595/001c.91284

Hoque, M., Phinn, S.,Roelfsema, C. & Childs, I. (2016). Modelling tropical cyclone hazards under climate change scenario using geospatial techniques. *IOP Conference Series: Earth and Environmental Science*, 47. 012024. 10.1088/1755-1315/47/1/012024

Hoque, M.,Phinn, S., & Roelfsema, C. & Childs, I.. (2016). Assessing tropical cyclone impacts using object-based moderate spatial resolution image analysis: a case study in Bangladesh. *International Journal of Remote Sensing*, *37*. 5320-5343. 10.1080/01431161.2016.1239286.

Hossain, B. M. R., Hassan, S. M. K., & Islam, M. S. (2017). Empowering the Vulnerable Women in Disaster Prone Areas: A Case Study of Southern and Northern Region of Bangladesh. https://doi.org/10.9790/0837-2209151421

International Federation of Red Cross and Red Crescent Societies- IFRC. (2019). *Operation Update Report Bangladesh: Cyclone Bulbul.*

Jena, P. & Kouamé, A.T. (2023, 3 Nov). Odisha's turnaround in disaster management has lessons for the world. *Relief web*. https://reliefweb.int/report/india/odishas-turnaround-disaster-management-has-lessons-world

Krauss, K. & Osland, M. (2019). Tropical cyclones and the organization of mangrove forests: A review. *Annals of botany*, *125*. 10.1093/aob/mcz161.

Malehmir, A.,Socco, L. V., Bastani, M., Krawczyk, C.,Pfaffhuber, A., Miller, R.D.,Maurer, H.,Frauenfelder, R.,Suto, K., Bazin, S., Merz, K. & Dahlin, T.. (2016). Near-Surface Geophysical Characterization of Areas Prone to Natural Hazards: A Review of the Current and Perspective on the Future. 10.1016/bs.agph.2016.08.001.

Li, K. & Li, G. (2013). Risk assessment on storm surges in the coastal area of Guangdong Province. *Natural Hazards*, *68*. 10.1007/s11069-013-0682-2.

Li, Y. & Padgett, J.. (2013). Closure to "Review of Methods to Assess, Design for, and Mitigate Multiple Hazards" by Yue Li, Aakash Ahuja, and Jamie E. Padgett. *Journal of Performance of Constructed Facilities, 27*. 216-216. 10.1061/(ASCE)CF.1943-5509.0000386.

Mansour, S., Darby, S.,Leyland, J. & Atkinson, P. (2021). Geospatial modelling of tropical cyclone risk along the northeast coast of Oman: Marine hazard mitigation and management policies. *Marine Policy*, *129*. 104544. 10.1016/j.marpol.2021.104544.

Murali, M., Misra, A.,Amrita, S. & Vethamony, P. (2013). Coastal vulnerability of Puducherry coast, India using analytical hierarchical process. *Natural hazards and earth system sciences, 1*. 509-559. 10.5194/nhessd-1-509-2013.

Muttarak, R. & Lutz, W. (2014). Is Education a Key to Reducing Vulnerability to Natural Disasters and hence Unavoidable Climate Change?. *Ecology and Society*, *19*. 10.5751/ES-06476-190142.

Odisha State Disaster Management Authority (OSDMA) Government of Odisha (2017). *State Disaster Management Plan June-2017*. https://www.humanitarianlibrary.org/sites/default/files/2019/05/Government%20of%20Odisha%20State%20Disaster%20Management%20Plan%20June%202017.pdf

Odisha State Disaster Management Authority (OSDMA), Government of Odisha. (2019). *State Disaster Management plan June- 2019.* https://www.osdma.org/state-dm-plan/#gsc.tab=0

Pln, M.,Bhaskaran, P.,Gayathri, R.,Sahoo, B.,Kumar, T. & Bonthu, S.. (2016). Numerical study of coastal hydrodynamics using a coupled model for Hudhud cyclone in the Bay of Bengal. *Estuarine Coastal and Shelf Science*, *183*. 13-27..

Revenue & Disaster Management Department – Government of Odisha. (2019). *MEMORANDUM- Extremely Severe Cyclonic Storm "FANI".* https://srcodisha.nic.in/calamity/Memorandum_Cyclone%20FANI_3rd%20May%202019.pdf

Revenue & Disaster Management Department (Disaster Management). (2018). *FINAL MEMORANDUM- Very Severe Cyclonic Storm "Titli" and Subsequent Floods.* https://srcodisha.nic.in/calamity/Final%20Memorandum%20-%20TITLI.pdf

Saaty T.L. (1980). *The analytical hierarchy process*. McGraw-Hill, New York

Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, *15*, 234–281.

Senapati, A. (2013, 23 Dec). UN felicitates Odisha for its disaster management model during Phailin. *Down to Earth*. https://www.downtoearth.org.in/news/un-felicitates-odisha-for-its-disaster-management-model-during-phailin-43087

Subbarayan, S., Devanantham, A., K S S, Parthasarathy., Masthan Reddy, N., Almohamad, H.,Dughairi, A.,Al-Mutiry, M., & Abdo, H. (2023). Multi-Criterion Analysis of Cyclone Risk along the Coast of Tamil Nadu, India—A Geospatial Approach. *ISPRS International Journal of Geo-Information*, *12*. 341. 10.3390/ijgi12080341.

UNDRR. (2009). *UNISDR terminology on disaster risk reduction*. Geneva, Switzerland.

Yadav, D. K & Barve, A.. (2017). Analysis of Socioeconomic Vulnerability for Cyclone-Affected Communities in Coastal Odisha, India. *International Journal of Disaster Risk Reduction, 22*. 387-396. 10.1016/j.ijdrr.2017.02.003.

Yarveysi, F.,Alipour, A., Moftakhari Rostamkhani, H., & Jafarzadegan, K. & Hamid, M.. (2023). Block-level vulnerability assessment reveals disproportionate impacts of natural hazards across the conterminous United States. *Nature Communications*, *14*. 10.1038/s41467-023-39853-z.

Ypersele van, Jean-Pascal. (2001). Climate Change 2001: Impacts, Adaptation and Vulnerability, Summary for Policymakers. Cambridge University Press