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VULNERABILITY ASSESSMENT OF NATURAL HAZARDS: A CASE STUDY OF COASTAL DISTRICTS OF ODISHA

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Abstract:
Natural hazard vulnerability assessment refers to the assessment of vulnerability to natural hazards covering the vulnerability of human and environmental systems. It is generally assumed that only the socio-economic factors determine the degree of impact of the natural hazards on the human life and on the environment, but this paper argues that both natural as well as socio-economic factors decide the level of impact of natural hazards on social life. Several studies have shown that in case of disaster events, socially vulnerable populations are more likely to be adversely affected, i.e. they are less likely to recover and more likely to die. Effectively assessing and addressing social vulnerability decreases human suffering and the economic loss caused during and after a hazard by strengthening the mechanisms of providing social services and public assistance. This paper attempts to construct a composite vulnerability index (CVI), based on selected socio-economic and natural variables to assess the level of spatial variation in degree of vulnerability to natural hazards by taking nine coastal districts of Odisha into account.

Key Words: Composite Vulnerability Index, Disaster, Hazard, Social Vulnerability.

INTRODUCTION:
A natural hazard is a threat of natural event and when the hazardous threat actually happens and harms human society and ecosystem, the event becomes a natural disaster. A system is vulnerable to hazards due to its specific social structure, its economic conditions and its ecological meaning (Walker et al., 2004). As every system has a capacity to buffer, the resilience factor or the adaptation capacity has to be opposed to vulnerability. Vulnerability and resilience balance each other. The outcome of this relation is the residual risk. i.e. *Risk = Hazard* (Vulnerability – Resilience)*. This remaining risk can be addressed as social risk, economic risk and ecological risk (Klein et al, 2003). Resilience and Resources are directly related to each other. The individual or collective perception of risk plays a crucial role in the whole concept of vulnerability (Brooks et al., 2005, Birkmann 2007). How risk is perceived may determine where people settle, how they are prepared, how they behave in case of an emergency, and finally of importance for management what kind of risk they accept (Brooks. 2003). Vulnerability is defined as the degree to which a system is susceptible to, or unable to cope with the adverse effects of natural hazards such as floods and cyclones (IPCC, 2001). Vulnerability is the function of three components—exposure, sensitivity, and adaptive capacity – which are influenced by a range of biophysical and socio-economic factors (IPCC, 2001). Vulnerability is assessed in the context of a region, a country, a community, a household, a sector or a system with respect to the different types of hazards. Once vulnerability is assessed and evaluated; regulations, capacity building

and awareness programmes can be designed and implemented to reduce vulnerability and to minimize it in the future (Adger et. al, 2004).

Numerous vulnerability assessment methods emanating from different points of view and different disciplines are developed and tested to determine the degree of vulnerability of a system. Such approaches simplify the framework of vulnerability to a format that allows for its assessment using available data (Downing and Patwardhan 2004). This paper describes the development of a composite vulnerability index (CVI), from 15 socioeconomic variables from Census of India and three natural variables by using Analytical Hierarchical Processes (AHP) methodology to examine the spatial variation of vulnerability to natural hazards at district level in nine coastal districts of Odisha.

STUDY AREA:

The study area is located on the east coast of India with a long coastline of about 480 km along the Bay of Bengal, extending from river Bahuda in the south to river Subaranarekha in the north. The study area (Fig. 1) extends from 19° 00' to 21° 59' N latitude and 84° 09' to 87° 30' E longitude. The study area extends from 19° 00' to 21° 59' N latitude and 84° 09' to 87° 30' E longitude. The region is geographically bounded by West Bengal in the northeast, Andhra Pradesh in the southeast, adjacent districts of the Chhattisgarh in the west, and the Bay of Bengal in the east. The study area encompasses a total of nine coastal districts, namely Baleswar, Bhadrak, Kendrapara, Jagatsinghpur, Puri, Ganjam, as well as the three adjacent coastal districts of Khurdha, Cuttack, and Jajapur. These districts are predominantly located in the coastal plains of the state and extend inland ward from the sea for about 100-120 km. The total area of all the nine districts is 31952 km², which constitutes 20.52% of the total landmass of the state. Mahanadi is a very large river which crosses through the region and its big delta merges into the deltas formed by the Brahmani and the Baitarani. The delta area is fertile and is provided with irrigation facilities. Administratively the study area comprises of 09 districts, 102 blocks, 67 tahsils, 15 sub-divisions, 2319 gram panchayats and 16829 villages. The capital city of Bhubaneswar lies in Khurdha district.

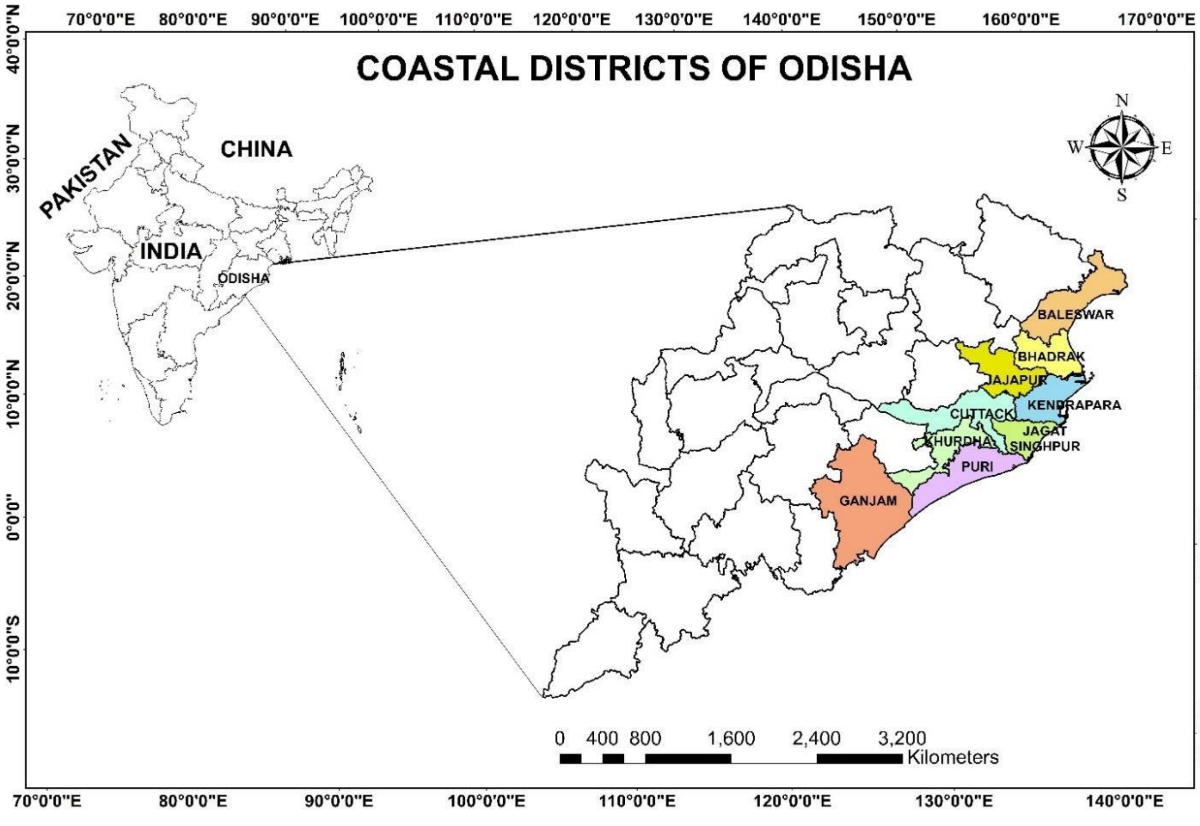

Fig. 1: Coastal Districts of Odisha

DATABASE AND METHODOLOGY:

Data on socio-economic variables such as demographic, health and education, transport and communication, and economic factors for each district was obtained from the Census of India, 2001. On the basis these variables the socio-economic vulnerability index was calculated. For vulnerability assessment of natural hazards data on natural variables such as soil, relief and land-use has been collected from National Atlas on Thematic and Mapping Organization (NATMO). Table 1 shows the list of socio-economic and natural variables which were taken for calculating the composite vulnerability index of the study area.

Table 1: Socio-economic and Natural Indicators

	Socio-economic Indicators				Natural Indicators		
Sl. No	**Demographic**	**Health and Education**	**Transport and Communication**	**Economic**	**Soil**	**Relief**	**Land-use**
1	Population Density	Beds per Thousand Population	Road Density	% Main Workers in primary Sector	Water bodies	< 100	Red Gravelly Soil
2	Age Structure	Hospitals per 1000 Population	No. of Telephone Exchanges	Female Work Participation Rate	Forest cover and Plantation	100 - 300	Sandy Soil
3	% of Disabled Population	Literacy Rate	No. of Post Offices	Rice Production	Irrigated land	300 - 600	Alluvial Soil
4	% of SC/ST Population	Educational Institutions per 1000 Population	% of Villages having no Electricity	House type	Settlement	600 - 900	Loamy Soil

Source: Census of India, 2001 (socio-economic indicators) and NATMO (natural indicators)

Data collected on various variables has been arranged in the form of a rectangular matrix with rows representing regions and columns representing variables. Where, X_{ij} be the value of the indicator *j* corresponding to district *i*. As the variables are in different units and scales, they have been normalized and standardized in to unit-free values. The methodology used by UNDP to calculate the Human Development Index (UNDP, 2006) has been used for normalization of the variables. Before normalization, the functional relationship between the variables and vulnerability has been identified. Two types of functional relationships have been identified. First, vulnerability increases with increase in the value of the variable. In this case normalization has been done using the fallowing formula (UNDP, 2006):

$$x_{ij} = \frac{X_{ij} - \underset{i}{Min}\{X_{ij}\}}{\underset{i}{Max}\{X_{ij}\} - \underset{i}{Min}\{X_{ij}\}}$$

The normalized values of all the variables lie between 0 and 1. Value 1 represents the region with maximum vulnerability and 0 represents the region with minimum vulnerability. The second functional relationship corresponds to increase in vulnerability with decrease in the value of variable. For this the normalization has been done by:

$$y_{ij} = \frac{\underset{i}{Max}\{X_{ij}\} - X_{ij}}{\underset{i}{Max}\{X_{ij}\} - \underset{i}{Min}\{X_{ij}\}}$$

Where,

y_{ij} = normalized value of variable *j* corresponding to district *i*.
X_{ij} = actual value of variable *j* corresponding to district *i*.
$Max\ \{X_{ij}\}$= maximum actual value of variable *j* corresponding to district *i*.
$Min\ \{X_{ij}\}$ = minimum actual value of variable *j* corresponding to district *i*.

Analytical hierarchy process (AHP) technique (Saaty, 1980) was used by assigning factor weights for each criterion determined by a pair-wise comparison matrix with scores given as described by Saaty (1990, 1994). Each factor is rated against every other factor by assigning a relative dominant value between 1 and 9 to the intersecting cell. After obtaining the weighted values of the variables the vulnerability indices have been calculated by employing the following formula:

$$NVI = \frac{\sum_{i=1}^{n} x_{ij}w_{ij}}{n}$$

Where,
$x_{ij}w_{ij}$= product of normalized value and weighted value of natural variables
n = $number\ of\ variables$

Similarly, the socio-economic vulnerability index (SVI) was calculated. Then by combining both the indices the composite vulnerability index was calculated as:

$$CVI = \frac{NVI + SVI}{2}$$

All the CVI values were then separated into five classes to represent five categories of the natural hazard vulnerability of the area; namely, very high, high, moderate, low and very low vulnerability zones.

RESULTS AND DISCUSSIONS:

Demographic factors such as population density, age structure, percentage of SC/ST population and percentage of disabled people are crucial factors in defining the vulnerability assessment. Higher population density would imply that more people are dependent on available resources for their livelihood. Furthermore, with limited resources, in case of an emergency, a dense population is less able to cope. Children and old age population form an important aspect of vulnerability analysis as population below 5 years of age and above 65 years age need help and are not able to act independently. *Percentage of SC/ST population* of a place indicates the social backwardness of a society as socially marginalized populations, such as scheduled Castes and scheduled tribes (SC/ST) are deprived of basic social and economic opportunities. They may be also termed as ‘socially vulnerable’ populations and are most likely to be affected by the natural hazards in the coastal areas. The *disabled people* to a great extent are affected by the occurrence of natural hazards because of their lesser degree of physical mobility and inability to take prompt actions. When natural disasters like cyclone and floods occurs, disabled people are more likely to be died, injured or fall sick and to lose their homes and income. They may be unable to run away or perhaps they do not hear early warnings.

The southern part of the region has a very low density of population as compared to the northern part of the region which has a quite high population density, which makes it comparatively more vulnerable than the southern part. There is a very little variation in the presence of child and old age population in all the districts. Kendrapara and Ganjam district has highest percentage of child and old age population. Khurdha and Puri has least percentage of child and old age population. Baleswar and Jajapur have highest percentage of SC/ST population sharing more than 30% of their total population. Puri and Khurdha has lower percentage of SC/ST population. The percentage of disabled population in the coastal districts of Odisha varies between 2 to 4 percentages. The districts of Puri, Khurdha and Bhadrak have larger concentration of disabled population constituting around 30% of the total disabled population in the coastal districts. The districts of Jagatsinghpur and Baleswar have least concentration of disabled population as compared to the other districts.

The districts of Bhadrak, Jajapur and Khurdha has very high demographic vulnerability index fallowed by Baleswar with high vulnerability Index. Cuttack, Kendrapara and Jagatsinghpur fall in the moderate category of vulnerability index. Puri and Ganjam have low and very low vulnerability index respectively. Overall the demographic vulnerability map (Fig. 2) shows that the demographic vulnerability index decreases from north to south with the exception of Khurdha.

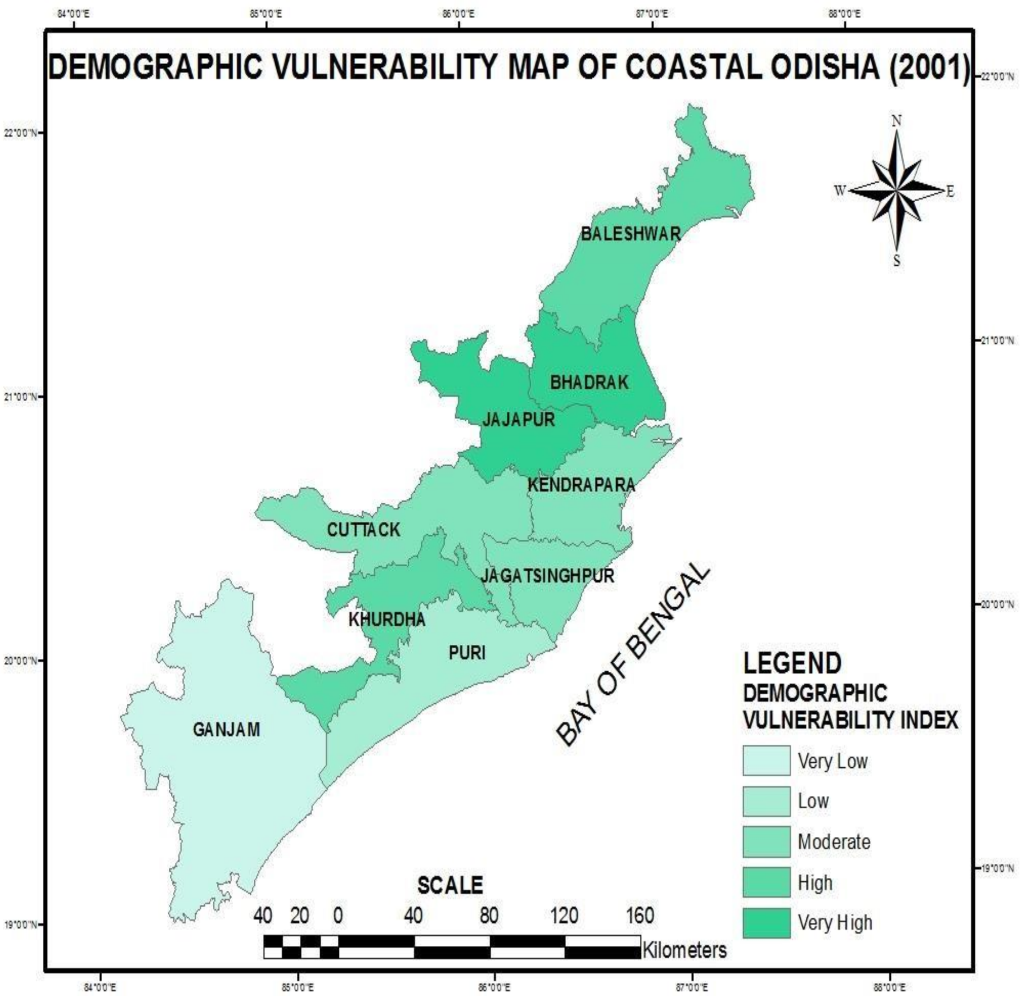

Fig. 2: Demographic vulnerability map

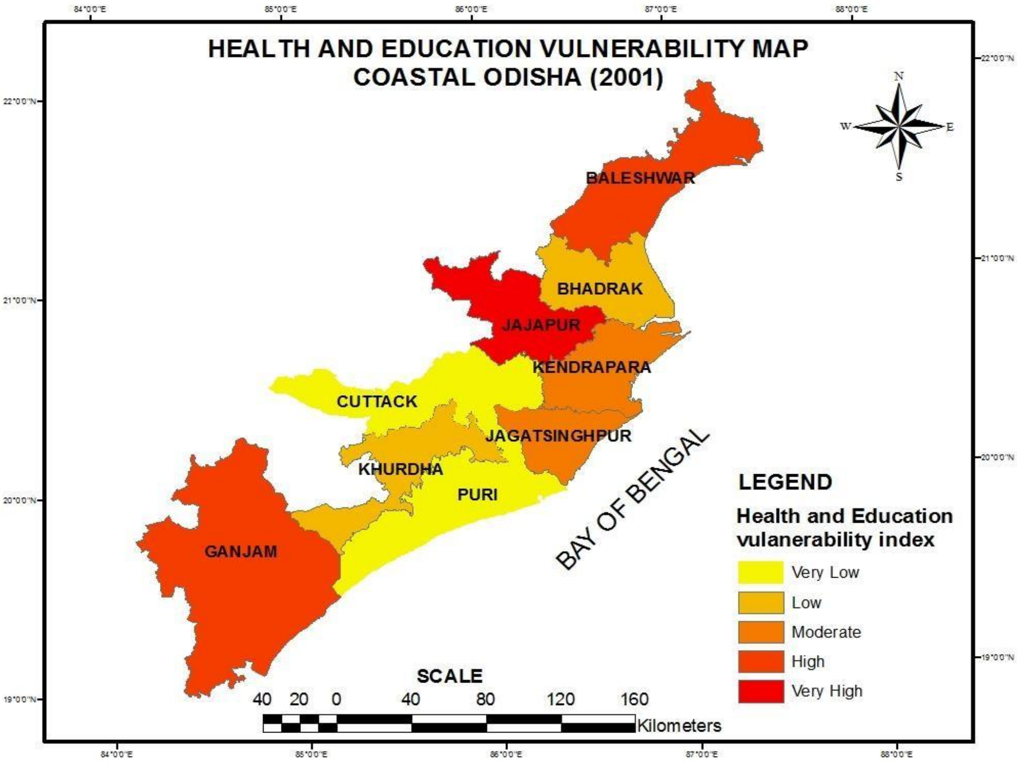

Fig. 3: Health and Education vulnerability map

Health and Education Vulnerability includes the factors such as *number of hospitals and hospital beds per 1000 population*, *Literacy Rate* and *educational Institutions per thousand populations.* Shortage of beds can result in delay in admitting emergency patients, and transfer of existing inpatients between wards at the time of natural hazards such as flood, cyclone, and earthquake etc. The regions with higher literacy generally experience lesser impact of natural hazards and these regions are more likely to have better disaster mitigation strategies. It is found that the ratio of beds per thousand populations varies from 0.14 to 0.42 for the coastal districts, which shows that not even a single bed can be availed for one thousand population in a hospital. Similarly, the number of medicals per thousand populations for all the coastal districts lies around 0.07, which indicates that approximately 14,000 people can avail the facility of medicals from a single hospital including primary health centers and community health centers located in rural and semi-urban areas respectively. In addition to above mentioned issues it is found that the facility of modern equipment's for better treatment of the patients is not available in hospital. From the overall observation it is found that Cuttack and Puri district has better medical facilities than the other coastal districts of Odisha as shown in Fig. 3.

As far as the literacy rate is concerned, Ganjam has the lowest literacy rate of 60.77% while Khurdha has the highest literacy rate of 79.59%. Khurdha district shows the highest female literacy (71.06%) rate due to the influence of state capital Bhubaneswar in the district. Next to Khurdha comes Jagatsinghpur district with 79.61% literacy rate. Among all the coastal districts of Odisha, Kendrapara and Jajapur have higher number of educational institutions per thousand population with the figures of 2.11 and 1.87 educational institutions per thousand populations respectively. Although Khurdha with a value of 1.26 has least number of educational institutions per thousand populations but the size and student intake capacity of the educational institutions is higher as compared to the educational institutions in other districts. So, in-spite of having least number of educational institutions Khurdha is less vulnerable to natural hazards in terms of education. The educational and health situation shows that the district of Jajapur is most vulnerable to natural hazards followed by Ganjam and Baleswar

(Fig. 3), which are the least urbanized districts. The district of Cuttack, Puri and Khurdha falls under low vulnerability zone as far as health and educational facilities are concerned.

Transport and Communication Vulnerability includes the factors such as *Road density per thousand population which* shows the accessibility of the people in a particular area. The higher accessibility in road transport helps in rapid evacuation of people from the natural hazard prone areas. Therefore, the areas with high road density are less vulnerable as compared with the areas having low road density. Puri with 6.22 km of road length per thousand population is the most accessible district in the coastal region. The districts of Baleswar and Bhadrak have least road length per thousand population making them most vulnerable districts in the coastal region. The location of higher number of *telephone exchanges* enables the people to have faster and easier ways to connect with the early warning systems regarding the occurrence of natural hazards thereby helping in taking pre-disaster preparedness in the hazard occurring zones.

Khurdha with around three telephone exchanges per one lakh population stands at the top followed by Ganjam and Jagatsinghpur. Kendrapara district with the value of 2.07 has least number of telephone exchanges in the study area. Cuttack and Jajapur lies in the most vulnerable zones in terms of transport and communication vulnerability (Fig. 4). As the available transport and communication facility is not sufficient for the existing population, the per capita use of these services is very low in these districts. Ganjam and Bhadrak are the least vulnerable districts in this respect.

Access to electricity improves the living standard of the households by giving them the opportunity to use other electronic devices such as television and refrigerator. Use of electricity at household and, to some extent, commercial level will also bring reduction in pollution, which will have a positive impact on environment. In the coastal region, the district of Bhadrak has the highest percentage of villages having no electricity (17.89%) followed by Ganjam and Kendrapara. Cuttack has least percentage of villages having no electricity (1.64%) followed by Puri and Jagatsinghpur. Ganjam and Jajapur are economically lagging districts in coastal Odisha. Therefore, economically they are most vulnerable districts followed by Kendrapara, Jagatsinghpur and Puri (Fig. 5). Khurdha and Cuttack are the least vulnerable districts as the percentage of workers engaged in primary sector are very less as compared to the other districts.

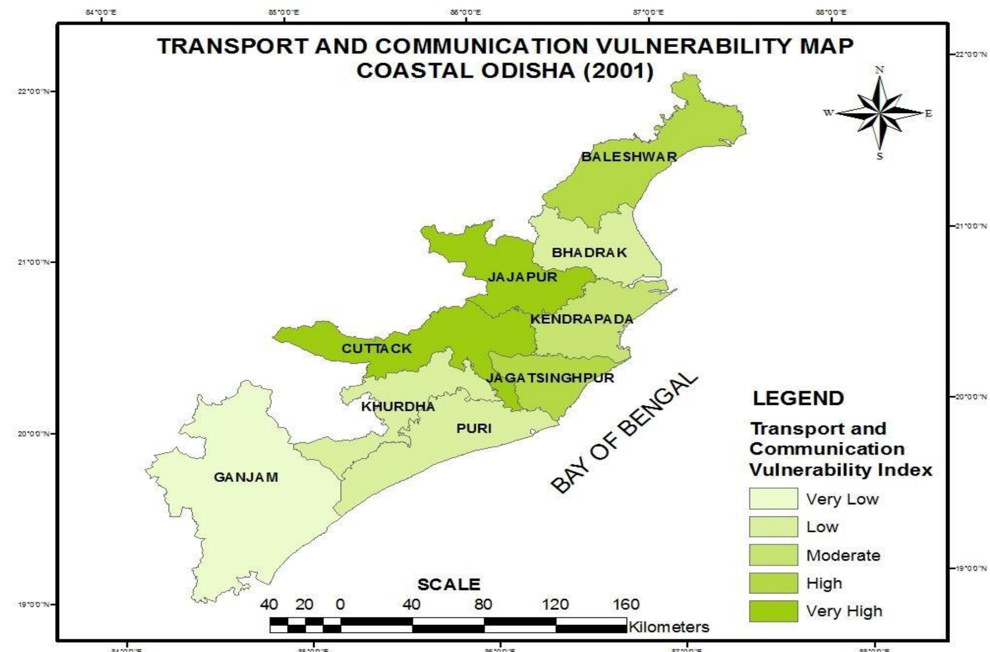

Fig. 4: Transport & Communication vulnerability map

China Petroleum Processing and Petrochemical Technology

Catalyst Research Volume 23, Issue 2, September 2023 Pp.1025-1038

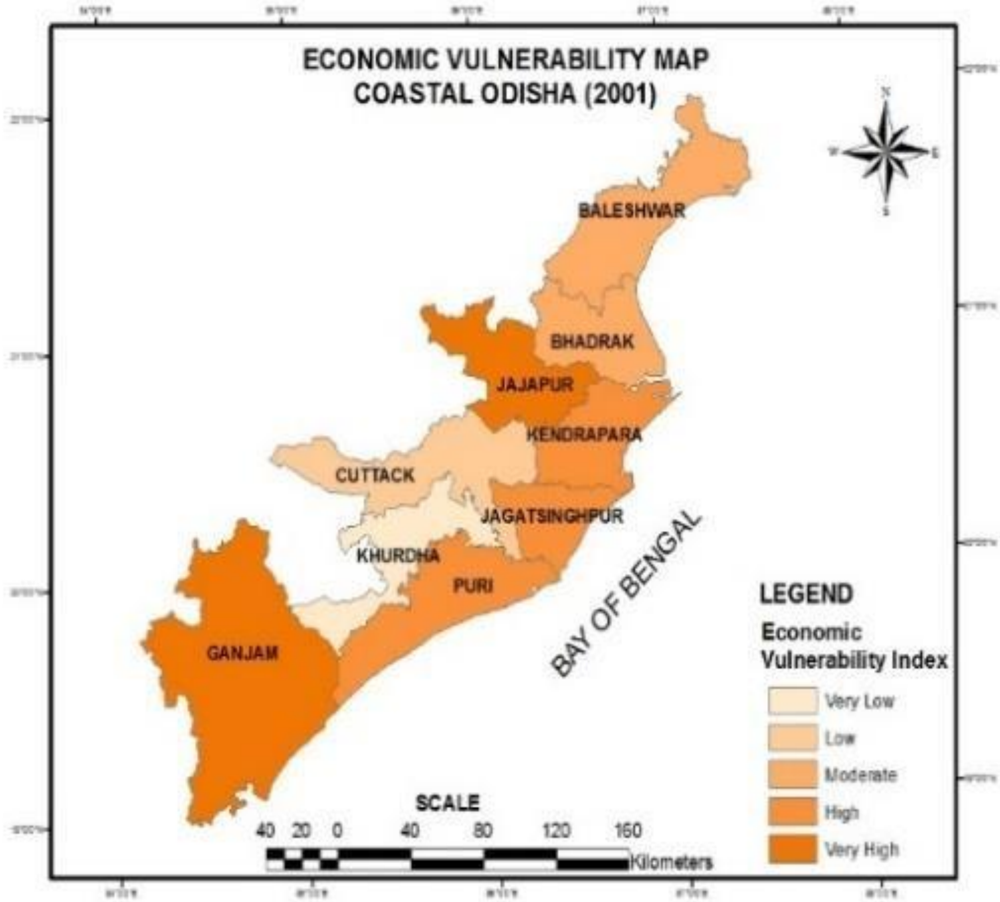

Fig. 5: Economic vulnerability map

Economic Vulnerability

is also related to occupational structure of a given region. For example, workers *engaged in primary sector* are more vulnerable to hazards as compared to workers engaged in other sectors. The workers in primary sector are more exposed to the natural hazards as they work in the open spaces such as farmlands, rivers, and seas. Ganjam has highest percentage of workers engaged in primary sector (87.57%) followed by Baleswar (76.41%). The districts with higher urbanisation rate such as Khurdha and Cuttack have least percentage of workers engaged in primary sectors, therefore these are the less vulnerable to natural hazards. *Food availability* depends on food grain production**.** Sufficient amount of food production leads to food security of a region, which gives access its population with sufficient amount of food. As the people of Odisha are predominant consumer of rice, food availability can be measured by production of rice per thousand populations per year. Baleswar and Bhadrak district are the major producers of rice with 189.86 tons and 188.91 tons per year respectively. Therefore, Baleswar and Bhadrak district are less vulnerable to natural hazards in terms of food availability.

The female work participation rate of a state indicates the state of economic empowerment of men and women in the society. Work participation rate of a state is the ratio of workers to total population of the state. The higher the female work participation rate the more they are exposed to natural hazards. Ganjam with female work participation rate of 30.90% tops the list followed by Cuttack (13.80%) and Jagatsinghpur (11.50%). The districts of Jajapur and Puri have least percentage of female work participation rate. Similarly, the *type of houses* with respect to its construction materials makes them vulnerable. Buildings, which are constructed with earth-based materials or stone and brick in mud mortars are highly vulnerable to heavy rains and floods. The huts made from biomass materials like bamboo, leaves, thatch or light construction materials using metal sheets are easily destroyed in flood. Bhadrak and Kendrapara district have the highest percentage of vulnerable houses where 80% of them comes under the Kutcha houses, which are made-up of biomass materials. Therefore, these are most vulnerable districts among all the nine districts. Socio-economically, the northern part of the study area falls under the highly vulnerable zone, which includes the districts of Jajapur, Baleswar, Bhadrak, Kendrapara and Jagatsinghpur whereas, the southern part of the study area is socio-economically less vulnerable to natural hazards (Fig. 6).

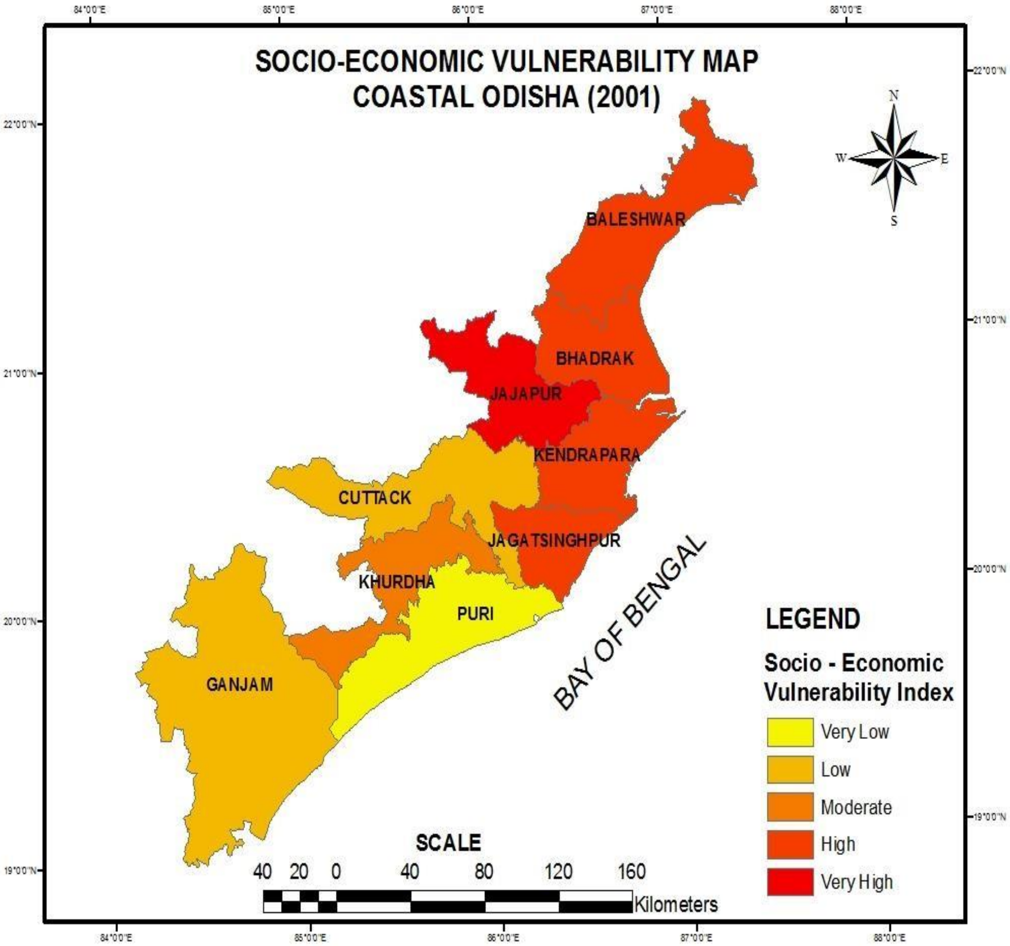

Fig. 6: Socio-economic vulnerability map of coastal Odisha

Natural factors such as *land-use, relief* and the *type of soil* determine the degree of vulnerability of a region to natural hazards. The settlement areas are likely to be the most vulnerable as people inhabit these areas. More than 83% of the total populations live in rural areas in the coastal region, where the existing type of houses makes them more vulnerable than urban settlements. Secondly, the agricultural lands are likely to be most affected in the alluvial plains in the coastal districts which constitutes more than 50% of the total land area. Alluvial plains are located in the northern and eastern part of the study area.

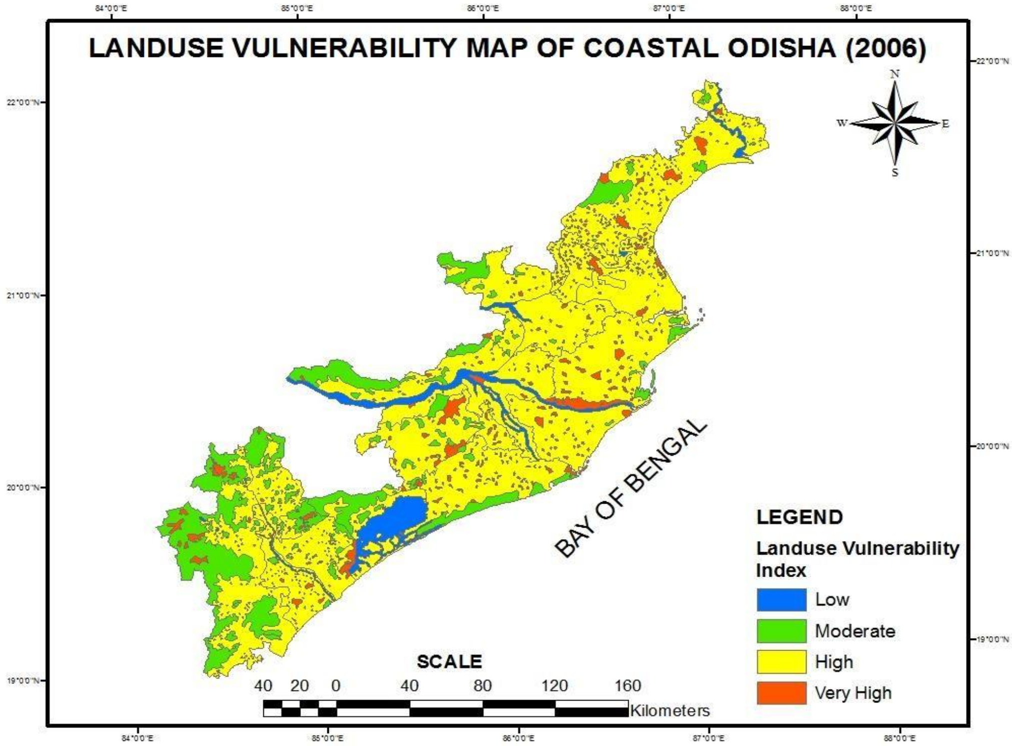

Fig. 7: Land-use vulnerability map of coastal Odisha

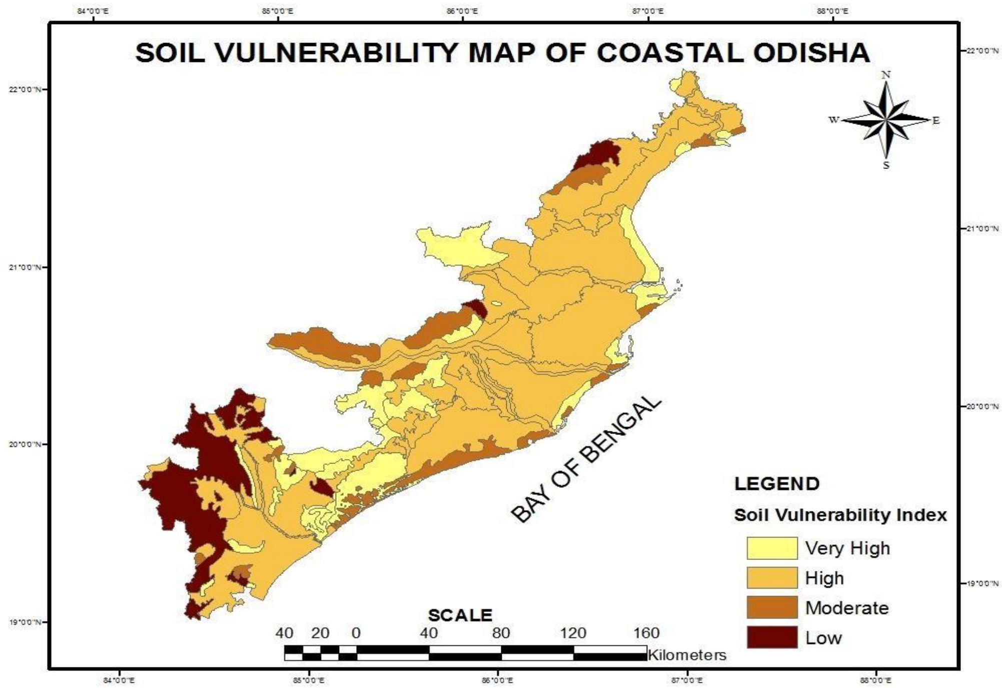

Fig. 8: Soil vulnerability map of coastal Odisha

Forest lands are also vulnerable to cyclonic hazards. The forests are mainly distributed in the coastal zones in the districts of Ganjam, Puri, Kendrapara, Bhadrak and Baleswar. Among the districts, Ganjam has the highest percentage of area under the forest cover. The extreme western part of the districts of Khurdha, Cuttack and Jajapur has small patches of forest lands, therefore they are less vulnerable to flood. Similarly, the high elevated lands such as hilly areas and plateaus in the western and the south western part are less vulnerable to floods. While, low land areas such as agricultural lands, pasture lands and settlement zones in low elevated areas of the northern and eastern part are highly vulnerable to floods and cyclones. (Fig. 7).

Infiltration as a part of hydrologic cycle plays an important role in reducing the surface runoff that can cause flood vulnerability in the downstream of watershed (Kabir, 2013). Soils having larger texture are more vulnerable to flood water than the small textured soils (Hasrullah, 2009). The infiltration rate of clay soil surpasses that of sandy soil due to the larger volume change of soil cavities as soil water content increases. On the other hand, in sandy soil the water content is lower because of the less-absorbent nature of sand that the number of pores is also small and the change of volume, due to the presence of water, does not make the soil expand. The loam and sandy soils are distributed in the south-eastern parts along the river banks and coast lines in the districts of Khurdha, Puri and Ganjam. Silty soils, on the other hand, exhibit least resistance to erosion because their permeability is low, resulting in more surface runoff and their particle size is neither small enough to promote cohesion nor large enough to prevent entrainment. This type of soil includes the lower catchment areas of the deltaic plains (Fig. 8).

From geographical point of view Ganjam and Khurdha shows lower vulnerability Index values because of presence of dense forest cover, high relief and lateritic soil while the coastal region in the northern parts are highly vulnerable to hazards owing to less forest cover, low relief and dense population. Major streams and rivers are also located in the northern part leading to more floods while the southern part has more seasonal streams, therefore it is least prone to floods. As far as the natural indicators are concerned, Baleswar and Jagatsinghpur fall under very high vulnerability zone followed by the districts of Kendrapara, Puri and Bhadrak (Fig. 9). The coastal districts of Jagatsinghpur, Khurdha and Balasore falls under high vulnerability zone, because of high population density, higher percentage of workers engaged in primary activities such as fishing and farming and higher percentage of disabled persons found in these districts. They have neither the minimum capacities to withstand the damage nor they have the economic support to recover from the losses incurred in the hazards. The existing social infrastructure such as educational, medical, transport and communication facilities are not sufficient enough to support the existing population.

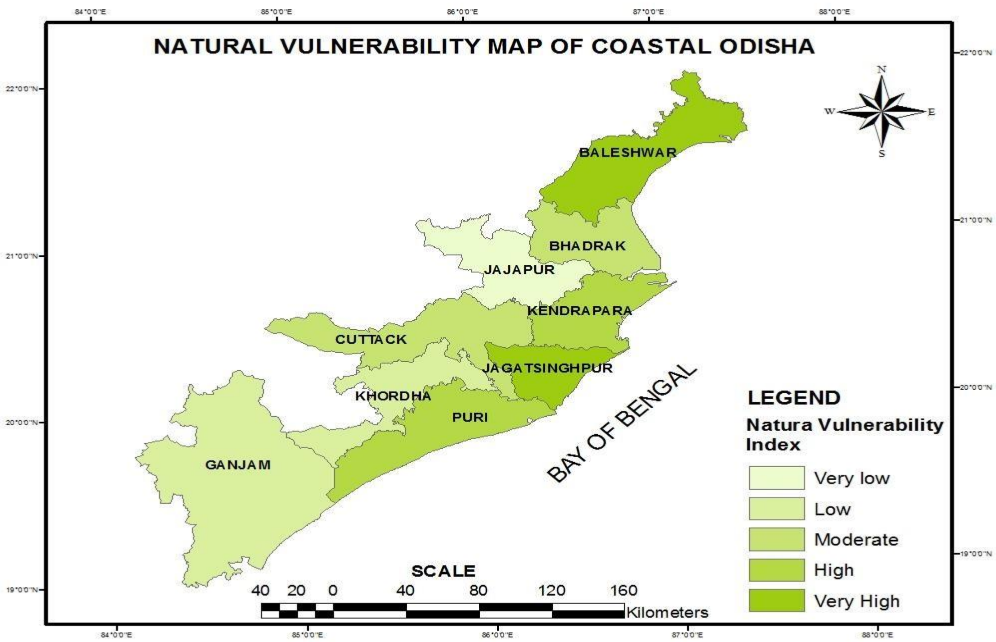

Fig. 9: Natural vulnerability map of coastal Odisha

Catalyst Research Volume 23, Issue 2, September 2023 Pp.1025-1038

The region has been divided into five zones depicting various levels of vulnerability of natural hazards with respect to flood and cyclone. The geography of **composite vulnerability index (CVI)** values among the nine coastal districts (Fig.10) reveal that maximum number of districts represents moderate to high levels of CVI with values ranging from 5.259 (moderately vulnerable) to 6.495 (highly vulnerable). The most vulnerable districts are located in the northern part of coastal Odisha, where Baleswar being the most vulnerable district with CVI value of 7.027. The value of composite vulnerability index increases from south to north and west to east. Therefore, northern and central part of the region falls under moderate to very high vulnerability category comprising more than 40 per cent of the whole study area, while the southern part of the region falls under low and very low vulnerability category.

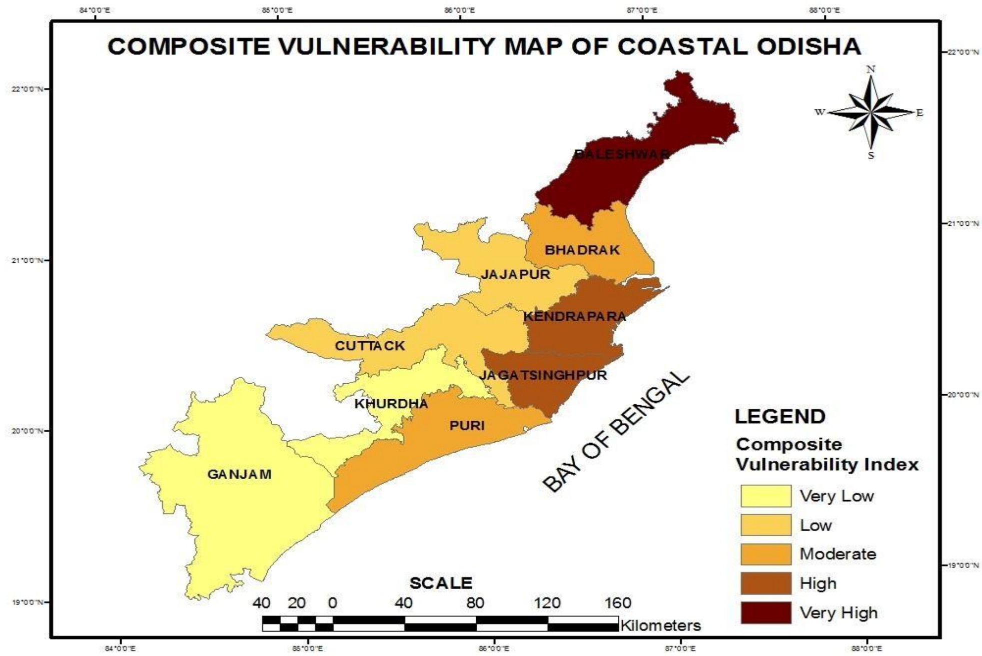

Fig. 10: Composite vulnerability map of coastal Odisha

CONCLUSION

The coast of Odisha is one of the most vulnerable regions to extreme natural hazards in India particularly, cyclone and flood. The bulging out and expose of middle part of the coastal districts to the Bay of Bengal plays the most important factor for landfall of cyclones. Therefore, this part is visited by cyclone at least once in a year. Occurrence of frequent floods and cyclones, almost every year in the coastal districts puts the rural population extremely vulnerable to the natural hazards. Flooding from the rivers caused by heavy precipitation associated with tropical cyclones, depressions and monsoon rainfall makes the lives of the people more vulnerable. Along with natural factors, poor socio-economic conditions of the people make them more vulnerable to natural hazards. The indicators used in the study represent various physical and social dimensions, which are crucial to portray a more complete picture of the hazard vulnerability assessment. The vulnerability maps shown in this paper may also be used for both crisis management and planning for future contingencies, including potential impacts of global climate change. Although the role of state government in disaster risk management and implementation of Integrated Coastal Zone Management (ICZM) programmes has benefited in reducing the risk to some extent in the recent past. However, the biggest challenge for flood and cyclone preparedness planning depends on the underlying capacities of the state and district authorities as well as the potential of available resources to undertake implementation of the priority activities. In order to improve disaster risk management, it is necessary to fortify ties between the National Disaster Management Authority and the State Disaster Management Authority, with the help of the local community.

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