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Cyclone vulnerability zonation of southern part of South Andaman, India using Multi-criteria weighted overlay analysis techniques

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Cyclones are one of the major natural hazards which frequently batter Andaman and Nicobar Islands (ANI). Cyclone '*Lehar*' made its first landfall south of Port Blair, ANI, early on 25th November 2013. Hence an attempt was made to demarcate flood vulnerable zone due to cyclone, at the outset of cyclone *'Lehar'* which can facilitate the district administration involved in disaster mitigation and management in confronting any disaster of similar kind in future using geospatial technology. Four parameters viz., Land use and land cover (LULC), geomorphology, slope and demographic data were used as input for demarcating cyclone vulnerability zones. The present study revealed that 14.49%, 44.34% and 23.86% of the coastline is in the high, moderate and low vulnerable category respectively.

[**Keywords**: GIS, Remote sensing, Cyclone LEHAR, vulnerability zonation, Multi-criteria weighted overlay analysis, Andaman]

Introduction

The coast is one of the most exuberant scrap of the earth surface. They contain some of the world's most sensitive but productive ecosystems like mangroves, wetlands, coral reefs, dunes and beaches[1], yet vulnerable ecosystems of the world[2]. These coastal belts often provide evidence to be the hot spots of ruthless impacts associated with permanent inundation of low-lying areas, increased flooding due to extreme weather events like storm surges, tsunami, greater erosion rates affecting beaches and cliffs and devastation due to calamities like cyclone[3-6]. Besides, they are home to a large human population too. About 23% of the world's population live within 100 km of the coast[7]. In the past two decades (1992-2012), the world has been devastated by a number of natural catastrophic events, some of which have affected coastal areas severely both in terms of loss of lives and damage of property. These include Hurricanes Andrew and Katrina in the USA, Typhoon Linda in Vietnam and Thailand, Hurricane Mitch in Central America, the super cyclone in Orissa, India, tsunami's in Papua New Guinea, Indonesia and Japan and flooding in Mozambique[1] Cyclone Phailin, Helen in Andhra Pradesh, India. Consequently, this is exerting both growing demands on the coastal resources as well as increasing human's exposure to coastal hazards[8]. Tropical cyclones typically have the highest property damage loss of any extreme event, and are therefore of great interest to state and local disaster preparedness organizations, as well as to the insurance industry[9]. Government officials and resource managers responsible for dealing with natural hazards also need accurate assessments of coastal hazards to make informed decisions before, during, and after such hazard events[8]. Geospatial technologies would suffice requisites of the decision makers through the identification of vulnerable zones[10].

Andaman and Nicobar Islands (ANI) are frequently battered by cyclonic storms arising on either side of it. That is Bay of Bengal on the west of it and Andaman Sea on the eastern side. One such cyclone is '*Lehar*' meaning 'wave' in Hindi language primarily affected the maritime union territory of ANI, India. It was the second most intense tropical cyclone of the year 2013. The origins of Lehar can be tracked back to an area of low pressure that formed in the South China Sea on 18 November. The system slowly drifted westwards and entered the Bay of Bengal, where it quickly consolidated into a depression on November 23. It moved west-northwest into an improving environment for further development before the system was named '*Lehar*' on November 24, after it had developed into a cyclonic storm and passed over the ANI into the Bay of Bengal[11]. '*Lehar*' made its first landfall south of Port Blair, ANI, early on 25th November 2013. Port Blair received 21.3Cm of rain in 24 hours with wind gusts of 110 Km/h[12]. It caused flooding, land slides, road blockage, uprooting of trees and damage to buildings.

The Port Blair is the centre for all the activities of the rest of the ANI with half of the population residing here. Hence an attempt is made to develop Cyclone Vulnerability indices, at the outset of cyclone *'Lehar'* which can facilitate the district administration involved in disaster mitigation and management in confronting any disaster of similar kind in future.

Study Area

Andaman and Nicobar Islands (ANI) is the maritime island territory of India in the Bay of Bengal between the peninsular India and Myanmar spreading like a broken necklace trending north-south direction. Bounded by the coordinates (92° to 94° East and 6° to 14° North), an archipelago with > 500 islands/islets, stretching over 700 km. There are 38 inhabited islands with a population of approximately 356,000 [13]. They are closer to the Indonesian landmass than to mainland India (1200Km), with the southernmost island only 150 km from Sumatra and the northernmost landfall ,190 km south of West Myanmar. The Andaman group of islands is made up of the South, Middle and North Andamans, whereas the Nicobar group is made up of several smaller islands, including Car Nicobar[14]. They appear to be un-submerged portion of a continuous belt from Manipur - Nagaland in north to the Indonesian islands in south, through Arakan Yoma range of Myanmar[15-17].

Study area, Southern part of South Andaman bound between 11°27'00" and 11°45'00" N and 92°30'00" and 92° 46' 47" E (figure 1) covering an area of 384.79 sqkm with a population of Population of 133337 in 30299 house holds[18]. The area runs roughly in a North-South direction for about 30.78 km from Wimberley Ganj to Chidiatapu. Along East-West direction, it runs for about 25.80 km. Coastal fringes of the study area are creased with sensitive and fragile wetland ecosystems such as estuaries, mudflats, sandy beaches, mangrove forests and coral reefs[19]. Also it has tropical evergreen, semi-evergreen, and moist-deciduous forest with exuberant biodiversity and productivity[20-21]. The important tourist places within the study area are Port Blair town, Cellular Jail, Anthropological Museum, Fisheries Museum, Naval Marine Museum, Chatham Saw Mill, Zoological Garden, Mount Harriet, Sipighat Farm, Viper Island, Corbyn's Cove (Beach) and Ross Island. These places attract both national and international tourists.

Materials and Methods

The following materials were used to suffice the objective of the investigation. Survey of India (SOI) restricted toposheet's on 50K scale (87A/10, 87A/11 & 87A/14) were used to generate base maps. Collateral data (demographic data & Administrative boundary map) was regenerated as per the demands of the investigation.

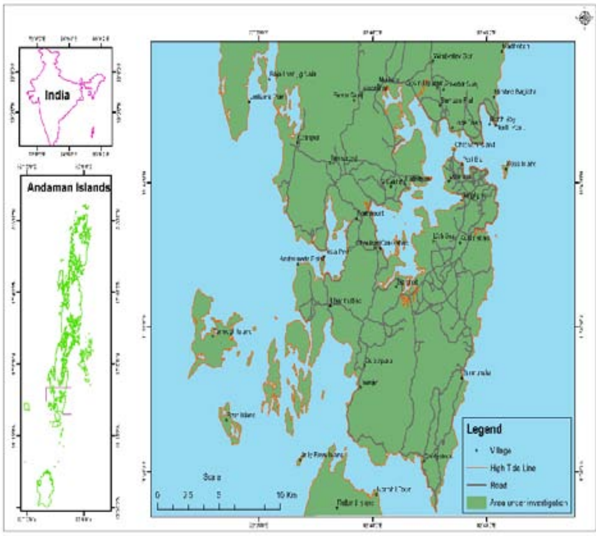

Figure 1: Study Area

Multi spectral satellite data product of the year 2011 Indian Remote sensing (IRS) P6 LISS-IV (Linear Imaging Self-scanning Sensor), ASTER GDEM (Global Digital Elevation Model) 2009 and The following software's ArcGIS 10 and Erdas 2011 were implemented to process the above mentioned data products

Vulnerability may be defined as an internal risk factor of the geophysical, biological and socio-economic system that is exposed to a hazard and corresponds to its intrinsic predisposition to cope with, or to be susceptible to damage[22]. In general, the concept of ''hazard'' is now used to refer to a dormant danger or an external risk factor of a system or exposed subject[8]. Vulnerability may be expressed in a mathematical form as the likelihood of surpassing an indomitable level of economic, social, or environmental consequence at a certain locality and during a certain episode.

Ground truthing as well as GIS and remote sensing applications were used for assessing various geo-environmental factors of the area with respect to CVZ mapping. IRS-P6, LISS-IV data of the year 2011 was used for interpreting Land Use and Land Cover (LULC). Individual bands as digital signatures were imported into the ERDAS Image processing software for noise removal and image enhancement. For CVZ mapping, slope class, geomorphology, and LULC map on 1:50K scale were prepared using standard procedure. Each layer's class was given a rank (table 1) and these layers were converted into a raster of similar pixel dimension. Multi-criteria weighted overlay analysis was executed to obtain CVZ map. The methodology adopted is depicted in the figure 2. Detailed methodologies of LULC, Slope, geomorphology, etc are presented in respective headings.

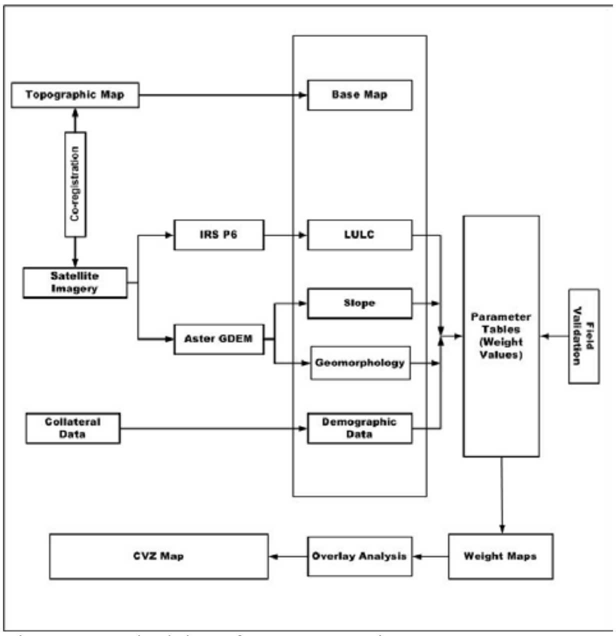

Figure 2: Methodology for CVZ Mapping

LULC

The land use/land cover pattern of a region is an upshot of natural and socio-economic factors and their consumption by man in time and space[23]. Coastal regions are the most important and thickly populated zone in the world. Coastal resources have been under intensive pressure, changes are one of the important aspects of global changes[24].

Base map was generated SOI toposheet. IRS-P6 LISS-IV image was visually interpreted and classified (Level-II classification) as per the guidelines of[25] followed by on screen digitization. Six classes of land use pattern were observed in the study area via., Forest, Settlement with plantation, plantation, mud, water body and water inundation. Forest appears as bright red to dark red in tone irregular in shape on the satellite imagery. In the satellite imagery Plantation appears as dark red tone with a larger areal extent with almost regular shape. Along the coastal plains of the study area coconut plantation has been observed. Human settlement was identified by its bluish green to bluish tone on the satellite imagery. Blue colour with smooth and irregular pattern is depicted by water body and water inundation on the imagery. Human settlement was given a highest rank of 3 followed by plantation (rank 2) as risk of any hazard is assessed in terms of life and property. Whereas, water body and water inundation receives a least rank of zero. Detailed ranking is catalogued in table 1.

Geomorphology

Geomorphology is defined as the study leading to an understanding of and appreciation for landforms and landscapes, including those on continents and islands, those beneath oceans, lakes, rivers, glaciers and other water bodies, as well as those on the terrestrial planets and moons of our Solar System[26]. Geomorphology seeks to recognize the constancy among landforms and what processes lead to patterns. Geomorphology includes endogenic processes like volcanism, tectonics, flooding, cyclones, tsunami, faulting and wrapping and exogenic processes like weathering, mass wasting, erosion, transportation, and deposition. The processes responsible for this are alluvial and fluvial, glacial, aeolian, and coastal[8].

The evolution in geomorphology will determine not only the quality and quantity of associated habitats and the nature of their ecosystem linkages but also the level of vulnerability of wildlife, people, and infrastructure in coastal areas[8].

The term ‘‘cyclone vulnerability’’ as used in the present investigation refers to the (geomorphic) vulnerability of coastal landforms to hazards such as wave erosion, tsunami, and storm surge flooding, Cyclone etc. The study on cyclone vulnerability assessment described here identifies coastal areas that are in many cases already vulnerable to Cyclone under present-day conditions but that are likely to become increasingly vulnerable in future as a result of climate change and sea level rise.

IRS-P6 LISS-IV data and Aster Global Digital Elevation (AGDEM) were used to extract the geomorphic features using ERDAS Imagine 2011 and ArcMap 10 software. The satellite data was co-registered with Survey of India (SOI) toposheets and projected to UTM (Universal Transverse Mercator) projection system. Then geomorphic classes were extracted based on the visual interpretation keys using the on-screen digitization technique as provided by[27]. The classes recorded in the study area include pediment, valley, intermountane valley, structural hills, and escarpment. Pediment is identified on the satellite image by its light grey to medium grey tone, coarse to medium texture, irregular shape, and sharp contact with hills. In the IRS image the valley and intermountane valley is expressed as light to dark red tone due to presence of natural vegetation, texture is coarse, irregular shape, and the drainage pattern is sub parallel. Structural hills exhibit light brown to dark tone due to the presence of dense forest cover, coarse texture and linear shape. Escarpments are expressed as light brown tone with no vegetation on the satellite image. Further, these geomorphic classes were assigned risk rating as depicted in table 1.

Slope

Slope is used to describe the degree of the steepness, incline, gradient, or status of a straight line. A higher slope value indicates a steeper slope and vice versa. Slope (steepness or flatness of the region) is linked to the susceptibility of a landmass to inundation by flooding[28]. Slope characteristic is an important parameter in deciding the degree to which land is at risk of flooding from storm surges and during cyclone[29]. Coastal locations having gentle land slope values have great penetration of seawater compared with locations with fewer slopes, and resulting in loss of landmass from inundation is simply a function of slope: the lower the slope, the greater the land loss[29]. Slope map was generated from Aster GDEM using Arcmap 10 software. Thus areas having gentle slope were considered as highly vulnerable areas and areas of steep slope as areas of low susceptibility (table 1).

Demography

Humans have been populating the coastal belts since times immemorial for both commercial and navigational purpose[30]. A report from United Nations Environment Programme (UNEP) indicates a projected 99 people/km^2 will inhabit the coastal girdle by 2010[31]. This population in this region are vulnerable to the fury of nature like Cyclone, storm surges, tsunami etc.,[1].

Village-wise demographic data (table 2) were populated in the administrative boundary map to generate a demographic density map (figure 3). In order to derive vulnerable population and household firstly, population density per square kilometre was calculated by simply dividing the total population of a village by its area.

A weighted overlay analysis of LULC, Geomorphology, Slope angle and demographic data results in coastal population and household susceptible to flooding due Cyclones of this kind. These areas prone to flooding due to cyclone were demarcated as cyclone vulnerable zonation.

Results

The satellite image (IRS P6, LISS-IV) interpretation reveals five classes of landuse pattern in the study area viz., Forest, Settlement with plantation, plantation, mud, water body and water inundation (table 1). The accuracy of image interpretation was verified by field investigation.

Water body, water inundation and mud cover an areal extent of 1.05 sqkm (0.27%), 13.02 sqkm (3.37%) and 0.37sqkm (0.10%) respectively. They receive a least risk rating. It is note worth to mention that the landmass inundated due to subsidence of land as a consequence of earthquake and tsunami in 2004[19]. Majority 41.42% (160.05 sqkm) of the study area is covered by dense evergreen forest which receives a moderate risk rating. Settlement with plantation and plantation covers an areal extent of 146.2 sqkm (37.84%) and 65.7sqkm (17%) respectively receives highest

Table 1: Ranking of different classes for CVZ mapping

	Class	Area (SqKm)	%	Rank
Landuse				
1	Mud	0.37	0.10	0
2	Water body	1.05	0.27	0
3	Water Inundation	13.02	3.37	0
4	Forest	160.05	41.42	1
5	Settlement with Plantation	146.2	37.84	3
6	Plantation	65.7	17.00	2
	Total	386.39	100.00	
Geomorphology				
1	Structural Hill	239.15	61.89	0
2	Escarpment	1.97	0.51	0
3	Pediment	123.23	31.89	1
4	Intermountane Valley	0.11	0.03	1
5	Valley	21.93	5.68	1
	Total	386.39	100.00	
Slope in degree				
1	Steep (> 35)	2.46	0.64	0
2	Moderate to steep (15 to 35)	81.14	21.00	1
3	Moderate (5 to 15)	166.10	42.99	2
4	Gentle (0 to 5)	136.69	35.38	3
	Total	386.39	100.00	

risk rating (Figure 4) around the coastal fringes through out the area under investigation.

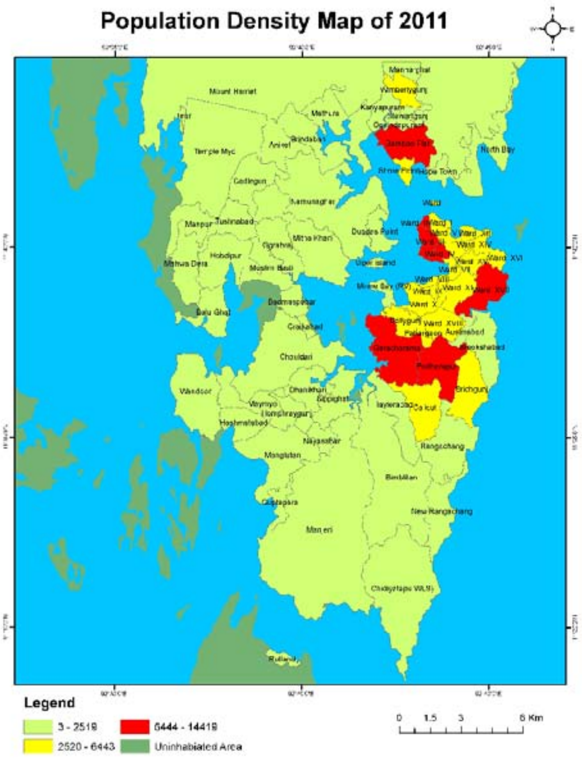

Figure 3: Population Density Map of the year 2011.

As inferred from the interpretation of satellite imagery using geomorphic identification key provided by[27], there are five classes of island geomorphic features in the study area viz., structural hills, escarpment, pediment, intermountane valley and valley (table 1). The study area is creased by pediments along the coastal fringes of Brookshabad, Rangachang, New Rangachang, Chidiyatapu, Manjeri, Guptapara, Manglutan, Garacharama, Sippighat, Dhanikhari, Hashmatabad, Wandoor, Craikabad, Badmaspahar, Dundas Point Mathura, Bamboo Flat, Maymyo, Wandoor, Balu Ghat, Mitha Khari, Muslim Basti, Brindaban, Ograbraj, Tushnabad, Cadlegunj, Stewartgunj, Wimberlygunj. Brichgunj, Taylerabad, Hashmatabad, Namunaghar, North Bay, Hobdipur and Temple Myo.

Structural hills are the dominant geomorphic feature occupying 61.89% (239.15 sqkm), trending NE-SW and are distributed throughout the study area. Structural hills and escarpment 0.51% (1.97sqkm) receives a least risk rank. Pediment, intermountane valley and valley receives high risk rating 123.23sqkm (31.89%), 0.11sqkm (0.03%) and 21.93sqkm (5.68%) respectively. In total 37.60% of the study area is under highly vulnerable rating. Humans and there associated activities were observed around the low lying areas of pediment, intermountane valley and valley hence they receive highest risk rating (Figure 5).

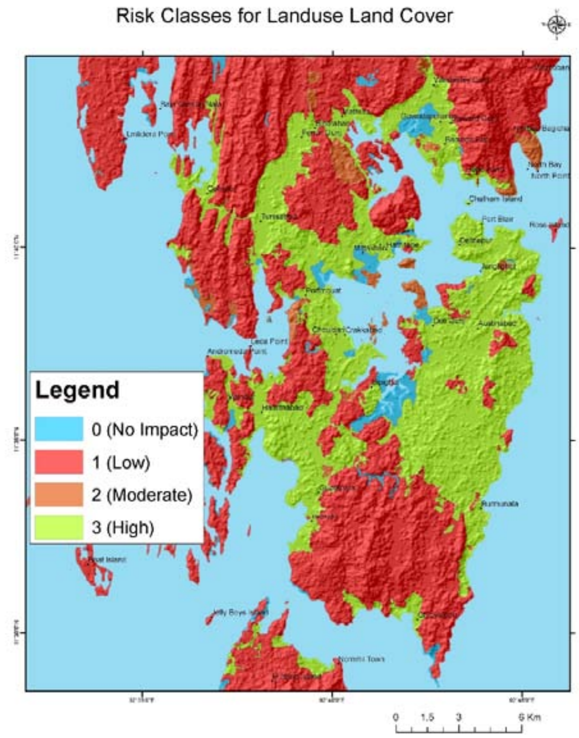

Figure 4: Risk Classes for Landuse and Land cover

The present investigation reveals that about 35.38% of the coastal fringes of the island have a high risk rating. Recording 0 to 5 degree of slope along Brookshabad, Rangachang, New Rangachang, Chidiyatapu, Manjeri, Guptapara, Manglutan, Garacharama, Sippighat, Dhanikhari, Hashmatabad, Wandoor, Craikabad, Badmaspahar, Dundas Point Mathura, Bamboo Flat, Maymyo, Wandoor, Balu Ghat, Mitha Khari, Muslim Basti, Brindaban, Ograbraj, Tushnabad, Cadlegunj, Stewartgunj, Wimberlygunj. Brichgunj, Taylerabad, Hashmatabad, Namunaghar, North Bay, Hobdipur and Temple Myo. 42.99% (5 to 15 degree) of the study area receives a moderate risk rating (Figure 6). Rest of the area under investigation receives least risk rating. Risk rating is depicted in table 1.

The present study reveals that 61% to 96% of the population live along high risk rating of coastal fringes around New Rangachang, Burmunalla, Guptapara, Badmaspahar, Manjeri, Craikabad, Chouldari, Dundas Point and Mathura, Bamboo Flat. About 32% to 61% of the population are settled around moderate risk rating along the coastal stretches of Brookshabad, Rangachang, Garacharama, Sippighat, Dhanikhari, Manglutan, Maymyo, Wandoor, Balu

Ghat, Mitha Khari, Muslim Basti, Brindaban, Ograbraj, Tushnabad, Cadlegunj, Stewartgunj and Wimberlygunj. Brichgunj, Chidiyatapu, Taylerabad, Hashmatabad, Namunaghar, North Bay, Hobdipur and Temple Myo are the coastal villages were risk rating is low with population ranging 1% to 32%. Table 2 speaks about the village-wise vulnerable area, population and household. Figure 7 depicts the coastal vulnerable population map.

Discussions

CVZ map was prepared by integrating the effect of various triggering factors. Individual ratings of Slope, Landuse, and Geomorphology were summed up to get total hazard rating. CVZ is a process of ranking different parts of an area according to the degrees of actual or potential vulnerability to storm surges due to cyclone. CVZ of the study area was prepared on the basis of the distribution of total hazard rating. Total vulnerable rating of 0-3 was considered as low vulnerable zone, Moderate vulnerable zone (>3-5) and High vulnerable zone (>5-7). This study revealed that 14.49% of the coastline is in the high vulnerable category, 44.34% in the medium vulnerable category, 23.86% in the low vulnerable category and 17.31% on impact (figure 6). Results showed that coastal areas of New Rangachang, Burmunalla, Guptapara, Manjeri, Badmaspahar, Chouldari, Craikabad, Dundas Point and Mathura, Bamboo Flat are in the high vulnerable to flooding due to cyclonic storm surges.

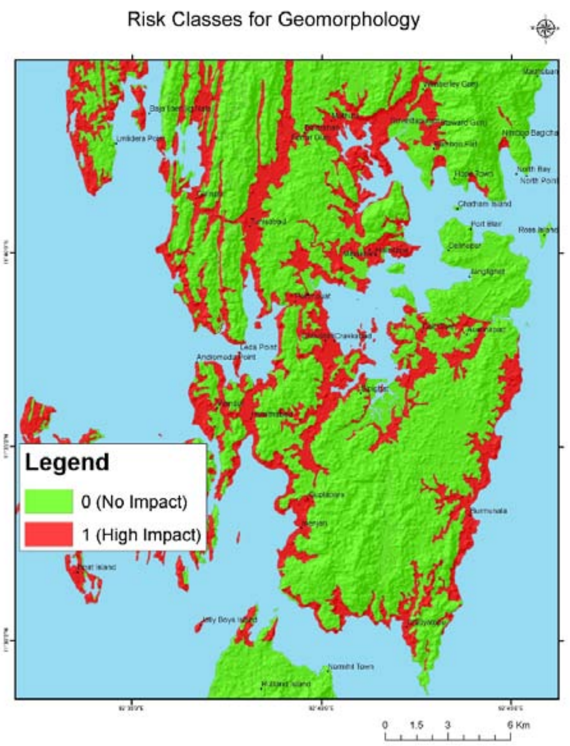

Figure 5: Risk Classes for Geomorphology

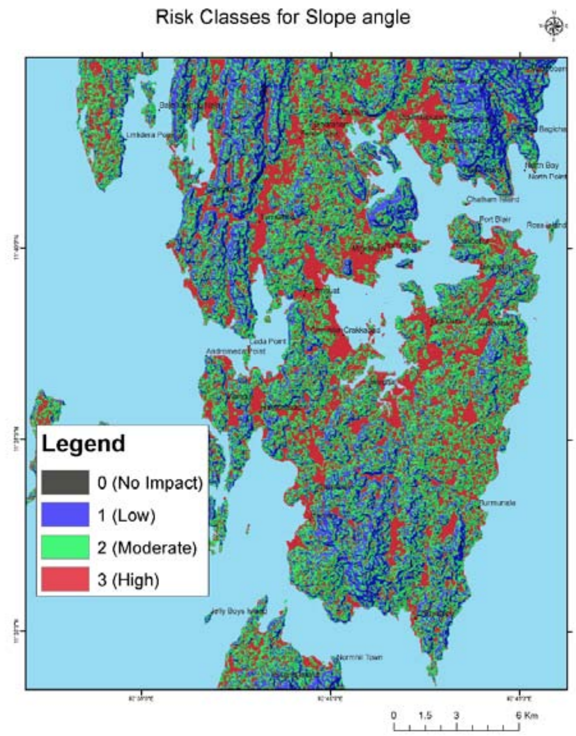

Figure 6: Risk Classes for Slope angle

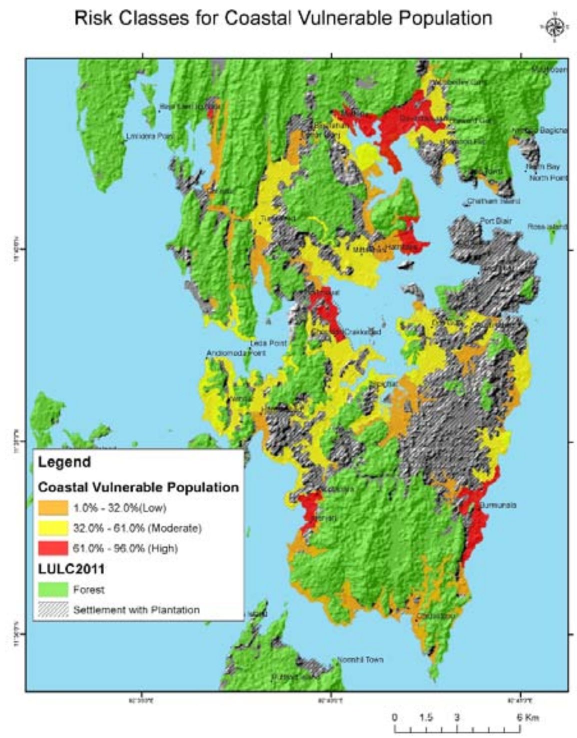

Figure 7: Risk Classes for Coastal Vulnerable Population

The coastal village falling in moderate vulnerablility category are Brookshabad, Rangachang, Garacharama, Sippighat, Dhanikhari, Manglutan, Maymyo, Wandoor, Balu Ghat, Mitha Khari, Muslim Basti, Brindaban, Ograbraj, Tushnabad, Cadlegunj, Stewartgunj and Wimberlygunj. Brichgunj, Chidiyatapu, Taylerabad, Hashmatabad, Namunaghar, North

Table 2: Village-wise vulnerable population and house hold

SlNo	Tehsil	Village	Pop2011	Hh	Area	VulArea	pop/sqkm	Hh/sqkm	vulPop	VulHh
1	Farergunj	Dhanikhari	714	182	3.77	2.03	189.24	48.24	384	98
2	Ferargunj	Dundas Point	539	129	1.83	1.38	293.99	70.36	407	97
3	Ferargunj	Muslim Basti	343	82	3.02	0.78	113.69	27.18	89	21
4	Ferargunj	Ograbraj	1467	331	3.58	1.60	410.33	92.58	657	148
5	Ferargunj	Mitha Khari	1071	254	8.59	3.96	124.61	29.55	493	117
6	Ferargunj	Tushnabad	1320	286	2.70	1.62	488.21	105.78	789	171
7	Ferargunj	Namunaghar	1926	468	13.88	3.30	138.72	33.71	458	111
8	Ferargunj	Govindapuram	102	520	0.84	0.80	120.71	615.40	96	491
9	Ferargunj	Stewartgunj	1172	220	0.82	0.45	1433.60	269.11	649	122
10	Ferargunj	Shore Point	3073	763	0.78	0.12	3947.13	980.04	457	113
11	Ferargunj	Bamboo Flat	7962	1907	3.87	1.63	2054.74	492.14	3351	803
12	Ferargunj	Wimberlygunj	4010	959	1.83	1.13	2190.55	523.87	2466	590
13	Ferargunj	North Bay	1603	368	4.76	0.35	336.70	77.30	119	27
14	Ferargunj	Hope Town	1258	297	1.03	0.13	1226.97	289.67	156	37
15	Ferargunj	Mannarghat	1259	282	1.27	0.27	988.22	221.35	271	61
16	Ferargunj	Hobdipur	476	101	5.35	1.71	88.92	18.87	152	32
17	Ferargunj	Mohwa Dera	14	7	4.43	0.18	3.16	1.58	1	0
18	Ferargunj	Kanyapuram	1317	263	1.71	1.57	768.18	153.40	1209	241
19	Ferargunj	Mathura	801	171	5.20	3.78	153.92	32.86	582	124
20	Ferargunj	Manpur	183	753	2.90	0.68	63.07	259.52	43	177
21	Ferargunj	Brindaban	1785	396	4.05	2.41	441.10	97.86	1062	235
22	Ferargunj	Aniket	129	28	3.28	0.88	39.27	8.52	35	8
23	Ferargunj	Cadlegunj	845	201	4.13	2.31	204.74	48.70	472	112
24	Ferargunj	Temple Myo	346	70	15.79	2.55	21.92	4.43	56	11
25	Ferargunj	Tirur	233	55	0.22	0.16	1057.83	249.70	169	40
26	Port Blair	Brookshabad	425	115	3.73	1.50	113.97	30.84	171	46
27	Port Blair	Dollygunj	3950	1051	1.67	0.98	2364.28	629.08	2322	618
28	Port Blair	Brichgunj	3412	562	4.17	0.83	818.25	134.78	679	112
29	Port Blair	Protherapur	10308	2609	4.60	0.95	2240.68	567.13	2136	541
30	Port Blair	Garacharama	14419	3732	6.13	3.17	2353.85	609.23	7461	1931
31	Port Blair	Rangachang	384	92	6.17	2.10	62.28	14.92	131	31
32	Port Blair	Calicut	4037	966	4.17	0.04	967.37	231.48	43	10
33	Port Blair	Taylerabad	1878	477	4.05	1.03	463.20	117.65	477	121

34	Port Blair	Bimblitan	2519	580	16.39	2.61	153.70	35.39	400	92
SlNo	Tehsil	Village	Pop2011	Hh	Area	VulArea	pop/sqkm	Hh/sqkm	vulPop	VulHh
35	Port Blair	Manjeri	613	137	34.63	4.57	17.70	3.96	81	18
36	Port Blair	Manglutan	2280	591	7.53	2.86	302.59	78.43	865	224
37	Port Blair	Sippighat	1522	367	3.69	1.98	412.04	99.36	816	197
38	Port Blair	Hashmatabad	626	149	2.56	0.80	244.75	58.26	195	47
39	Port Blair	Wandoor	1437	364	7.30	4.10	196.78	49.85	808	205
40	Port Blair	Homphraygunj	424	103	1.84	1.07	230.58	56.01	247	60
41	Port Blair	Maymyo	406	91	3.46	1.69	117.36	26.31	199	45
42	Port Blair	Craikabad	167	44	0.53	0.51	312.28	82.28	161	42
43	Port Blair	Chouldari	576	2382	11.19	4.60	51.46	212.82	237	979
44	Port Blair	Badmaspahar	728	163	1.61	1.19	451.99	101.20	540	121
45	Port Blair	New Rangachang	482	110	4.14	2.76	116.55	26.60	322	74
46	Port Blair	Chidiyatapu WLS	111	30	14.73	4.04	7.54	2.04	30	8
47	Port Blair	Nayasahar	425	100	1.19	0.04	356.68	83.93	15	4
48	Port Blair	Balu Ghat	3	2	3.23	1.20	0.93	0.62	1	1
49	Port Blair	Guptapara	936	225	1.30	1.19	719.14	172.87	858	206
50	Port Blair	Ward XVII	9952	2386	3.31	0.05	3005.45	720.56	141	34
51	Port Blair	Ward XI	5681	1452	2.13	0.03	2671.39	682.78	75	19
52	Port Blair	Pahargaon	3303	894	0.63	0.27	5260.80	1423.90	1414	383
53	Port Blair	Austinabad	1330	290	0.78	0.15	1697.41	370.11	251	55
54	Port Blair	Minne Bay (RV)	45	13	0.87	0.21	51.78	14.96	11	3
55	Port Blair	Ward X	6274	2762	2.24	0.05	2795.36	1230.60	135	59
56	Port Blair	Ward XVIII	6443	1663	2.31	1.11	2783.53	718.46	3084	796
		Total	119044	33595	261.96	83.50			38928	11070
						31.87			32.70	32.95

Hh= Household, Vul Area= Vulnerable Area, pop/sqkm= Population per square kilometre, Hh/Sqkm= House hold per square Kilometer, Vulpop= Vulnerable Population, VulHh= Vulnerable Household

Bay, Hobdipur and Temple Myo falls in least vulnerable zone. The coastal belt around science centre, Judge house, Carbyn's cove and Sesostris Bay had no impact because this part of coast are creased by cliffs.

The vulnerability maps derived from this study depict vulnerable areas as per the four parameters considered. These maps are therefore not maps of entire vulnerability but of crucial aspects constituting overall vulnerability. They depict the challenging regions, and therefore further attention should be directed to these regions to analyze their vulnerability in the context of nested scales and on higher resolution. Evolving geospatial technologies and numerical modelling are making accurate data available at better spatial and temporal scales for all the considered variables. Use of such data sets might throw better insight on coastal vulnerability aspects at a much more local level.

Conclusion

The present investigation overwhelmingly proves the usefulness of satellite data, geospatial technologies and in situ observations for cyclone vulnerability studies. The Cyclone vulnerability maps produced using this technique serve as a broad indicator of threats to people living in coastal zones. This is a objective methodology to characterize the risk associated with cyclone hazards and can be effectively used by coastal managers and administrators for better planning to mitigate the losses due to hazards as well as for prioritization of areas for evacuation during disasters episodes of this kind in future.

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