A framework to identify risk level of areas for the formation of evacuation zones during cyclones

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Abstract

India has 7516km long coastline, close to 5700km is prone to cyclones and tsunamis. Approximately 250 million people lived within 50km from the coast in the year 2010. Major cities like Mumbai, Chennai, Surat, Vadodara, Vishakhapatnam, Pondicherry etc. lie along these coasts. The rapidly growing urban population in these coastal zones and the increase in severe weather events have magnified risk in these areas. On an average, nine cyclonic and severe cyclonic storms are formed over north Indian ocean per year. Evacuation during cyclones is one of the most effective strategies to reduce human loss. The purpose of this work is to propose criterions for defining the risk level of different zones that will help in the management of phased evacuation. In this study, an approach is proposed to identify the risk level of zones in hazard impact area based on parameters related to hazard, vulnerability and exposure. The hazard frequency is considered for measuring the proneness of a block to the cyclone. The level of vulnerability is determined using social and economic parameters. The exposure component is a combination of physical susceptibility and response infrastructure of an area. The spatial pattern of these three components is mapped on the GIS platform to understand the distribution of risk. The proposed approach will help emergency managers understand about the disaster impacts and the response needed to counter them. This will also help in the efficient utilization of resources during an evacuation process and will improve the total evacuation time.

Keywords: Disasters, Evacuation zoning, Risk assessment

1. Introduction

Human developments from their nature of location, activities and other factors are susceptible to natural and man-made disasters. The impacts are generally in the form of capital and human losses. According to the Centre for Research on the Epidemiology of Disasters (CRED) global database, the hydrological, meteorological and geophysical hazards have respectively contributed to the maximum number of disasters across continents in the past decade. The increasing number of Hydro-meteorological (climatological, hydrological and meteorological) disasters are linked to climate change and its related impact. Studies have shown that developed countries generally face high capital losses while the number of victims is more in the case of developing nations. Although the capital losses in the case of developing countries appear to be small in absolute terms as compared to developed countries, they correspond to a significant percentage of their GDP.

An estimate from the global database of CRED between the year 1900 to 2009 shows that the maximum number of disaster events and deaths in India have resulted from Hydro-meteorological hazards. These hazards together contributed to 78.4% of the events and 47.94% of the deaths over the period of 1900-2009 (Government of India, 2011). India is second among the countries with a large share of the population living in low elevation coastal zones (LECZ) and among the top ten countries according to the land area under LECZ exposed to coastal hazards (McGranahan, Balk and Anderson, 2007). Based on scenarios predicted by Neumann et al. (2015), Indian coasts are likely to show rapid population growth in the future, putting it among the countries with the highest population exposed to storm surge following China. The socio-economic condition in developing country like India adds to the vulnerability of the exposed population and amplifies the disaster. This configuration of population equates to the concentration of risk and disaster affecting these areas have compounding impact with a par to the population and infrastructure density of the place. Since urbanization and economic development are unavoidable, disaster mitigation clearly has an important role in managing the disaster. Identifying and measuring risk and vulnerabilities are essential tasks in mitigating the effect of a disaster. In pre-disaster conditions, these assessments help in communicating and managing disaster operations and after disaster these help in the reconstruction process (Joern Birkmann, 2007).

Studies related to risk mapping of threat from cyclones in India generate risk profiles of area based on hazard characteristics and physical characteristics of place. Currently, zoning for evacuation during cyclones is based on personal judgment to some degree. The risk maps are used for ordering evacuation without defining manageable zones corresponding to the risk-levels, thus leading to inefficient utilization of resources. Such ad hoc planning of evacuation hinders estimation of priorities during an evacuation and results in unsuccessful evacuation from high-risk areas.

The purpose of this study is to develop block level indicators to prioritize evacuation based on exposure, vulnerability and coping capacity of communities. Local level analysis of vulnerability has not been attempted in this study. The study looks into factors which lead to the spatial variability of the risk of communities in coastal areas. The damaging agents of the cyclonic storm are considered for identifying the type of threats they impose on settlements in the coastal region. It also focuses on the socio-economic condition which adds to the vulnerability of the exposed population and amplifies the disaster in developing countries like India, Philippines. The study is based on block level analysis of a district highly vulnerable to cyclones in the east coast of India. It attempts to identify the risk levels of different blocks in a hazard (cyclone) prone area by considering factors related to hazard, vulnerability and exposure of population in an area to map risk. The hazard component is studied using the historical data on cyclones. The difference in exposure and socio-economic vulnerability gives the variability in block level impacts. The spatial variability of risk at the block level is demonstrated on the GIS platform.

In the first section, the existing body of work on the components of risk and its dimensions like hazard, exposure, vulnerability etc. have been reviewed. It is followed by a brief explanation of concepts of these dimensions from the previous studies. The list of indicators is finalized from the existing literature. The next section of the paper gives a broad framework for the valuation of these indicators into a risk index. Furthermore, the framework is implemented in the study area and the results are discussed in the next section. The implications of the study are discussed in the final section.

2. Literature review

The familiarity of systems, that interact to produce a disaster, is necessary for any disaster-related study. The system characteristic influences the level of impact, suitable responses and recovery period in a disaster. Some study considers disaster to be the result of interaction between the following three systems: the hazard system, the geophysical system and the social system (Chakraborty, Tobin, & Montz, 2005). The hazard system looks at the characteristics of a hazard over space and time. The Geophysical and social systems are occasionally combined together to give place-based vulnerability as described in the hazard of place model (Susan L Cutter, 1996). The exposure, susceptibility and coping capacity of communities vary over space and time depending on the characteristics of their geophysical and social systems. The social system differs from location to location and is modified by changes brought over time in subsystems, like economic, political and institutional. The weaknesses in any of these systems can lead to enormous loss of human life and damage to property.

2.1 Theoretical concepts: Risk, Hazard, Exposure and Vulnerability

Risk as a theoretical concept that does not have an established universal definition. Risk of an area depends on its exposure to hazard and vulnerability of the elements exposed. It has always been estimated based on functions built on components like the probability of a hazard, vulnerability, exposure, coping capacity, resilience etc. The risk is conceptualized in many ways mainly as a function of hazard and vulnerability (ISDR,2004) with its other dimensions like elements at risk (Alexander, 2000), Deficiencies in Preparedness (Villagran,2001), exposure (Dilley et al; 2005), exposure and coping capacity (Hahn, 2003). Risk of a place increases with simultaneous increase in the severity of the hazard and increased vulnerability. Combination of these hazard and vulnerability characteristic gives distinct risk profile of a region over different points in time and spatial distribution of risk across regions. The importance of risk mapping lies in the function that it serves while estimating the level of risk and evacuee population from a zone. The higher the risk level of a zone, the more population is likely to evacuate from that zone.

For the purpose of this study the definition of risk given by UNISDR (2015) is adopted which considers the risk to be "a function of hazard, exposure and vulnerability. It is normally expressed as a probability of loss of life, injury or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time".

Hazard

Hazard is a phenomenon that has the potential to cause severe adverse effects and can either result in emergency, disaster or catastrophe. Hazards involve more complex patterns of onset (instantaneous or slow), frequency (frequent and infrequent) and impact (small-scale and large scale), and can last for months, years or intermittently even for centuries.

The hazard potential is either moderated or enhanced by the place-based vulnerability i.e. interaction of biophysical and social configuration of a place (Susan L Cutter, Boruff, & Shirley, 2003). In order to quantify hazard, each magnitude is tied to a specific return period or its inverse, frequency. The magnitude-frequency relationship of a particular hazard is locality or region-specific (Thywissen, 2006).

Exposure

Exposure is one of the preconditions for a disaster other than vulnerability and hazard. Exposure is a measure of the number of physical units (Number of households, number of health and education facilities, livestock, length of road, the extent of irrigated agricultural areas, the number and capacity of electricity, water supply and sanitation systems, etc) that can get affected by a hazard. Exposure of an inhabited place is also dynamic and is based on the demographics of that place over time. Exposure is considered as a component in defining vulnerability as given by Jörn Birkmann & Wisner (2006). Exposure is defined as elements (People, property, systems, or functions) at risk of loss that are exposed to a hazard (UNISDR, 2004). While exposure is also used to include the characteristic of the hazardous process ('biophysical vulnerability) (S. Cutter, Mitchell, & Scott, 2000). Exposure has been used as an indicator of the spatiotemporal distribution of an 'element at risk', rather than 'just' an account of what is potentially harmed by natural hazards (Hollenstein, 2005). This comprehension of exposure does not imply an influence on vulnerability as such but represents an additional component of risk. The elements, which do not fall, in the region of hazard impact area, have zero exposure for that particular hazard. Measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability of the exposed elements to any particular hazard to estimate the quantitative risks associated with that hazard in the area of interest.

Vulnerability

The vulnerability is a function of exposure (who or what is at risk) and sensitivity of a system (the degree to which people and places can be harmed) (Adger, 2006; Susan L Cutter, 1996) along with the coping capacity of the affected entities (Joern Birkmann, 2007).

The complexity of vulnerability is not only given by its multiple dimensions but also by the fact that it is site-specific and that its parameters change with geographic scale. The parameters that determine vulnerability are different on the household, community, and country level. Vulnerability is a dynamic process, but for measurement, purposes are often viewed as static phenomena (Susan L. Cutter et al., 2008). While Kelman (2007) suggests that for a more comprehensive understanding and analysis of vulnerability one should also consider that vulnerability is qualitative, subjective, proportional and contextual. Although the theory is important in defining and understanding the concepts clearly, the data-driven approach is

mostly used in making policy decisions. The need for identifying and assessing vulnerability has been emphasized in international declarations (The Hyogo framework for action; Jörn Birkmann & Wisner, 2006). It can be operationally defined by providing a method for mapping theoretical concepts to operational concepts. The process of providing operational definition to vulnerability concept is generally called as a methodology for vulnerability assessment (Hinkel, 2011).
The UNISDR (2009) terminology for vulnerability i.e. "the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard" are followed in this study.

Researchers have considered various criteria's for establishing evacuation zones. A notable work which attempted to establish criteria and procedure for determining the delineated hurricane evacuation zone was done by C. Wilmot & Meduri (2005). Few works following this have been carried out for delineating evacuation zones by considering only the hazard characteristics and zone formation criteria, but they did not cover the social and economic dimensions which generate varying evacuation demand during disasters (Hsu and Peeta,2014; Lim et al.2016). Studies defining a method based on social vulnerability to identify the population that would need evacuation during a disaster are fewer in number. Chakraborty et al. (2005) provide one such method for calculating evacuation assistance need index by combining the geophysical risk and social vulnerability indices. This study attempts to assess the differential risk faced by blocks during the tropical cyclone and thereby defining the appropriate evacuation zones.

2.2 Indicators for measuring spatial variability of risk for evacuation need assistance

Disaster vulnerability is socially constructed i.e. it arises out of the social and economic circumstances of everyday living. Morrow (1999) identifies that certain categories of people such as the poor, the elderly, women-headed households and recent residents, are at greater risk throughout the disaster response process. Identifying the concentration of these vulnerable communities can be useful for effective response during disasters(Morrow, 1999).
A list of indicators for the estimation of geophysical, social vulnerability and economic vulnerability have been identified from the literature review and are discussed under following components
The initial list of parameters identified for measuring vulnerability is categorized into five components: social, economic, housing, physical and response capacity. Studies have shown that the young children and the old people have higher risk of death than the rest of the population (equal among genders). People other than children and old, it is observed that the female population is at higher risk of mortality than men. One of the key risk factors found for high mortality of women was their inability to swim. The proximity to the sea is also found to be a very significant factor for contribution to the risk of mortality People living with mental or physical disabilities are less able to respond effectively to disasters and require additional assistance in preparing for and recovering from disasters (McGuire et al. 2007). Emergency managers need to target areas with high concentrations of disabled people, particularly in group-living quarters, for early evacuation and other preparatory measures (Morrow 2008)
Social inequities and limited availability and unequal distribution of resources make people vulnerable to disasters. Some social aspects of vulnerability are beyond quantification (Jörn Birkmann & Wisner, 2006).

The residential units with semi-permanent or temporary construction type are highly vulnerable. Temporary houses in coastal areas lying outside the evacuation zones are also vulnerable to events like overturning in strong wind, windblown objects and falling trees can penetrate their exteriors (Baker, 1991). The response infrastructure includes parameters like proximity to medical services, proximity to transport infrastructure, the density of road network, coastal defense structures (natural and artificial) and availability of cyclone shelter, unavailability of these response systems can lead to loss of life (Cutter, Boruff, & Shirley, 2003).

	Parameters / factors	Indicators	Description	Source
Social / Demographic	**Population Density**	Persons per sq.km	Population density is measured in a number of persons living in per square kilometre of a zone. Higher the population density of a zone, more traffic will be generated from that zone.	Turner et al 2003a; Chandra Sekhar Bahinipati 2014;S Maiti,2015;M mahapatra 2017
	Female population	Percentage of Female Population	Women are considered more vulnerable than men at the time of disasters and during the recovery period	Cutter, Boruff, & Shirley, 2003
	Children	Percentage of children(<6 years)	Extremes of the age spectrum affect the movement out of harm's way, Need more care during the evacuation process	Cutter, Boruff, & Shirley, 2003; Mazumdar & Paul, 2016
	Old People	Percentage of Old People(>60years)		
	Special Needs Population (Institutional HH+ Houseless)	Percentage of Special Needs Population	Special needs populations will require mobility assistance for evacuation.	Chakraborty et al., 2005 , Mazumdar & Paul, 2016
	Demographic Pressure	Population Growth Rate (decadal growth rate)	Rapid population growth would create demand for more shelters, social services network and often results in unpredictable demand of relief supplies during disasters	Cardona, IDEA (2005), Bollin and Hidajat, 2006
	Disabled	Percentage of disabled Population	They need special care as they face constraints in terms of information gathering and mobility during the evacuation	Cutter, Boruff, & Shirley, 2003;Mazumdar & Paul, 2016
	Literacy rate	Percentage of illiterate Population	Literacy level influences the ability to understand warning and information related to evacuation measures.	Cutter, Boruff, & Shirley, 2003;Mazumdar & Paul, 2016
	Poverty Level	Percentage of people below the poverty level	Households below the poverty line are more vulnerable	Bollin and Hidajat, 2006
Economic / Access to resources	**Vehicle Ownership**	Percentage of Households having a vehicle	Vehicles help in mobilization during evacuation and recovery. In absence of any vehicle, families may have to travel by foot or public transport to reach the nearest shelter	Mazumdar & Paul, 2016, Devendra K. Yadav and Akhilesh Barve (2017)
	Information devices	Percentage of houses with television, radio, mobile phone	These devices act as a source of information on hazard conditions, warnings, evacuation notice and guidance.	Joerin et al. 2012;Mazumdar & Paul, 2016
Location / Physical	**Elevation**	Percentage of low lying area	Low lying areas are susceptible to inundation	R. Prerna et.al 2014, Arun Kumar 2012, S das 2012, Jana 2016, Parthasarathy and natesan 2015
	Land use/Land cover	Percentage of built-up area in a zone	Type of activity in a zone will give the size of the population present in a zone at a particular time.	V Poompavai , 2013,R. Prerna et.al 2014
	Proximity to cyclone track	Distance from cyclone track	The distance from the path of the cyclone is an indicator of the level of risk. More the distance from the centre of the cyclone the safer is a zone.	V Poompavai, 2013
	Proximity to landfall	Distance from landfall (Surge)	The distance from landfall decides the impact of the surge in an area. If the zones are away from the landfall point they will receive relatively less damage	V Poompavai, 2013
	Proximity to sea/coast	Distance from coast	The effect of damaging agents on houses and assets decreases with increasing distances from the coast	V Poompavai, 2013

	Proximity to the major river	Distance from a major river	Major rivers have large carrying capacity, carry away surge water and help in reducing the surge velocity to flooding. Nearness to the major river should reduce death	S das, 2012
	Proximity to the minor river	Distance from a minor river	Minor rivers get inflated and bring in more water to interior areas during the storm surge and can cause more death in nearby areas	S das, 2012
	Hazardous facilities (factories, power plants)	Distance from a hazardous facility	Households living near hazardous facility are vulnerable to the damage from the breakdown of these facilities	
	Distribution (Built Density)	Number of Households per sq.km of a zone	Evacuation demand depends on the number of HH in an area.	Chakraborty et al. 2005
	Critical road connections	No of bridges and culverts	The failure of these elements can lead to a loss in evacuation route for the people in risk zones and will increase the pressure of re-routing and management on managers	
Housing Condition	**Construction Material or type of Dwelling**	Percentage of Semi Pucca Houses	Pucca house can resist high-speed winds during cyclones while thatched/mud houses are less resilient to cyclones	Devendra K. Yadav and Akhilesh Barve (2017)
		Percentage of Kutcha Houses		Cutter, Boruff, & Shirley, 2003; Mazumdar & Paul, 2016
	The condition of the dwelling unit	Percentage of dilapidated units	The condition of a structure decides its resilience to disaster. Weak structure are prone to damage from cyclones	Cutter, Boruff, & Shirley, 2003
Response capacity	**Medical Services**	Number of Healthcare Centres	The lack of proximity to medical services effects immediate relief and longer-term recovery from disasters. Delay in medical attention may lead to an increase in fatalities	Cutter, Boruff, & Shirley, 2003, Devendra K. Yadav and Akhilesh Barve (2017)
	Transport Infrastructure	Distance to a paved road	Inadequate transportation infrastructure leads to difficulties in access to evacuation route and relief supply resources	Cutter, Boruff, & Shirley, 2003, D K. Yadav and A Barve (2017)
	Road Network	Road density per sq.km	The road density shows the level of accessibility to the population of that area. Higher road density provides more alternatives to people during the evacuation.	Upasna Sharma and Anand Patwardhan(2008)
	Coastal defense structures (natural and artificial)	Length or density of coastal defense structures (Mangrove(sq.km), Sand Dunes(km), length of rocky coast(km))	Coastal defense structure reduces the impact of the cyclone by acting as barriers against strong winds, flood water and decreasing the energy of storm surge when they pass through the defenses.	Cutter 2008,M Mahapatra et.al 2017
	Cyclone shelters	Number of cyclone shelters	Availability of shelters in the local area will reduce the travel distance and distributed demand	Devendra K. Yadav and Akhilesh Barve (2017)

3. Study Area

India has 7,516 km long coastline, close to 5,700 km is prone to cyclones and tsunamis. Approximately 250 million people lived along the coastline in India in the year 2010. The Indian coast is subject to severe weather events, such as cyclones and super-cyclones at an average of nine cyclones per year (ICZMP 2010).

3.1 *Tropical cyclones over the Indian Ocean*

Cyclones form over seven basins worldwide out of which the North Indian Ocean(NIO) basin provides favourable conditions for cyclone landfall over India. The NIO basin is divided into two areas: The Bay of Bengal and The Arabian sea and they receive cyclones averagely in the ratio of 4:1. The breeding season for the storm over NIO are generally pre and post-monsoon period i.e. periods from April to May and October to December are the months during which most of the cyclonic storms occur in the Bay of Bengal(BoB) and Arabian Sea(AS) as shown in Figure 1.

The probability of Genesis and intensification is less in the Arabian sea as compared to the Bay of Bengal due to the relative difference in their Sea surface temperature(SST). The sea surface temperature of AS is about 1-2ºC lower than that of BoB.

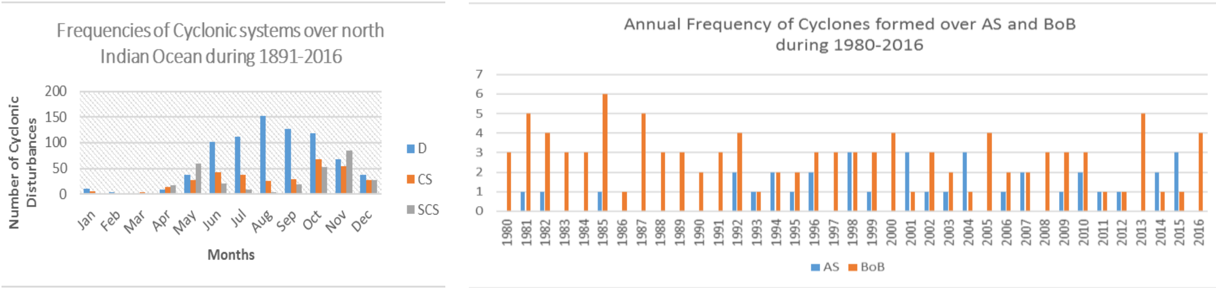

Figure 1: *Frequency of cyclones formed over NIO during 1980-2016*

The effect of cyclone is amplified in the north Indian Ocean (NIO) due to shallow depth of the Bay of Bengal and low flat coastal terrain which produces larger storm surges and takes heavy toll of life (India Meteorological Department, 2013) and the concavity of the bay and its estuaries produce further amplification (Dube et al., 1982).

The study area selected i.e East Medinipur district, it came into existence after bifurcation of erstwhile Midnapur on and from 1.1.2002. The district is located in the southern part of West Bengal adjoining Bay of Bengal. According to the 2011 census, East Medinipur district has a population of 5,094,238 and ranks 20th out of 640 districts in India. The decadal growth rate of the population of the district is 15.36% which is higher when compared to the decadal growth rate of the population of the state i.e.13.9 %.

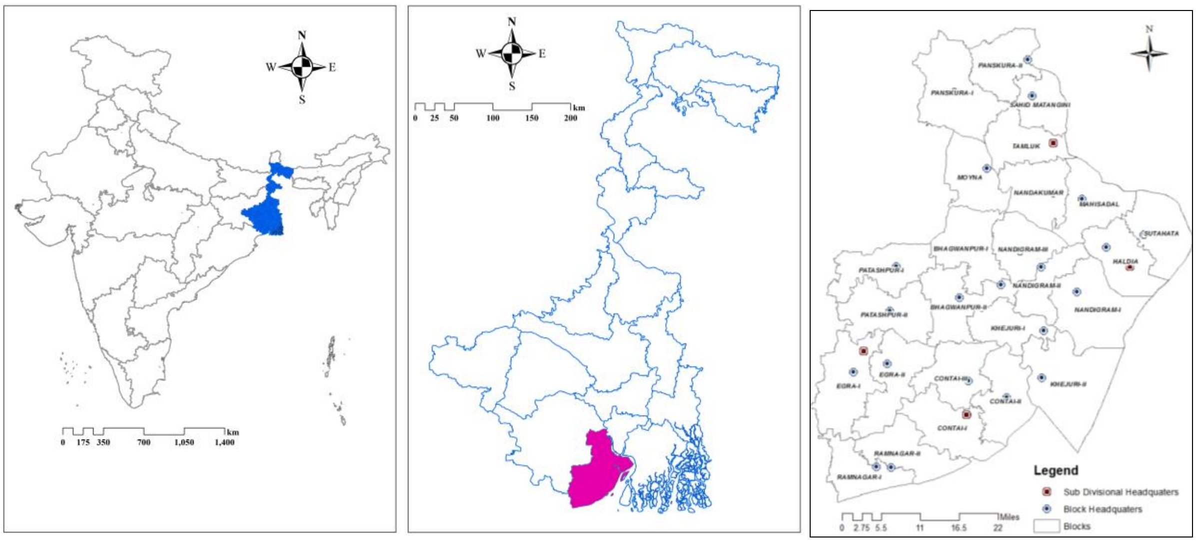

Figure 2: *Study Area*

East-Midnapur district is highly susceptible to floods and cyclones and it falls under 'Very High Damage Risk Zone' according to the vulnerability atlas of India. The major portion of the study area falls under low elevation coastal zone (LECZ). The probable maximum storm surge height in the study area is 12m according to the vulnerability atlas prepared by the Building Materials and Technology Promotion Council (BMPTC), India. The elevation map (see figure 3) prepared using digital elevation model (DEM) image obtained from USGS shows that the Major part of the district falls in low elevation coastal zone (LECZ). In the past, this region has experienced a number of storms which were very destructive and have created tremendous damage. In Last 100 years, 34 Cyclones have occurred over this coast and three of them (1942, 1974 &1976) is in Severe Cyclones list.

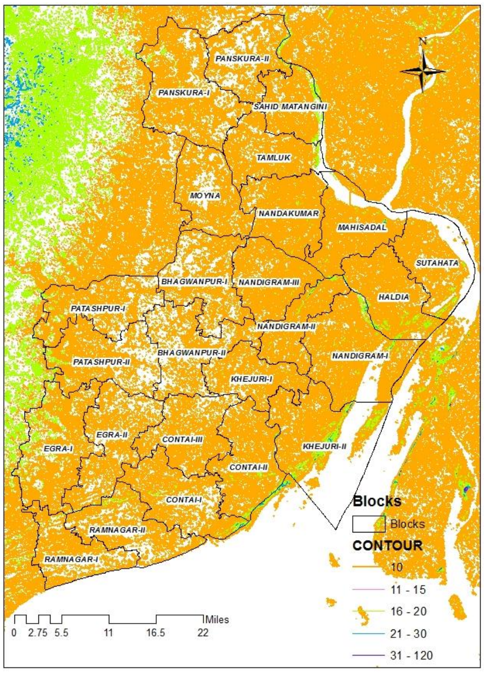

Figure 3: Elevation profile of East Midnapur

3.2 *Data collection*

The data is collected from secondary sources, mainly the source of data is the census of India, 2011, district census handbook district disaster management reports and flood reports. The data used to describe the current vulnerability of Community Development blocks of East Medinipur district include: *Hazard data*: frequency of cyclones; *Demographic data*: Female Population, Children below 6years, decadal growth rate; *Economic data*: Households owning mobile phones, motorized vehicles; *Housing data*: Number of Temporary and Semi-permanent households; *Physical Location Data:* Proximity to coastline, Flood Prone Area; *Response capacity data*: Population served by medical facilities, transport and communication and pucca roads.

3.3 *Methodology*

Disaster management in India had undergone a first paradigm shift from 'response and relief'' approach to 'prevention, mitigation and preparedness' centric approach. Efforts through 'hazard-vulnerability and environment' centric approach focused on disaster risk reduction strategies in various sectors is seen as a second paradigm shift for a holistic understanding of the vulnerability of communities to hazards.

In India, studies on vulnerability assessment of coastal area have mostly focused on hazard and physical characteristics of the area with some recent analyses accounting for socio-economic characteristics (Das, 2012; Bahinipati, 2014; Maiti et al., 2015; Mazumdar & Paul, 2016; Yadav & Barve, 2017). Although most of these studies compared vulnerability at the district level, few measured it at the block (Yadav & Barve, 2017) and the village level (Das, 2012). The method employed in this study integrates hazard characteristics with the vulnerability characteristics and geophysical(exposure) characteristics to form risk indices at the block level.

Indicators are formed based on a function which maps the theoretical concepts to an operational or observable variable. Based on the number of variables needed to make concepts operational, there can be scalar, composite and vector-valued indicators. However, there are challenges in making theoretical concepts operational like the vague definition of theoretical concepts and how they are combined. The broad steps in the development of vulnerability indicators are to define what is to be indicated, selection of indicating variables and aggregation of the indicating variables(Hinkel, 2011).
Index based study to relate the mortality has been done in the past using vulnerability indicators in climate change and Disaster risk reduction domains (Brooks, Adger, & Kelly,

2005; Chakraborty, Tobin, & Montz, 2005). The index method has been used in several studies in Indian context to assess vulnerability in case of tropical cyclones (Dube, Mazumder, & Das, 2006; Bahinipati, 2014; Yadav & Barve, 2017). Use of Indicators for measuring vulnerability at the local scales has been found appropriate for identifying vulnerable people, communities and regions (Hinkel, 2011).

The hazard component in determining risk considers frequency and probability of hazard in its measure. A set of indicators of exposure, vulnerability and response capacity to adapt to a disaster is derived from the literature using a deductive approach. Indicators used to assess vulnerability in case of the study area is based on ease in availing data from the census or other secondary sources. The effect of an indicator on the index value is important to calculate all the indices on the same scale. For example, indicators taking into account the age of children below 6 years and of the old person above 60 years, the higher number of old person and children will indicate high vulnerability.

3.4 *Index Calculation*

The study assigns equal weight to each indicator since the weight of indicators can change for the different study area(Hinkel, 2011). The indicators considered for analysis follow different dimension, in order to use them in the same function, the data was normalized(Dube, Mazumder and Das, 2006). The indicators or variables have been brought to an increasing scale (0 to 1) i.e the higher value of the variable corresponds to the high level of risk. Depending on the relation of the indicator to the risk index the data was converted into decreasing or increasing form.

$$\textbf{Index}\ (X_1) = \frac{X - X_{min}}{X_{max} - X_{min}}$$

X_i = the Index value of ith Block, X is the value of the indicator for ith Block

Following are the indicating variables used for the purpose of this study:

Components	***Parameters***	***Indicator Data***	***Effect***
Exposure	Flood Prone Area	Indicates Low lying Area (1-yes, 0-No)	Increases
	Proximity to sea/coast	Distance from coast	Decreases
Population Structure	Population Density	Persons per sq.km	Increases
	Female population	Percentage of Female Population	Increases
	Children population	Percentage of children(<6 years)	Increases
	Demographic Pressure	Population Growth Rate (decadal growth rate of the population)	Increases
Access to Resources	Vehicle Ownership	Percentage of Households having a motorized vehicle	Decreases
	Information devices	Percentage of houses with mobile phones	Decreases
Housing Condition	Building type	Percentage of Semi Pucca Houses	Increases
		Percentage of Kutcha Houses	Increases
Response Infrastructure	Medical Services	Percentage of population with access to Healthcare	Decreases
	Transportation service	Percentage of population with access to Transportation Services	Decreases
	Transport Infrastructure	Percentage of population with access to paved roads	Decreases

Rather than simply summing the standardized variables, values were averaged yielding aggregate index (Exposure and Vulnerability) normalized between zero and one.

$$F = (X_1+X_2 \ldots +X_n)/n$$

The risk Index is calculated based on the following function:

$$Risk = Hazard \times Exposure \times Vulnerability$$

This study considers the frequency of cyclones in each block over the past for estimating the level of impact faced by a community from a hazard.

Hazard incidence probability of the Blocks

The Probability Density Function for describing cyclone arrivals during a specified period follows the Poisson's Distribution (Dube, Mazumder and Das, 2006).

$$F(x) = \frac{1}{ARI} * e^{-X/ARI})$$

Intervals between successive arrivals follow Negative Exponential Distribution The distribution of time 'x' between successive arrivals of a random event is given by:

$$AEP = = (1- e^{-1/ARI})$$

ARI *= Annual Reoccurrence interval,* ***AEP****= Annual Exceedance Probability*

Hazard Analysis

The cyclones considered for hazard analysis combine both severe cyclonic storm and cyclonic storm data from 1890-2013.

Block	ARI	AEP	Block	ARI	AEP
Panskura	61.5	1.61	Haldia	0	0.00
olaghat	61.5	1.61	Nandigram - I	20.5	4.76
Tamluk	30.75	3.20	Nandigram - II	20.5	4.76
Sahid Matangini	0	0.00	Khejuri - I	61.50	1.61
Nanda Kumar	24.6	3.98	Khejuri - II	30.75	3.20
Mahisadal	41	2.41	Contai - I	17.57	5.53
Moyna	123	0.81	Deshopran	15.38	6.30
Potashpur - I	13.67	7.06	Contai - III	13.67	7.06
Potashpur - II	11.18	8.55	Egra - I	13.67	7.06
Bhagawanpur - II	20.50	4.76	Egra - II	10.25	9.30
Bhagawanpur - I	30.75	3.20	Ramnagar - I	15.38	6.30
Chandipur	30.75	3.20	Ramnagar - II	11.18	8.55
Sutahata	24.6	3.98			

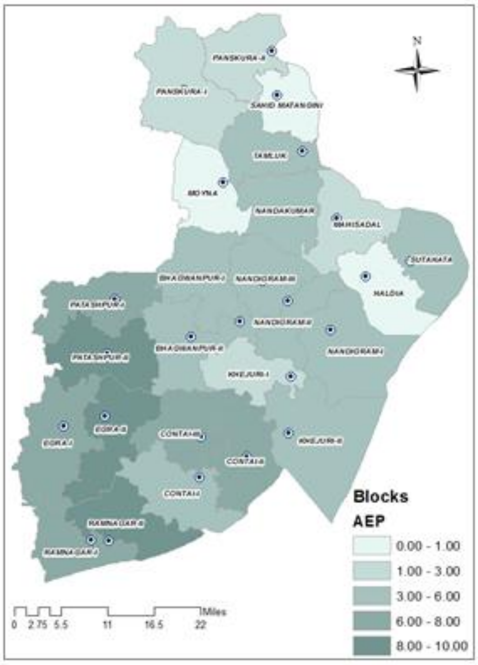

Figure 4: Annual Exceedance Probability of Cyclones

4. Results

The risk index showed that the blocks which had higher number of cyclones passing through them, thus more Annual Exceedance Probability (AEP), face high level of risk. The result shows that the blocks Ramnagar-II, Egra-II and Potashpur-II are at very high risk. Ramnagar-II and Egra-II are at high risk largely due to their exposure while Potashpur-II block ranks second highest in vulnerability. The blocks under high risk are Contai – I, Potashpur – I, Deshopran, Egra – I and Contai – III. Haldia and Shahid Matangini ranked lowest as no cyclones have crossed over these blocks in the past. They had the least probability of receiving a tropical cyclones and are relatively protected from danger.

As risk index mainly presents those blocks as high-risk areas which have had a high occurrence of cyclones in past, thus it is important to compare the exposure and vulnerability of population in a block while preparing for cyclones and for identifying a population that needs to be evacuated in a future hazard. The impact highly depends on the level of exposure and the vulnerability of population exposed.

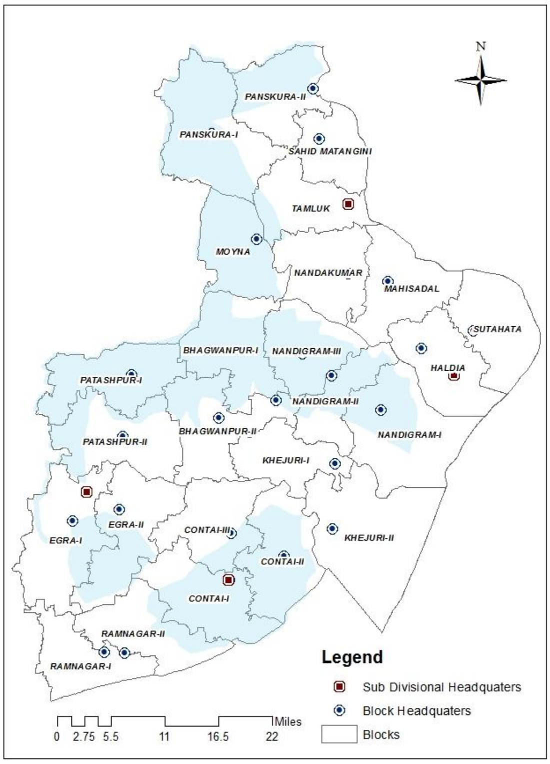

Figure 5: Flood-Prone Areas

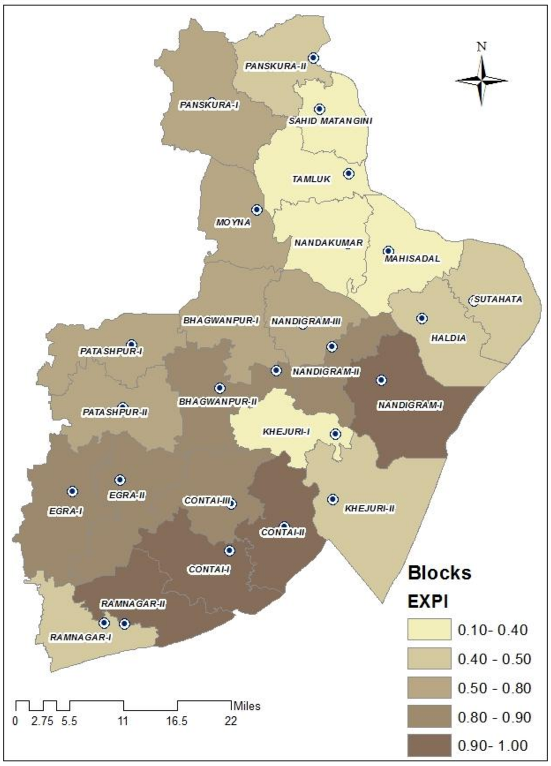

Figure 6: Exposure Index

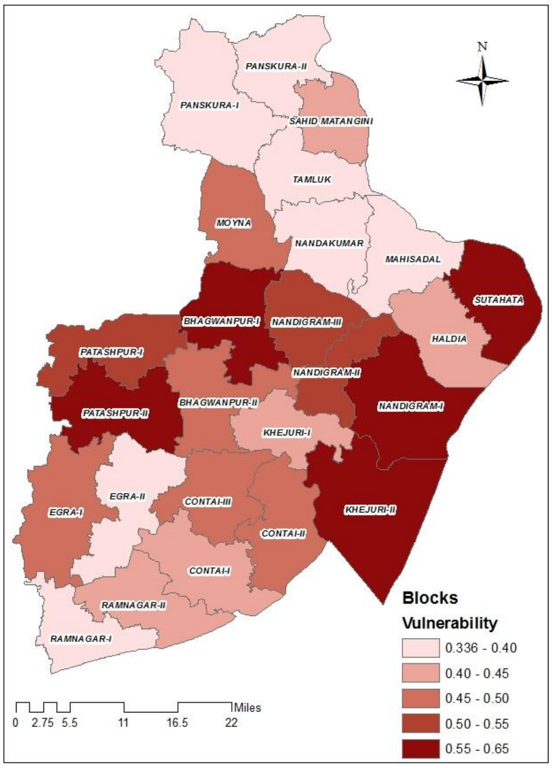

Figure 7: Vulnerability Index

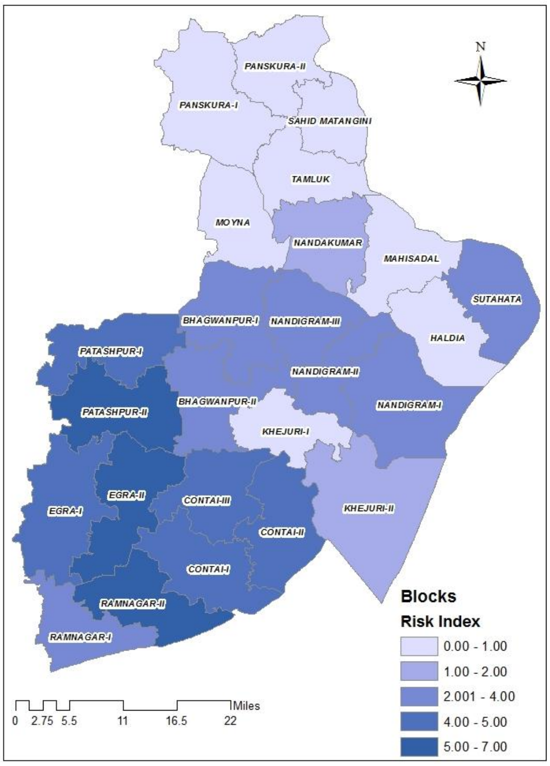

Figure 8: Risk Index

This analysis indicates that reduction in mortality can be achieved by addressing factors of the vulnerability of communities in highly exposed areas. The more complex processes that lead to high mortality can be better understood by examining the local level risks using given indicators.

5. Conclusion

The selected indicators cover dimensions like exposure, vulnerability and response capacities to identify the relative risk of development blocks. It will help us understand how the risks are distributed over geographical space and how it changes over time. In long run, it will help us identify the important factors which are responsible for these changes. These factors could be a good measure to check the effectiveness of the implementation of programs and guiding policies. The level of vulnerability of different blocks will help in decision making in prioritizing the allocation of capital and other resources for pre and post-disaster activities.

In case of evacuation during cyclones, origin zones are concentrated in threatened coastal areas and destination zones are spread inland to neighbouring areas and states. The risk identification can probably indicate the area that is risk-free and could accommodate evacuees from risk areas. The method would help in determining evacuation zones and their risk levels for prioritizing block-wise evacuation. The organization of evacuation according to these risk levels will lead to efficient utilization of resources, personnel and improved traffic management.

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