EasyChair Preprint

№ 6953

Disaster Vulnerability Assessment: a Case Study of Puducherry

Riddhi Sarda and Sarika Bahadure

October 30, 2021

Title: Disaster Vulnerability Assessment: A case study of Puducherry

Abstract:

Resilience is a multidisciplinary term and since 1970s has been used in the context of disasters. Globally, disasters witnessed in the first six months of the year 2020 are more than the number of disasters witnessed from 2000 to 2019. In the Indian context, disasters like floods, cyclone, and drought affect more than 50 million people. Increase in disasters along with lack of preparedness increases vulnerability, leading to lack of development. There is a need to address the link between disaster risk and poor development to build resilience, which can be achieved by decreasing vulnerability and increasing capacity.

This paper presents disaster vulnerability assessment of the Puducherry, a multi hazard prone city highly vulnerable to tsunami and cyclone. The vulnerability assessment is examined by the determinants of vulnerability: hazard and exposure; sensitivity; and adaptive capacity. The vulnerability indexing is done using weighted average formula, followed by normalization. Based on the vulnerability index, vulnerability index map is prepared using GIS application to identify and prioritize the vulnerable areas of the city. The broad proposals and preparedness measures are recommended to build resilience. This assessment method can be adopted to assess vulnerability of any coastal city to reduce vulnerability by building resilience.

Keywords: Disaster, Vulnerability Assessment, Coastal, Resilience.

Authors:

Riddhi Sarda, M.Tech Urban Planning Student, Department of Architecture and Planning, Visvesvaraya National institute of Technology, Nagpur-440010, email: riddhisarda12@gmail.com

Sarika Bahadure, Assistant Professor, Department of Architecture and Planning, Visvesvaraya National institute of Technology, Nagpur-440010, email: sarikabahadure@arc.vnit.ac.in

1. Introduction

Disaster risk reduction and Sustainable development are often treated as two different sectors for planning any city. But both the sectors are fundamentally entwined. A single disaster, natural, manmade or by negligence or accident can reverse the progress made and impediment development by years. Concurrently, unsustainable development increases the risk of disasters (Shaw, January 2016), so the disaster risk is linked to unsustainable development. The more we develop communities resiliently, the more we can contribute to reducing the disaster risk.

The year 2020 has been one of the historically astonishing and alarming as 207 disasters were reported from January to June, 92% of which were weather related disasters. This is overly concerning figure as

it is above the total disasters reported in the 21st century (Pandey, 2020). The figure 1. shows the deadliest disasters faced by the world in 2020.

Figure 1. Disasters in 2020 (Monteiro, 2020).

1.1. Understanding Disaster

For this study, three definitions of the term "Disaster" are studied to understand the types, causes, and impacts of disaster given by different organizations.

"*Disaster is a sudden, calamitous event bringing great damage, loss, destruction, devastation to life and property. The damage caused by disasters is immeasurable and varies with the geographical location, climate, and the type of the earth surface/degree of vulnerability. This influences the mental, socio-economic, political, and cultural state of the affected area* (National Disaster Management Toolkit for urban planning)*."* This definition in the "Toolkit for Urban Planning in Disaster Management" emphasizes the damage caused varies as per the geographic location of the disaster and recognizes the threat to mental as well as cultural state of the affected area.

"A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts (UNDRR, 2016)*."* This definition by UNDRR, 2016 describes disaster as interaction of exposure, vulnerability, and capacity at any scale which affects human, material, economic and environment.

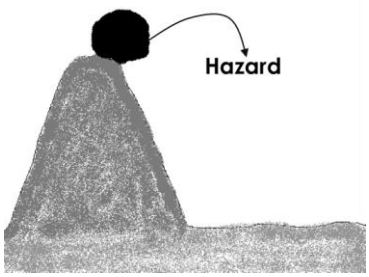
"Disaster" means a catastrophe, mishap, calamity or grave occurrence in any area, arising from natural or manmade causes, or by accident or negligence which results in substantial loss of life or human suffering or damage to, and destruction of, property, or damage to, or degradation of,

environment, and is of such a nature or magnitude as to be beyond the coping capacity of the community of the affected area (NDMP, 2019)*."* This definition given by the DMA gives different synonyms of the term "disaster" like "catastrophe, mishap, calamity and grave occurrence", it emphasizes on causes of disaster, nature, and magnitude of the disaster.

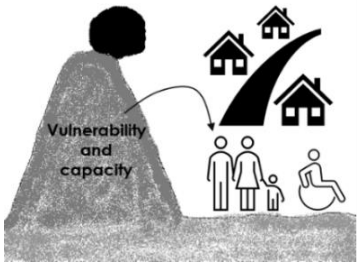
1.2. Concepts related to Disasters

To understand the disaster further, it is important to understand various concepts related to disaster. The different concepts are explained below supported by illustration (BMTPC, MoUPA and UNDP, December, 2016):

- Hazard: A dangerous phenomenon, substance, human activity, or condition that may cause damage to health, property, livelihood, services, social and economic disruption, or environmental damage (fig. 2a).
- Vulnerability: The characteristics and circumstances of a community make it susceptible to any hazard (fig. 2b).
- Capacity: The combination of all the strengths, attributes, and resources available within a community, society or organization that can be used to achieve agreed goals (fig. 2c).
- Risk: It is the combination of the probability of an event and its negative consequences (fig.2c).
- The risk of disaster is a composite function of the type and nature of the hazard and the number of people who are exposure to the hazard event, characterized by their varying degrees of vulnerability to that specific hazard.



a) the image represents the Hazard.



b) the image represents vulnerability and capacity.

c) the image represents risk.

d) the image represents preparedness towards disaster risk.

Figure 2. the images represent concepts related to disaster

The equation for calculating risk at any given space is given below (BMTPC, MoUPA and UNDP, December, 2016):

$$\boldsymbol{Hazard\ X\ \frac{Vulnerability}{Capacity}\ =\ Risk\ at\ a\ place} \qquad \textit{Equation 1}$$

It is perceived that to reduce disaster risk at any given place, there is a need to reduce vulnerability and improve capacity.

1.3. Vulnerability assessment and data requirement

Vulnerability Assessment is a process of identifying vulnerability and potential risk in any city which can help in taking actions for preparing and mitigating those risks (BMTPC, MoUPA and UNDP, December, 2016).

To perform vulnerability assessment for any city, the first step is to identify historical trend of disasters in the city and to understand the exposure of the disasters that is making the people, infrastructure, and other resources susceptible to these disasters. This spatial mapping of vulnerable population and infrastructure can help to visual spatially the magnitude of potential vulnerability. The next step is to establish the probability of intensity and frequency of different disaster risks and the

final step is to prioritize risk reduction measures based on the understanding of the disaster risks (refer table 1). For the vulnerability assessment, the city needs a base map of different thematic layers such as geology, lithology, topology, land use/land cover, natural drainage, basic services, transportation network, emergency lifeline systems and telecom. The data required the vulnerability assessment can be categorized into three datasets: 1) Hazard dataset, 2) Vulnerability dataset, and 3) Capacity dataset (BMTPC, MoUPA and UNDP, December, 2016).

Table 1. Steps to be taken for Vulnerability assessment of any city.

Step 1	Step 2	Step 3	Step 4	Step 5
				
Identify hazards using scientific study and historical database	Do the spatial mapping of the vulnerable population	Assess the infrastructure/assets. Identify the weak buildings	Ascertain the probability of intensity and frequency of different hazards	Prioritize risk reduction measures based on the understanding of the risk

1.4. Disasters in developed and in developing countries.

Both the developed and developing countries are being affected as the frequency of natural disasters has increased globally. There is a correlation between poverty and natural disaster which can be witnessed as vast majority of people that are affected due to disasters are from developing countries. The poor population reside in environmentally sensitive places and the disasters are triggered from these poor population making the more vulnerable. As the developed countries have better access to resources, this enables them to cope up with the disaster before it becomes a crisis. The root cause of this disparity between developed and developing countries is poverty (Walter & Mukhier, 2006).

India, a developing country, is the second most populated country in the world. It has an immense physiographic multiplicity and vast spatial stretch which when combined with human interference has rendered the people of the country vulnerable to disasters (Dr. Barkatullah Khan, 2014).

India one of the most disaster-prone countries in the world (refer figure 3) as 68% of India’s land is prone to drought, 60% to earthquakes, 12% to floods and 8% to cyclones, affecting over 85% of Indian land and over 50 million people (2014).

Figure 3. Disaster risk map of India (India climatic disaster risk map en.svg, 2007).

1.4.1. Major causes of disaster vulnerability in Indian cities

The industrialization, rapid and unplanned urbanization has resulted in to increase stress on the environment. There is high concentration of people, infrastructure and economy in urban areas making them vulnerable to disaster. The high population density in urban areas, imposes additional challenges on the city authorities to provide basic infrastructure and services to the people and as a result forced 30-60% of the people to live in stressful urban environments.

Rapid and unplanned development, high population density and poor infrastructure leads to:

1. High demand of land in urban areas compels the use of unsuitable terrain prone to natural hazards.
2. Inappropriate construction.
3. Urban development is disrupting natural drainage channels.
4. There is concentration of political, economy, and other resources in urban areas.
5. Ecological imbalance.
6. Increased risk of technological and industrial hazards.

1.4.2. Existing Planning Norms and Standards in India

With the introduction of Disaster Management Act 2005 (DMA) and National Plan for Disaster Management (NPDM) 2009, there has been a paradigm shift from a relief centric approach to proactive approach in order to overcome the impacts of disasters in India. The DMA provides "the effective management of disasters and for matters connected there with or incidental thereto". The NDMP provides a framework and direction to the government agencies for all phases of disaster

management cycle. It is in accordance with the provisions of the DMA, the guidance given in the National Policy on Disaster Management (NPDM) 2009, and the established national practices. It proactively helps to realize the global goals as per agreements to which India is a signatory – Sendai Framework for Disaster Risk Reduction (SFDRR), Sustainable Development Goals (SDGs) and Paris Agreement on Climate Change, acknowledges mainstreaming Disaster Risk Reduction as an integral feature, provides with preventive, mitigation measures, roles, and responsibilities of different departments of the GoI (NDMP, 2019)

1.5. Need of the study

India has a coastline exceeding 7,500 km surrounding the mainland and various islands. The natural disasters experienced in the coastal India are cyclones which are usually accompanied by storm surges along with coastal shoreline changes which affect the coastal tracts, and frequently causes widespread misfortunes. The frequency of coastal hazards and the damaged caused by these disasters have increased over the years. There is growing human tenancy in risky stretches of the coast along with rising urbanization in coastal areas. The risk profile of the coastal areas is influenced by global climate change, especially the higher frequency and intensity of extreme weather events including cyclones and the sea level rise. Often the coastal disasters affect a larger region and sometimes more than one state (NDMP, 2019). There is a need to analyse the coastal vulnerability in order to take proactive measures to reduce the damage cause due to coastal hazards, to develop in a resilient and sustainable communities.

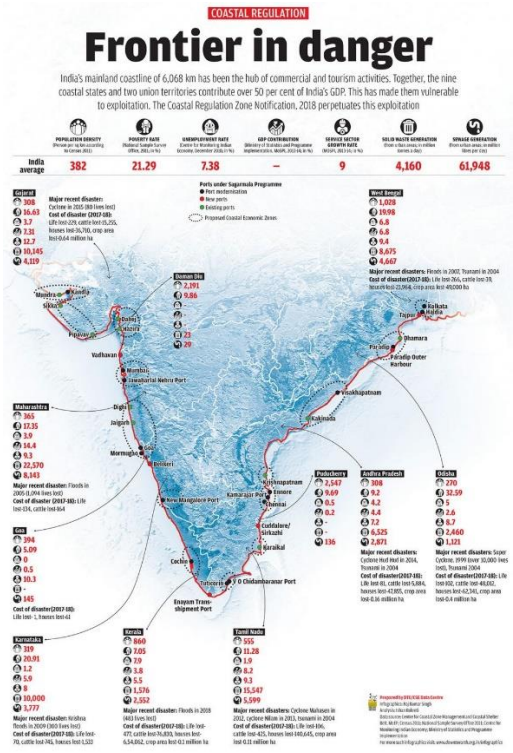


Figure 4. Map of Indian Coastline Showing Disaster Affected Regions.

The objective of this study is to understand the risk of disasters and identify vulnerable areas by conducting vulnerability assessment of an Indian coastal city, Puducherry. The first section is the introduction of the study which includes understanding disaster and different concepts related to disasters, India's disaster profile, causes of disaster vulnerability in Indian cities, existing planning norms and standards in India. It also illustrates the general steps to be taken and data required for vulnerability assessment. Second section elaborates the study area identified for the vulnerability assessment. It introduces Puducherry and informs the trends of disasters. The third section illustrates the vulnerability assessment of Puducherry which consists of vulnerability assessment approach, elaborates the analysis method and proposals based on the assessment. The last section concludes the study.

2. Study Area

The identified study area is Puducherry Municipal Council, a coastal city lying on the east coast of India. Puducherry is the capital city of The Union Territory (UT) of Pondicherry and is one of the most popular tourist destinations in South India. The Puducherry UT consists of four districts, situated at different geographical locations isolated from one another. Puducherry city, lies on the east coast, is the largest of all the four, (refer fig. 5). The total area of Puducherry Municipal Council is 19.46 sq. km. which is divided into 42 wards. Puducherry is prone to many natural hazards like floods, cyclones, and earthquakes. Previously, cyclones and associated storm surges have inundated vast area of land along the 24 km long coastal stretches of Puducherry. A major part of Puducherry is lying on the coast of Bay of Bengal and is influenced by Northeast Monsoon. The heavy rain/cyclone that occur under the influence of Northeast Monsoon sometime causes heavy damage to life and property (Action plan of Puducherry, 2019).

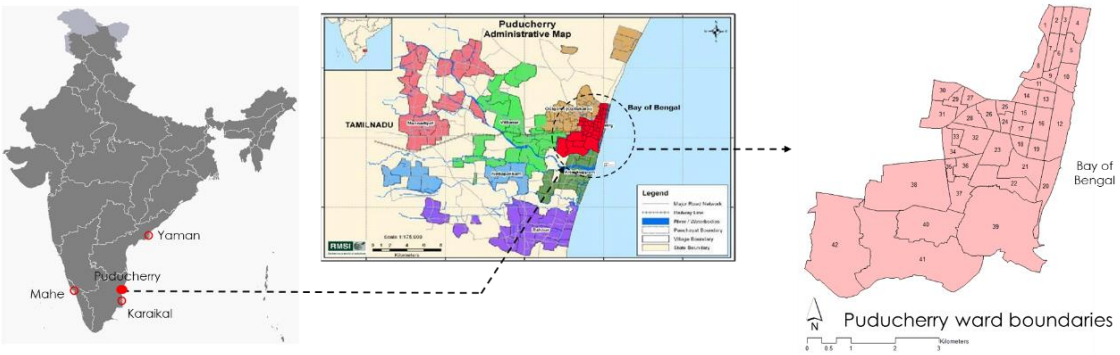


Figure 5. Location map of Puducherry (Action plan of Puducherry, 2019).

2.1. Trends of disasters in Puducherry

Puducherry has been classified as a multi-hazard prone district. It is highly vulnerable to cyclone and Tsunami; moderately vulnerable to flood/heavy rains, fire, and industrial hazards. Tsunami 2004 severely affected the district. The district falls in earthquake zone III, moderate damage risk zone (MSK

VII) and does not have any history of damaging earthquake events. The district has a plain to rolling topography and is not vulnerable to landside hazard, drought, and epidemics (Action plan of Puducherry, 2019).

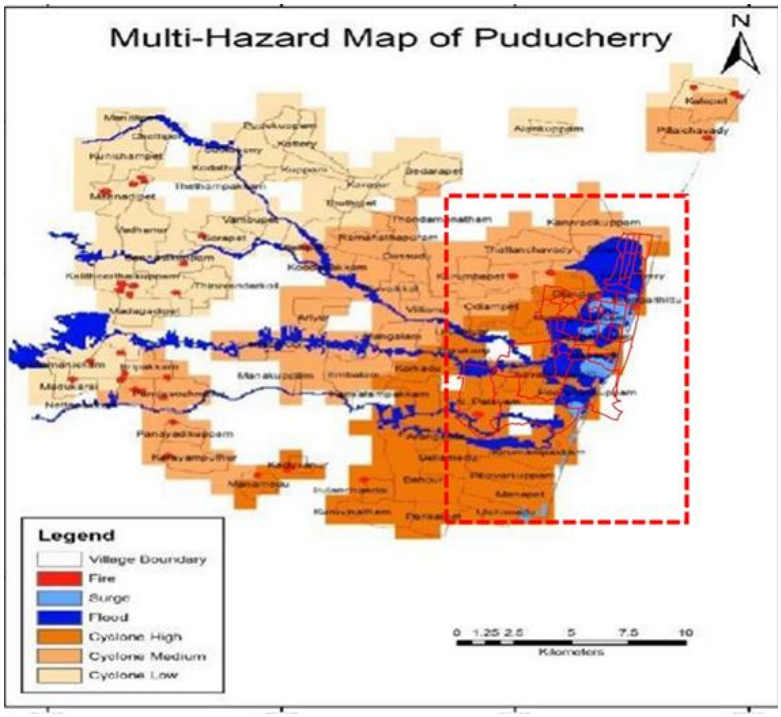


Figure 6. Multi-hazard map of Puducherry (Action plan of Puducherry, 2019).

Table 2. Trends of Natural hazard in Puducherry (Action plan of Puducherry, 2019).

No.	Year	Hazard	Death	Affected People	Loss in Lakh rs
1	1993	Cyclone and Heavy rain	-	-	4647
2	1996	Heavy rain/Flood	-		4648
3	1998		-		911
4	2000	Cyclone	02		5165
5	2004	Tsunami	601	43432	50065
6	2005	Floods	-	-	-
7	2006		-	-	-
8	2007	Heavy rain/Flood	-	-	-
9	2008	Cyclone Nisha		16000	-
10	2001	Cyclone Thane	12	1145000	247213

Based on the past trends of Disasters in Puducherry hazard categorization is done as follows:

Table 3. Hazard Categorization (Action plan of Puducherry, 2019)

Hazard and Exposure	Flood	Cyclone	Strong Wind	Tsunami	Drought	Industrial Chemical hazard	Fire hazard	Epidemics	Land slide
	Moderate	High	Moderate	High	Low	Moderate	Moderate	Low	Low

3. Vulnerability assessment

The study for the vulnerability assessment for Puducherry city was conducted in January 2019. The primary and secondary data were collected, base map, and thematic maps were prepared. Figure 8 presents the methodology of the study. The stages adopted for the assessment of the study area is as follows:

Study past trends of disasters- frequency and intensity of disasters.

i. Identify and define the parameters and indicators for vulnerability assessment.

ii. Map risk and hazard profile of the Puducherry region as per different forms of disasters.

iii. Map the Multi Hazard prone areas and assess their parameters and prioritize.

iv. Recommend preparedness measures and evacuation plans.

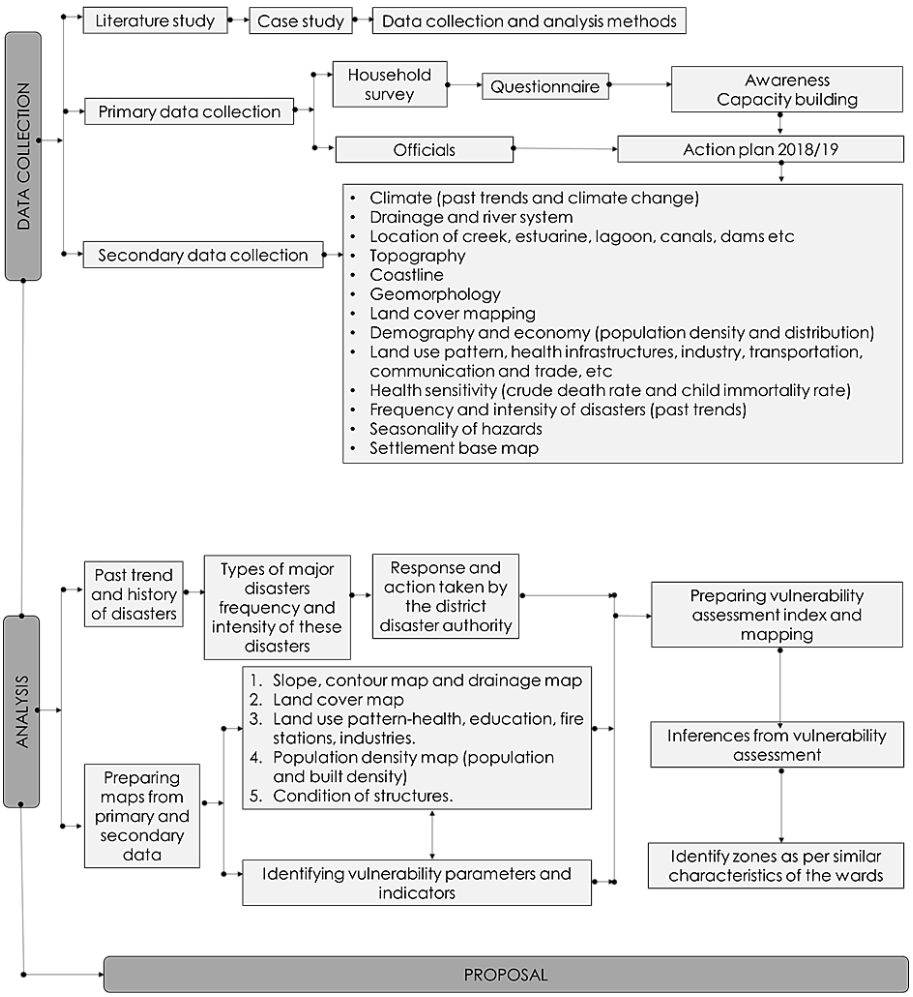


Figure 7. Methodology of the study

The approach for the vulnerability assessment is preliminarily to identify indicators for the assessment, for which case example of Orissa (Bahinipati, 5 DECEMBER 2014) was studied and indicators are ascertained. Subsequently, the Weighted average mean, and Normalization method are finalized for doing statistical analysis and based on this analysis vulnerability index is prepared (refer fig. 9).

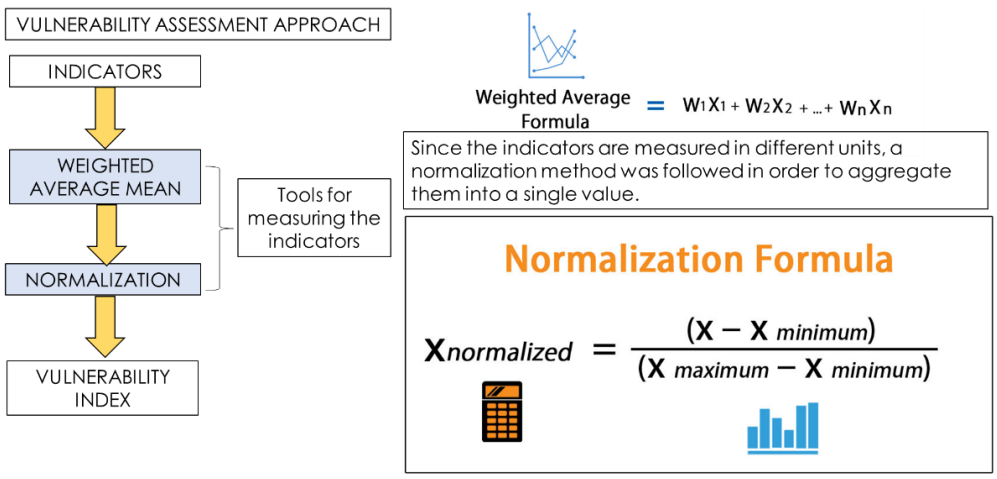


Figure 8. Vulnerability assessment approach

3.1. Analysis

3.1.1. Indicators

The identified indicators for the vulnerability are classified into three determinants of vulnerability: 1) Hazard and Exposure; 2) Sensitivity. 3) Adaptive Capacity. These indicators are studied at ward level and city level. The Table 3 given below shows the list of indicators for vulnerability assessment. Each indicator is assigned a sign depending increasing or decreasing vulnerability of the indicators. To calculate the weighted average, the indicators that will be more affected or trigger the disasters has more weight.

Table 4. Parameters and indicators for Vulnerability assessment

Determinants of Vulnerability	Components	Indicators	Sign	Weight assigned	Data Source	Remarks
Hazard and Exposure	**Characteristics of disasters frequency and magnitude**	Flood	+	0.05	Action plan 2018/2019	At city level
		Cyclone		0.125		
		Strong Wind		0.05		
		Tsunami		0.125		
		Drought		0.0125		
		Industrial Chemical hazard		0.05		
		Fire hazard		0.05		
		Epidemics		0.025		
		Land slide		0.0125		
		Coastal Vulnerability		0.5	R. Mani Murali et al.: Coastal vulnerability assessment of Puducherry coast, India	
Sensitivity	**Demographic Sensitivity**	Growth rate of the population	+	0.1	Census data	At city level
		Informal settlements		0.1	Primary Source	At ward level
		Population Density		0.25	Census data	
		Percentage of female population		0.1		
		Percentage of children below 6 years		0.1		
	Agricultural Sensitivity	Percentage of cultivators		0.05		
		Percentage of agricultural labours				
		Percentage of net area sown		0.05		At city level
				0.15		
	Health sensitivity	Infant Mortality rate		0.05	Secondary source	At city level

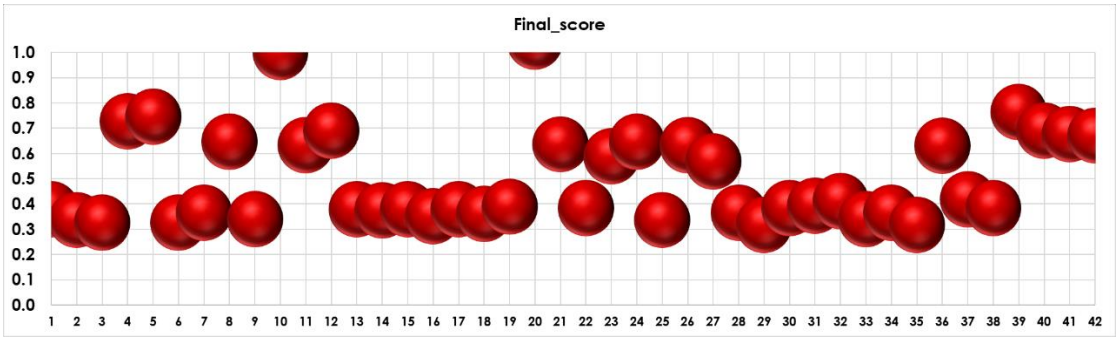
Adaptive capacity	**Economic capacity and equity**	Percentage of people below poverty line	+	0.25	Secondary source	At city level
		Per capita district gross domestic product	-	0.15	Action plan 2018/2019	At city level
		Percentage of people employed		0.2	Census data	At ward level
		Percentage of female employed		0.15		At ward level
	Information and skills infrastructure	Literacy rate		0.25	Census data	At ward level
		Female literacy rate		0.25		
"+" means increasing vulnerability and "-" means decreasing vulnerability						

To calculate the final score, the determinants of vulnerability are also assigned weight (refer table 6).

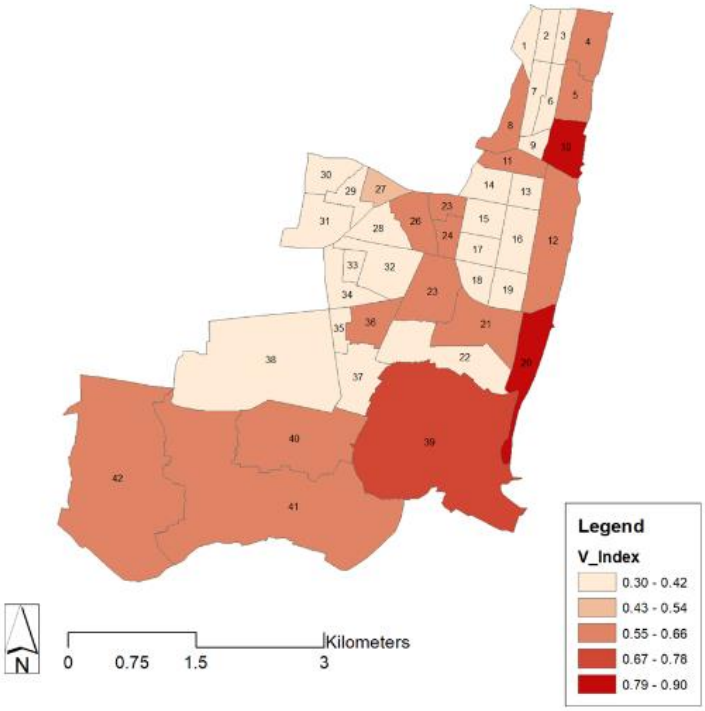
Table 5. Weights assigned to the components.

Determinants of Vulnerability	**Weight assigned**
Hazard and Exposure (E)	1.5
Sensitivity (S)	0.75
Adaptive capacity (AC)	0.75
Final Score : V=(E+S+(1-AC))/3	

The final indexing is done through the vulnerability assessment approach and the final normalized score obtained is from 0 to 1 as per the wards. Here, 1 represents high vulnerability and 0 represents no vulnerability. In accordance with the vulnerability index, figure 11 represents a vulnerability index map as per wards.



a) Final indexing

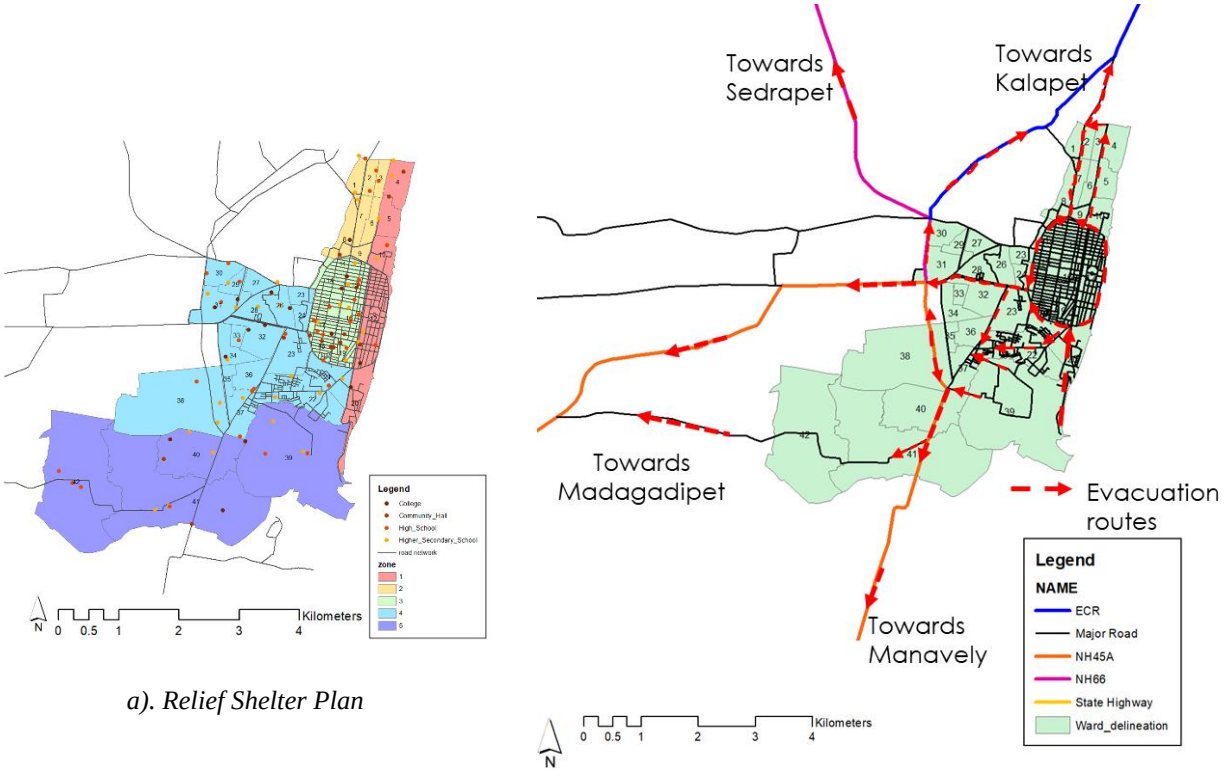


b) Vulnerability Index Map

Figure 9. Vulnerability Index of Puducherry city represented as per wards.

3.2. Proposals based on vulnerability assessment

The conclusions obtained from the vulnerability index mapping enabled the identification and prioritization of the more vulnerable areas of the region and proposals include relief shelter plan and evacuation plan (refer fig. 12). Relief Shelters provides with temporary accommodation, medical facilities, food, clothing etc. in case of any disasters. The relief shelters identified are high schools, colleges, and community halls in different wards (refer fig 12a). The evacuation plan shows evacuation routes which are majorly includes Highways, East coast Road (ECR) and major road network (refer fig. 12b).



a). Relief Shelter Plan

b). Evacuation plan

Figure 10. Proposals based on vulnerability assessment

In addition to the above proposals, recommendations are proposed for watershed management and Mangrove Conservation. No development zones are planned where vulnerability is high. It is also recommended mainstreaming of Disaster management into conventional planning.

Conclusion

Disaster, also known as calamity, catastrophe or mishap can be natural or man-made, is a sudden event which can occur at any scale. It often leads to human losses, material damage, economic failures, and environmental destruction. There is a two-way correlation between poverty and disasters. The poor population is majorly affected by the disaster. Concurrently, the poor population trigger the disasters by exploiting the environmentally sensitive locations and residing in dilapidated conditions. The lack of access to resources further contributes to impact of disasters in developing countries.

In a developing country like India which has a vast spatial expense, diverse physiography, second largest population in the world and a multi hazard prone country, it becomes crucial to prepare for the disasters to cope up resiliently. India has a vast coastline of more than 7500 m which is prone to coastal hazards like cyclone, storm surge, coastline alteration etc. These coastal hazards affect often causes impact at a large scale and sometimes affect more than one state. There is need to analyze the impact of these disaster and plan for resilient communities by taking anticipatory measures.

The study area identified for the study is Puducherry city which lies on the eastern coast of India. The Vulnerability Assessment is conducted for the Puducherry city with the help of vulnerability indexing. The vulnerability indexing quantifies the vulnerable areas, and the vulnerability index map presents the quantified vulnerability index into spatial map. The vulnerability index map enables us to visualize the extent of vulnerable zones. The results obtained from the vulnerability index mapping and inferences facilitated the identification and prioritization of the more vulnerable areas of the region. This assessment method can be adopted for calculating risk at any given place to prepare and take measures for building a sustainable and resilient city.

References

(2014). *World Focus*(Disaster Management in India).

(2019). *Action plan of Puducherry.* Puducherry U.T.: Department of Revenue and Disaster management .

Curly tales. (n.d.). Retrieved 01 15, 2021, from https://curlytales.com/9-natural-disasters-that-have-already-happened-in-just-5-months-of-2020/

(December, 2016). *Disaster Risk Reduction: A handbook for Urban Managers.* New Delhi: Ministry of Housing & Urban Poverty Alleviation, GoI; Building Materials & Technology Promotion Council, New Delhi; United Nations Development Programme, New Delhi.

Down To Earth. (n.d.). Retrieved 01 15, 2021, from https://www.downtoearth.org.in/

Dr. Barkatullah Khan, D. A. (2014). INCESSANT DISASTERS, VULNERABILITY AND COMMUNITY RESPONSE IN INDIA. *World focus*(Disaster Management in India).

India climatic disaster risk map en.svg. (2007, March 23). (Wikimedia commons) Retrieved March 14, 2021, from https://upload.wikimedia.org/wikipedia/commons/3/35/India_climatic_disaster_risk_map_en.svg

(2019). *National Disaster Management Plan.* New Delhi: NATIONAL DISASTER MANAGEMENT AUTHORITY, MINISTRY OF HOME AFFAIRS, GoI.

(November, 2019). *National Disaster Management plan.* New Delhi: National Disaster Management Authority, Ministry of Home Affairs, GoI.

(n.d.). *National Disaster Management Toolkit for urban planning.* New Delhi: DDF Consultants Pvt. Ltd.

(2017). *Opportunities and options for integrating climate change adaptation with the Sustainable Development Goals and the Sendai Framework for Disaster Risk Reduction 2015–2030.* Bonn, Germany: United Nations Climate Change Secretariat.

R. Mani Murali, M. A. (2013). Coastal vulnerability assessment of Puducherry coast, India, using the analytical hierarchical process. *Natural Hazards and Earth System Science*, 21.

Shaw, J. U. (January 2016). *Sustainable Development and Disaster Risk Reduction.* Japan: Springer.

United Nations Office for Disaster Risk Reduction. (n.d.). Retrieved 10 15, 2020, from https://www.undrr.org/terminology/disaster

WHO ARE MOST VULNERABLE TO NATURAL HAZARDS? (n.d.). (21st Century Challenges: informed discussion from the Royal Geographical Society (with IBG)) Retrieved October 26, 2020, from https://21stcenturychallenges.org/who-are-most-vulnerable-to-natural-hazards/

Acknowledgements

This study is a part of the Planning Studio II conducted in summer 2020 at Visvesvaraya National Institute of Technology, Nagpur, India under the M.Tech. Urban Planning program. The authors thank all the students of the batch 2019-2021 for conducting the primary survey and compiling the data.