Report on Framework on

Habitat Strategies to Reduce Climate Vulnerabilities in Indian Cities

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List of Abbreviations

AC	Adaptive Capacity
AHP	Analytical Hierarchical Process
AKAH	Aga Khan Agency for Habitat
AKDN	Aga Khan Development Network
AL	Avalanche
BE	Bank Erosion
COP	Climate Change Conference
CY	Cyclone
DF	Debris Fall
DR	Drought
ESZ	Earthquake Susceptible Zones
EQ	Earthquake
FF	Flash floods
FL	Floods
IPCC	Intergovernmental Panel on Climate Change
LSZ	Landslide Susceptible Zones
GIS	Geographic Information System
HVRA	Hazard Vulnerability Risk Assessment
HW	Heatwaves
LS	Landslide
RF	Rockfall
TAR	Third Assessment Report
TS	Tsunami
UF	Underground Flooding
V	Vulnerability
WRI	World Resources Institute

1 Introduction

1.1 Background

The Aga Khan Agency for Habitat (AKAH) is an international organisation established in 2016 by bringing together a network of agencies by setting Aga Khan Development Network (AKDN). AKAH together with AKDN undertake programmes to tackle issues related to degradation of habitats and depletion of resources. In addition, increasing threat posed by natural disasters and climate change are also addressed. AKAH is majorly engaged in the following activities:

- Housing and Habitat
- Humanitarian Response
- Disaster Preparedness
- Environmental Stewardship
- Water and Sanitation

AKAH's goal is that people live in safe, sustainable, and resilient habitats. To achieve this goal, AKAH collaborates with communities to help them prepare for and respond to natural disasters and the effects of climate change.

Increased incidences of emerging natural disasters due to climate change necessitates a closer look at the vulnerabilities and adaptation strategies in our cities. There is a need therefore to use scientific and technological knowledge and tools at a larger scale to build and implement preventive, mitigative, and adaptive strategies for climate proofing. In this regard, AKAH has developed various assessment methodologies and tools for habitat assessment. These tools include:

1) Hazard Vulnerability Risk Assessment
2) Ecosystem Health Assessment Framework

To move forward, AKAH proposes to develop a comprehensive Climate Change Risk Assessment Framework for the urban settlements by integrating the existing Hazard Vulnerability Risk Assessment (HVRA) framework with Ecosystem Health Assessment framework. The proposed framework will focus on addressing risk to urban habitat from different natural and climate change induced hazards. Such an integrated framework can help the city administrators, city planners and architects, to plan and prepare short-term mitigation and long-term adaptation strategies.

1.2 Scope of Work

The scope of work under this study includes:

- Development of a Climate Change Risk Assessment Framework for the urban areas by integration of the existing HVRA framework with Ecosystem Health Assessment Framework.

- Application of the Climate Change Risk Assessment Framework on Ahmedabad City at the level of Zones.

- Based on the risk assessment, preparation of adaptation strategies that could help in undertaking interventions for risk reduction.

1.3 Organization of the Report

Chapter 2 describes the impacts of climate change on Indian cities and need to integrate the existing assessment frameworks.

Chapter 3 describes the climate change risk assessment framework as per the Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC AR6). It explains various components of risk assessment and lays down the steps to be followed for risk assessment.

Chapter 4 presents a way forward for application of the climate change risk assessment framework for the various Zones of the City of Ahmedabad.

The report is supported by four annexures that provide detailed list of indicators along with justification that can be used for climate change risk assessment of an urban area.

2 Need of Integrated Climate Change Risk Assessment Framework

2.1 Impacts of Climate Change on Cities

The United Nations defines climate change as the long-term variations in the thermal and weather patterns which are majorly being driven by the anthropogenic activities in the urban areas. According to Intergovernmental Panel on Climate Change (IPCC), climate change is recognized as a significant human-made global environmental challenge. The IPCC has concluded that the impact of human activities on climate is indeed ongoing and unequivocal. The debate at this point is on the extent and magnitude of climate change and not as to whether it is going to happen[1].

The issue of climate change is even more urgent for cities. This is because urban areas with concentration of population and economic capital (assets and activities) make them important centres for a well-functioning economy and society. At the same time, cities are vulnerable to the effects of climate change - not only from the external global forcing but also from local forcing such as from urban heat islands resulting from impervious surface areas which alter temperature and hydrology. 70 percentage of the global cities are dealing with the effects of climate change, and nearly all are at risk[2]. Extreme weather conditions, such as heat waves and extreme rainfall, threaten a large number of people, infrastructure assets and value chains. In addition, the impacts are manifold that include impacts on human health, loss of biodiversity, water availability and issues like frequent flooding and food insecurity. (refer Figure 1).

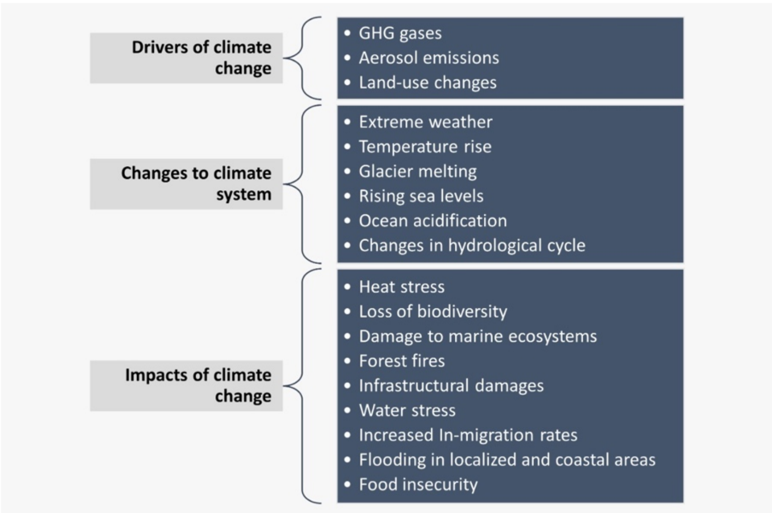

Figure 1 Impacts of Climate Change[3]

[1] Bernstein, Lenny et al. "Climate change 2007: synthesis report. Summary for policymakers." Climate change 2007: synthesis report. Summary for policymakers. IPCC, 2007

[2] https://www.c40knowledgehub.org/s/article/Why-all-cities-need-to-adapt-to-climate-change?language=en_US, accessed on 15-11-2021

[3] https://www.metoffice.gov.uk/weather/climate-change/effects-of-climate-change

The importance of urban climate change adaptations is especially important in rapidly developing countries such as India. India is the second most populated country of the world and has witnessed a tremendous increase in urban population in recent past (refer Fig. 2). It is expected that India will have a large share of the most populous urban centres in the world in the coming 50 years[4]. It is critical that sustainability and climate resilience are addressed in the management of India's growing cities.

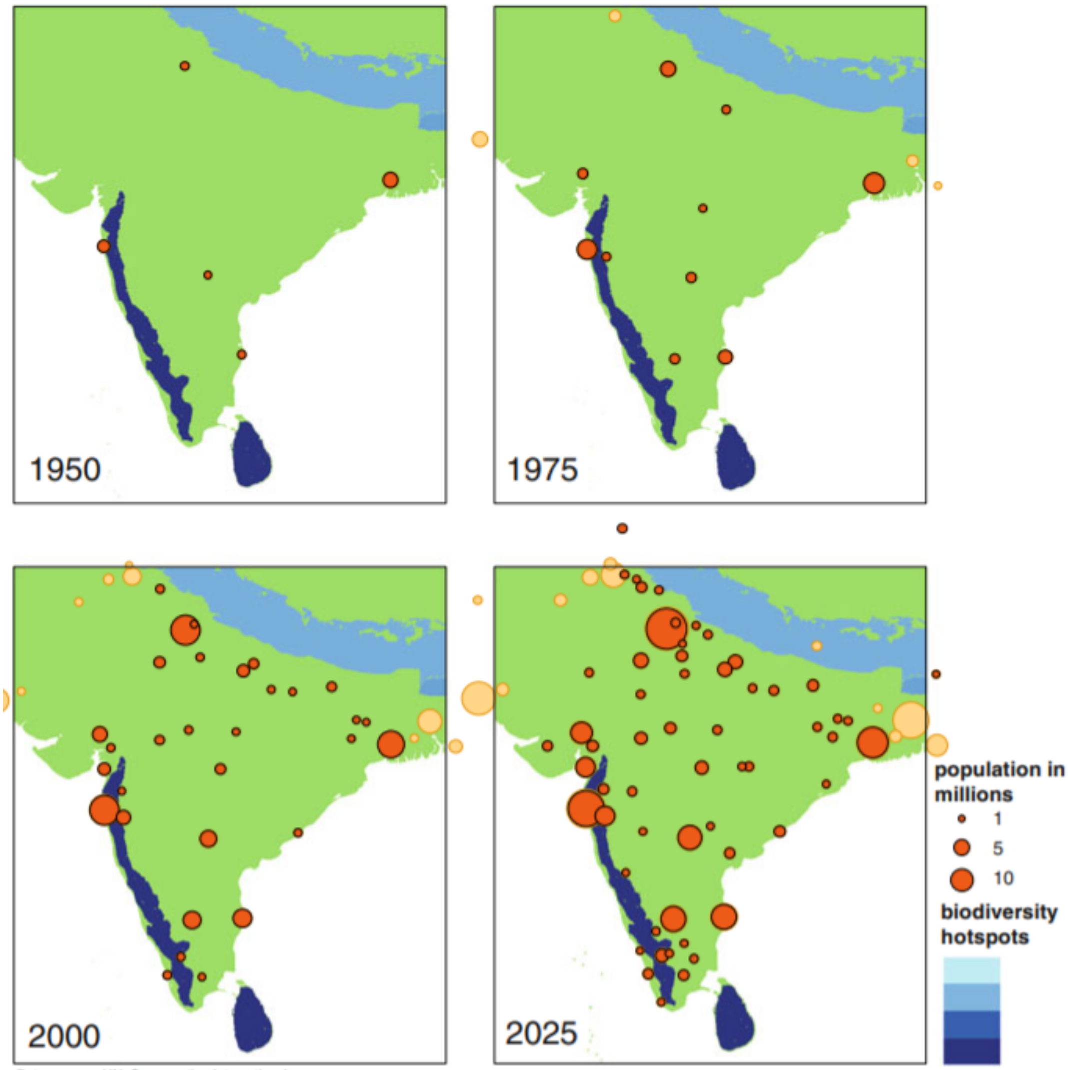

Figure 2 Urban Population Growth in India (red dots)

India has been ranked at the seventh position in the Climate Risk Index (CRI) of 2019 as per the IPCC report[5]. A report on Assessment of Climate Change by the MoES (Ministry of Earth Sciences), 2020 has published the state of climate change in India[6]. According to this report, India has witnessed a thermal increase by 0.7℃ in the past century, decline in monsoon precipitation by 6 percent in 60 years, rise in sea levels by 3.3 mm per year, increase in the number of droughts (2 droughts/ decade) and affected area by droughts (increase by 1.3 percent/ decade), and a rise in the severe cyclone intensity. The

[4] http://base.d-p-h.info/en/fiches/dph/fiche-dph-8632.html, Accessed on 15-11-2021
[5] https://www.bbc.com/news/world-asia-india-58155294, Accessed on 15-11-2021
[6] Assessment of Climate Change Over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India. (2020). Germany: Springer Singapore, Accessed on 15-11-2021

situation has been expected to worsen in the coming future. Table 1 shows a list of some of the major climate change hazards that have occurred in the Indian cities over the last decade (2011- 2021) along with the damages or losses incurred by the cities due to these hazards.

India's prime minister announced that India will achieve a net-zero emissions target by 2070 in the United Nations Climate Change Conference (COP26) 2021, Glasgow. This commitment would mean need for the urgency in prioritizing climate change mitigation strategies[7]. However, these targets seem rather ambitious when looking at the present scenario of GHG emissions in India. Although India is close to its target of achieving 1 billion tonne reductions in GHG emissions by 2030 as per the Paris agreement, a study by the World Resources Institute (WRI) indicated about 50 percent growth in total GHG emissions from the year 1990 to 2018, which are expected to increase further[8].

[7] https://www.climatechangenews.com/2021/11/01/india-ups-climate-targets-aiming-net-zero-2070, Accessed on 15-11-2021
[8] https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors, Accessed on 15-11-2021

Table 1 Occurrence of Major Climate Change Hazards in India (2011-2021)

State/ Region	City/ District	Year	Damages incurred		
			Human	Infrastructure	Others
Heatwaves					
Northern and Southern parts of India	New Delhi, Churu, Jharsuguda, Allahabad, Hyderabad, Khammam, and many more	2015, 2019	Human life loss and illness (2081 deaths- 2015, 495 deaths- 2019)[9,10], 125+ deaths due to Acute Encephalitis Syndrome in Children in 2019.[11]	-	Droughts, Water scarcity
Floods					
Maharashtra	Mahad, Chiplun	2021	251 human deaths[12]	Damages to bridges, communication networks, water supply, electrical supply	Damage to crops
Uttarakhand	Rudraprayag, Uttarkashi, Pithoragarh, Chamoli	2021, 2013	5748 presumed human deaths in 2013[13]	Infrastructural damages	Food scarcity; Water borne diseases[14]
Assam	Nalbari, Darrang, Lakhimpur	2020, 2017,	6.47 lakh people affected in 2020	-	Wildlife losses[15]; Damage to crops in 398.3 sq. km area

[9] https://earthobservatory.nasa.gov/images/145167/heatwave-in-india, Accessed on 15-11-2021
[10] https://moes.gov.in/sites/default/files/LS-English-270-06082021.pdf, Accessed on 15-11-2021
[11] https://www.news18.com/news/india/litchi-toxins-or-heat-wave-doctors-explain-whats-causing-the-deadly-encephalitis-epidemic-in-bihar-2191335.html, Accessed on 15-11-2021
[12] https://www.newindianexpress.com/nation/2021/jul/27/maharashtra-floods-claim-251-lives-13-districts-across-state-affected-says-nawab-malik-2336073.html, Accessed on 15-11-2021
[13] https://www.iol.co.za/news/world/5-748-feared-dead-after-india-floods-1546813#.UePfZdIVNlc, Accessed on 15-11-2021
[14] https://timesofindia.indiatimes.com/india/Uttarakhand-floods-Epidemic-looms-as-people-complain-of-fever-diarrhoea/articleshow/20770540.cms, Accessed on 15-11-2021
[15] https://www.thehindu.com/news/national/other-states/assam-floods-impact-over-647-lakh-people/article36239249.ece, Accessed on 15-11-2021

State/ Region	City/ District	Year	Damages incurred		
			Human	Infrastructure	Others
		2016			(approx.)[11] in 2020
Kerala	-	2019, 2018	483 human deaths[16] in 2018. Around 36,000 people displaced[17] in 2018	10,000 km roads damaged, damage to houses[18] in 2018	Landslides
Tamil Nadu	Chennai	2015	Life losses	Infrastructural damages	Financial losses of over 50,00 crores[19]
Kashmir	Rajouri, Srinagar, Bandipore	2014	200+ deaths[20]	Bridges damaged, roads submerged, damage to communication networks	Massive deforestation
Cyclones					
Cyclone 'Tauktae' in Western coast – Goa, Maharashtra, Kerala, Karnataka, Gujarat, and many more	Goa, Mumbai, Bhavnagar, Junagadh, Ernakulam, and more.	2021	26+ deaths, 50 people missing[21]	Damage to 16,000+ houses, 70,000 electric poles, 196 roads, water supply systems[17]	40,000 trees uprooted[17]
Cyclone 'Amphan' in Odisha, West Bengal		2020, 2017	About 90 deaths; 4.4 million people affected in Amphan cyclone 2020[18]	Damage of 3.2 billion INR to power in 2020[22]	Loss of 4000 livestock in 2020[18]

[16] https://indianexpress.com/article/india/483-dead-in-kerala-floods-and-landslides-losses-more-than-annual-plan-outlay-pinarayi-vijayan-5332306/ , Accessed on 15-11-2021
[17] http://www.walkthroughindia.com/walkthroughs/15-worst-ever-floods-in-india-over-last-decade/ , Accessed on 15-11-2021
[18] https://www.aljazeera.com/news/2018/8/16/india-death-toll-in-devastating-kerala-floods-rises-to-77, Accessed on 15-11-2021
[19] https://www.deccanchronicle.com/151206/nation-current-affairs/article/chennai-floods-caused-loss-50-thousand-crore, Accessed on 15-11-2021
[20] https://archive.ph/20140909042958/http://www.hindustantimes.com/news-feed/floodfuryhitsjk/kashmir-cut-off-phones-down-roads-submerged/article1-1261607.aspx, Accessed on 15-11-2021
[21] Situation report #3, India western-region cyclone response, UNICEF, May 19, 2021, Accessed on 15-11-2021
[22] Final report, India: Cyclone Amphan, International Federation of Red Cross and Red Crescent Societies, February 24, 2021, Accessed on 15-11-2021

State/ Region	City/ District	Year	Damages incurred		
			Human	Infrastructure	Others
Droughts					
Uttar Pradesh, Madhya Pradesh		2015-2018	Around 330 million people affected[23]		Groundwater depletion. Wat stress, 90% people affected I food shortage, agricultur losses
Maharashtra	Solapur, Ahmednagar, Latur, Pune, Satara, Nashik, and more	2013	Suicides among farmers	-	Water scarcity, hike in food prices, crop losses, livestock losses, migration to urban areas

[23] When coping crumbles, Drought in India 2015- 2016, RedR, UNICEF India, December 2016, Accessed on 15-11-2021

2.2 Assessment Frameworks developed by AKAH

In this chapter, assessment methodologies/tools for hazard risk assessment and framework for ecosystem health assessment as developed by AKAH are described.

2.2.1 Hazard Vulnerability Risk Assessment (HVRA) Methodology

HVRA is a tool developed by AKAH for identifying hazards and their risks that can affect the community. It is a technique for assessing the potential risk to people, property, infrastructure, industry, and the natural resources, as well as areas that are particularly susceptible to hazards. The HVRA tool identifies potential hazards and examines the consequent damage of each hazard on the surrounding environment. Furthermore, the tool is capable of identifying the exposed population and the degree of exposure of the community.

The HVRA tool is regarded an essential part of every emergency management system. After application of the tool mitigation measures can be suggested. The results could be used for spreading awareness about the risks involved, prepare for the hazard, and most importantly, build the local community's capacity to respond to disasters. The HVRA methodology is designed to quantify and document the probability and overall severity of various types of hazards. HVRA is thus, the first point of entry to systematically identify risk and provides a basis for informed planning and interventions tailored to each settlement or area for community resilience building through effective disaster risk reduction engagement.

HVRA process consists of four stages. (refer Figure 3).

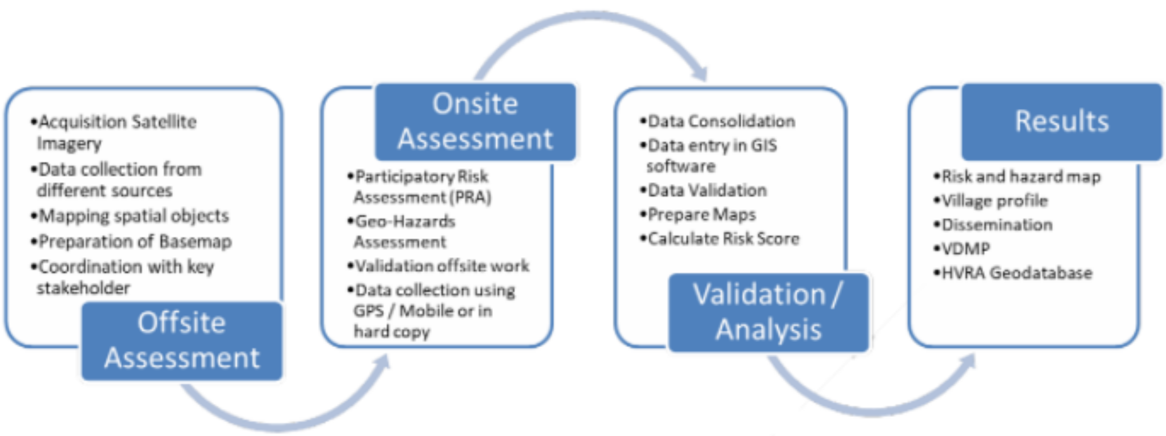

Figure 3 AKAH's HVRA Framework

2.2.2 Ecosystem Health Assessment Framework

AKAH has developed a methodology adapted from the Pressure - State - Response framework supported by a toolkit for Urban Ecosystem Management. This framework can be used for conducting ecosystem health assessments of urban areas to identify hot spots and prepare a holistic plan with Nature Based Solutions (NBS). The toolkit presents a compendium of NBS with recommendations. The efficacy of the ecosystem health assessment framework was tested in three urbanized and urbanizing areas of Mumbai city in Maharashtra, India.

2.3 Need for Integrated Climate Change Risk Assessment Framework

Given the impacts of climate change on Indian cities in section 2.1, it is of utmost importance to develop an integrated framework supported by tools that can be used by urban practitioners/urban local bodies for the climate change risk assessment of an urban area and to plan for mitigation and adaptation strategies for risk reduction.

The methodologies and frameworks developed by AKAH and described in section 2.2 form a basis for integration. The HVRA tool requires expansion to include various climatic and non-climatic hazards (for example, heat waves and droughts). Further, the HVRA is majorly applicable to rural context. Urban areas are much more complex and larger in comparison to rural setting.

The HVRA component was therefore enhanced (refer Annexure I for details). Similarly, the framework for ecosystem health assessment was expanded to include climate variables as per the latest IPCC guidelines. The integration thus resulted into an assessment framework that could address hazard, ecosystems and climate impacts to come up with the mitigation and adaptation plans for urban areas.

3 The Integrated Climate Change Risk Assessment Framework

In general, risk is defined by any hazard and exposure of people to the event, including its impact. In climate change-related studies, the usage of term 'Risk' is widely being adopted. However, different literature argues with various definitions to explain the consequences of potential disasters under climate change[24]. At present, there is no consensus about the precise meaning and interpretation for the term's vulnerability and risk in the climate science literature. Much of the understanding has evolved from IPCC Third Assessment Report (IPCC TAR) and has progressed to the Fifth Assessment Report (IPCC AR5). This understanding is however still open for interpretation[25] (refer Figure 4).

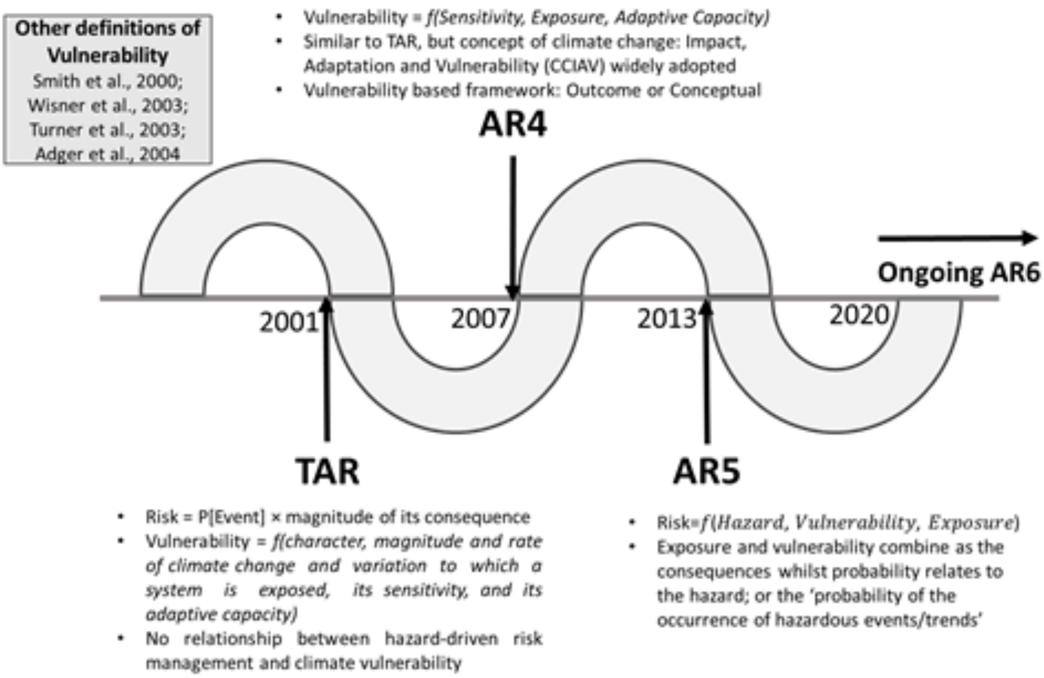

Figure 4 Evolution of Concepts of Climate Risk and Vulnerability to Present According to IPCC Frameworks[26].

For this report, the risk framework described in IPCC AR5 is adopted to quantify risk of an urban area. According to IPCC AR5, vulnerability is a property of a system itself. The interaction of hazard with the

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[24] Scholz, R. W., Blumer, Y. B., & Brand, F. S. (2012). Risk, vulnerability, robustness, and resilience from a decision-theoretic perspective. Journal of Risk Research, 15(3), 313-330; Räsänen, A., Juhola, S., Nygren, A., Käkönen, M., Kallio, M., Monge, A. M., & Kanninen, M. (2016). Climate change, multiple stressors, and human vulnerability: a systematic review. Regional Environmental Change, 16(8), 2291-2302.

[25] Sharma, J., and Ravindranath, N. H. (2019). Applying IPCC 2014 framework for hazard-specific vulnerability assessment under climate change. Environmental Research Communications, 1(5).p1-7.

[26] Gusain, A. (2021). Perception Of Risk to Hydro-Climatic Extremes Under Changing Climate: An Implication on Flood Risk for Data-Scarce Catchment (Unpublished doctoral dissertation). Indian Institute of Technology Bombay, Mumbai, MH (India).

system's vulnerability and exposure produces an outcome/disaster (IPCC AR5[27]). The risk framework developed on this basis is described in detail in the subsequent sections.

3.1 Components of Climate Change Risk Assessment

As per IPCC AR5, the risk is defined as a function of hazard (H), vulnerability (V), and exposure (E) (Figure 5) as represented in the equation (Box 1). These components are aggregated to estimate the overall risk of a system. Vulnerability and exposure assessment is contextual, and the selection of indicators depends on the goals to be achieved under the climate risk framework[28] .

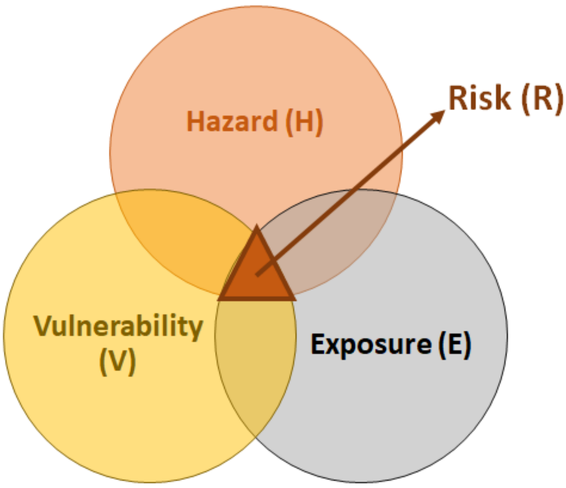

Figure 5 Components of Climate Risk as per IPCC AR5

Box 1 Equation for Risk

$$Risk = f\ (Hazard, Vulnerability, Exposure)$$

The definition of each of the components of risk is given in the subsequent sections.

3.1.1 Hazard

As per the IPCC AR5, hazard (H) is defined as "the potential occurrence of a natural or human-induced physical event or trend, or physical impact, that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental

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[27] Oppenheimer, M., M. Campos, R. Warren, J. Birkmann, G. Luber, B. O'Neill, and K. Takahashi, 2014: Emergent risks and key vulnerabilities. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1039-1099.

[28] Gusain, A. (2021). Perception Of Risk to Hydro-Climatic Extremes Under Changing Climate: An Implication on Flood Risk for Data-Scarce Catchment (Unpublished doctoral dissertation). Indian Institute of Technology Bombay, Mumbai, MH (India).

resources". Natural hazards can further be categorized according to geological, hydro-meteorological, and biological, based on the processes occurring in the natural ecosystem.

3.1.2 Exposure

The second component of the risk assessment framework, as per IPCC AR5, is exposure (E). It is defined as "the presence of people, livelihoods, species or ecosystems, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected."

3.1.3 Vulnerability

Vulnerability (V) of a system is the inherent property that states the propensity or predisposition to be adversely affected (IPCC AR5). Vulnerability assessment can act as an authoritative guide in enhancing well-being by reducing risk. Improved support of vulnerability evaluation, including knowledge of local vulnerabilities, can assist better management choices and adaptation measures for a system. Vulnerability is considered as a function of sensitivity (S) and adaptive capacity (AC) as mentioned in Box 2.

Box 2 Equation for Vulnerability

$$V = f\,(S, AC)$$

Sensitivity, as per IPCC AR5, is defined as "the degree to which a system will be affected by, or responsive to climate stimuli, either positively or negatively."

Adaptive capacity describes the ability of the system to adapt to the changes in the system caused by external factors such as climate change or human interventions. IPCC AR5 defines it as "the ability of people, institutions, organizations, and systems, using available skills, values, beliefs, resources, and opportunities, to address, manage, and overcome adverse conditions in the short (mitigation) to medium and long term (adaptation)".

3.1.4 Risk

Risk assessment is a cumbersome task with numerous uncertainties incorporated with the datasets used, selection and categorization of indicators, and aggregation methods to quantify risk. As per IPCC AR5, the risk is considered as "the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values".

Risk is often represented as the probability of hazard events or trends multiplied by the impacts of these events or trends. Here, the IPCC AR5 framework is adopted where risk results from the interaction of vulnerability, exposure, and hazard.

The detailed information about the calculation and aggregation of indicators into different components of risk assessment is given in section 3.2.

3.2 Climate Change Risk Assessment Process

The steps involved in estimation of risk of an urban area to different natural hazards is described in Figure 6. Detailed description of each step is provided in the following sub-sections.

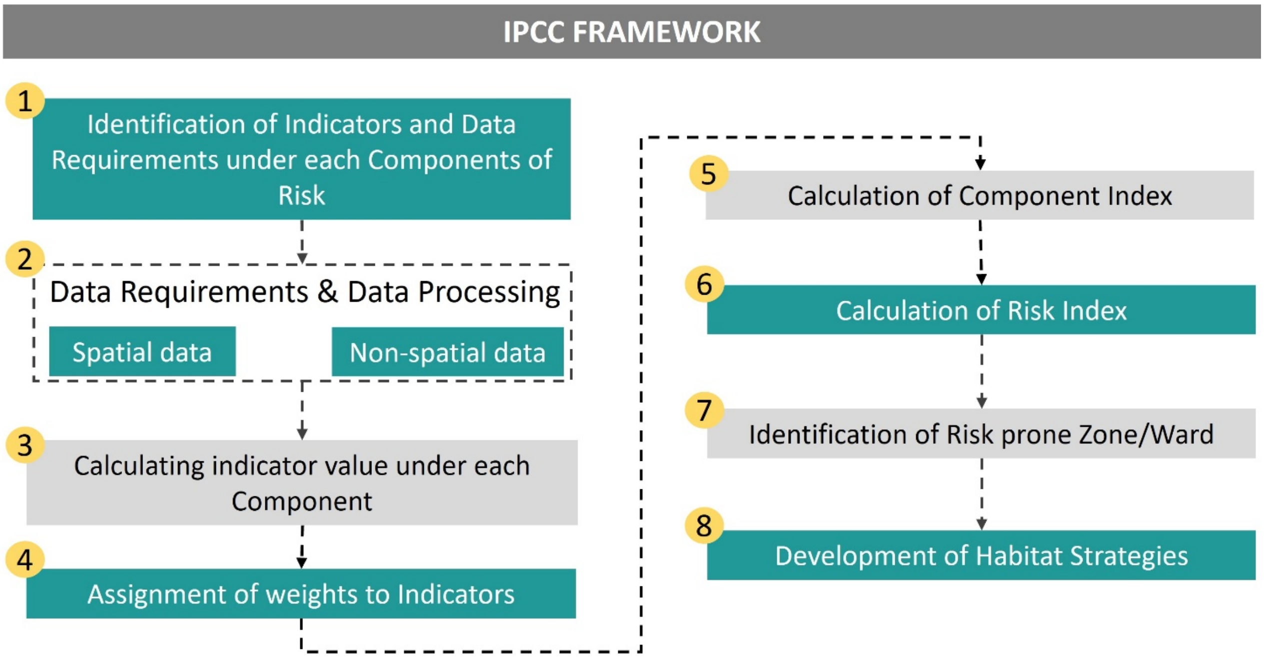


Figure 6 Flowchart showing the Climate Change Risk Assessment Process

3.2.1 Identification of Indicators and Data Requirements

To evaluate the risk of an urban area to climate change; the factors influencing the risk components - exposure, sensitivity, and adaptive capacity of an urban area need to be assessed. Thematic indicators (themes - ecosystem, infrastructure, social) need to be identified to assess/measure each of the risk components (exposure, sensitivity, and adaptive capacity) of an urban area (refer Figure 7). The ecosystem health assessment framework earlier developed by AKAH was used here to form the basis.

As a next step, indicators need to be identified based on their importance in making the urban area more vulnerable or more exposed to natural hazards. This task was carried out through a thorough literature survey. The selected indicators included the attributes that strengthen the ability of an urban area to cope up or adapt to the consequences of hazard. However, all the indicators selected may not be relevant for all hazards. Therefore, the final selection of indicators will need to be made hazard specific.

3.2.1.1 Identification of Indicators for Hazard Component

The proposed risk assessment framework considers geological and hydro-meteorological hazards for estimating risk indices (Figure 8). The magnitude of each hazard is represented in terms of hazard index derived using historical incidences, frequency analysis, GIS based information layers, or hazard zones maps. Each hazard index is quantified using different indicator(s), as exemplified in Table 2. A detailed list of all the hazards and their indicators is provided in Annexure II.

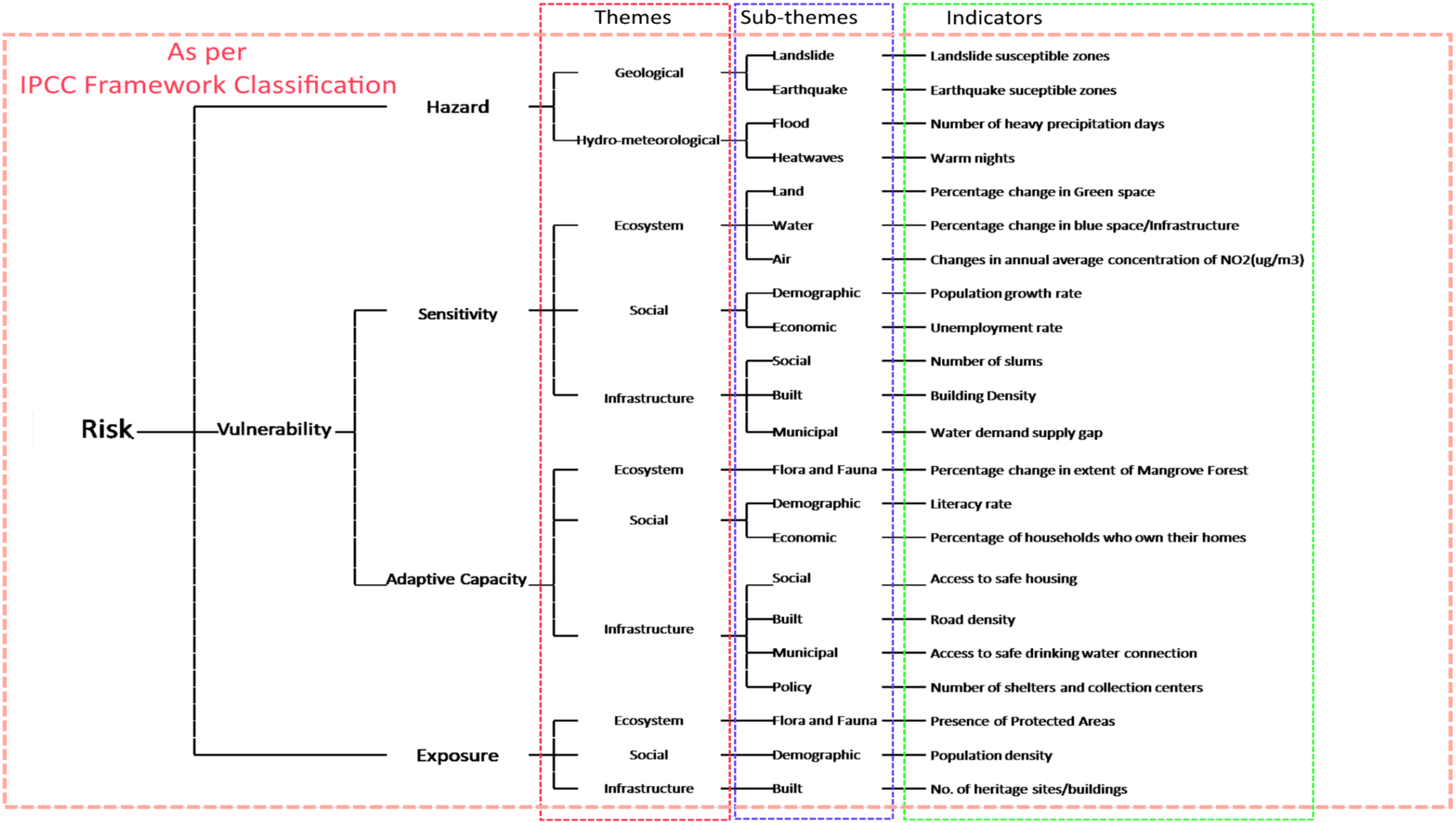


Figure 7 Indicative list of Themes, Sub-themes and Indicators for Climate Change Risk Assessment of an Urban Area

Hydro-meteorological

- Flood
- Underground Flooding
- Cyclone
- Flash Flood
- Heatwaves
- Droughts

Geological

- Rockfall
- Landslide
- Bank Erosion
- Earthquake
- Tsunami
- Debris Flow
- Avalanche

Figure 8 List of Hazards Considered in the Framework

Table 2 Illustrative Indicators to Estimate Hazard Indices

Type of Indicator	Example of Indicators	Related Hazard(s)
Frequency-based	Frequency of cyclone events	Cyclone
	Warm Spell Duration Indicator	Heatwaves, Droughts
	Frequency of HW events	Heatwaves
Zonation based	Landslide susceptible zones	Landslides, Debris Flow
	Earthquake susceptible zones	Earthquake, Tsunamis
GIS-based	Root density %	Bank Erosion
	Bank angle (degrees)	Bank Erosion
Climatic data-based	Extremely wet day precipitation	Floods
	Maximum 5-day precipitation	Floods
	Maximum day time temperature	Heatwaves, Droughts
	Standardized Precipitation Index	Droughts, Floods

3.2.1.2 Identification of Indicators for Exposure Component

As per IPCC AR5, exposure is the presence of people, livelihoods, species or ecosystems, environmental services and resources, infrastructure, or economic, social, or cultural assets in an urban area that could be adversely affected by the impacts of climate change. Several direct and proxy indicators can be used to quantify exposure of an urban area. The indicators can be categorized under different themes and sub-themes. Refer to Table 3 for examples of a few exposure indicators. A detailed description of exposure indicators is given in Annexure III.

Table 3 Illustrative Indicators to Evaluate Exposure of an Urban Area

Theme	Sub-themes	Example of Indicators	Related Hazards
Ecosystem	Flora and Fauna	Presence of Protected Areas	All hazards
Social	Demographic	Population density	All hazards
Infrastructure	Built	No. of heritage sites/buildings	All hazards

3.2.1.3 Identification of Indicators for Vulnerability

Vulnerability of an urban area is considered as a function of sensitivity and adaptive capacity of an urban area. The indicators selected to compute sensitivity and adaptive capacity of an urban area can be classified under different themes and sub-themes like in the case of exposure indicators.

The sensitivity of a system tends to pose positive or negative impacts to different sections of the socio-ecological system. In this report, the sensitivity indicators that tend to increase the system's vulnerability are considered, and representative examples are mentioned in Table 4.

Table 5 describes examples of indicators that increases the adaptive capacity of an urban area to address, manage, and overcome adverse conditions due to climate change. A detailed list of vulnerability indicators is given in Annexure IV.

Table 4 Illustrative Indicators to Evaluate Sensitivity of an Urban Area

Theme	Sub-theme	Example of Indicators	Related Hazards
Ecosystem	Land	Percentage change in Green space	Floods, Heatwaves, Droughts
	Water	Percentage change in blue space/Infrastructure	Floods, Heatwaves, Droughts
	Air	Changes in the annual average concentration of NO_2 ($\mu g/m^3$)	Heatwaves
Social	Demographic	Population growth rate	All hazards
	Economic	Households below poverty line (BPL)	All hazards
Infrastructure	Social	Number of slums	All hazards
	Built	Building Density	All hazards
	Municipal	Water demand-supply gap	Floods, Cyclone, Tsunami, Droughts

Table 5 Illustrative Indicators to Evaluate Adaptive Capacity of an Urban Area

Theme	Sub-theme	Example of Indicators	Related Hazards
Ecosystem	Flora and Fauna	Percentage change in the extent of Mangrove Forest	Floods, Cyclone, Tsunami

Theme	Sub-theme	Example of Indicators	Related Hazards
Social	Demographic	Literacy rate	All hazards
	Economic	Percentage of households who own their homes	All hazards
Infrastructure	Social	Access to safe housing	All hazards
	Built	Access to transport infrastructure (public transport)	All hazards
	Municipal	Efficiency of waste collection	Floods, Cyclones, Earthquakes, Tsunami, Heatwaves, Drought
Institutional Capacity	Policy	Number of shelters and collection centres	All hazards
		Early warning system/contingency plans, Mapping of risk areas	All hazards

3.2.2 Data Requirements and Data Processing

The data required for the computation of each indicator needs to be identified. The data should be sourced from recognized secondary resources such as from the government and other departments as well as portals. The datasets collected should be checked for consistency before using for further analysis. If significant data gaps exist in the datasets some alternate data sources should be considered or the indicators can be altered accordingly. However, if alternate/proxy datasets are used, these would be checked for consistency with the available observed datasets (e.g., Land Surface Temperature versus Normalized Differential Vegetation Index). In building the integrated assessment framework, due consideration is to be made to the data availability, its quality or authenticity. The data collected then should be cleaned and processed to arrive at the indicator. During this process, multiple quality checks and validations/calibrations should be performed.

3.2.3 Calculation of Indicator Value

Post-data processing, indicators value should be compiled using suitable methods. For some indicators, advanced excel functions could be used while GIS-based spatial analysis will be more effective for some indicators (refer Table 6). All indicator values should be normalized say between 0 to 1, to assess them on a common scale for inter-comparison.

Table 6 Illustrative Example – Method for Calculating Indicator Value

Theme	Sub-themes	Example of Indicators	Method	Description
Exposure Component				
Social	Demographic	Population density	**Ratio (excel)**	Total number of people living in a particular area. Pop. density = Total population divided by the area accommodating the population (persons / km^2)

Theme	Sub-themes	Example of Indicators	Method	Description
Infrastructure	Built	No. of heritage sites/buildings	**Absolute**	Historic site or heritage site is an official location where pieces of political, military, cultural, or social history have been preserved due to their cultural heritage value. Total number of heritage buildings/ sites in an urban area.
Sensitivity Component				
Ecosystem	Flora and Fauna	Percentage change in green space	**GIS-based spatial analysis**	Green space (land that is partly or completely covered with grass, trees, shrubs, or other vegetation); includes parks, community gardens, and cemeteries; percentage change in green areas can be calculated using LULC map or NDVI.
Ecosystem	Flora and Fauna	Low-lying areas in flood prone zone	**GIS-based spatial analysis**	Low lying areas estimated using DEM

3.2.4 Assignment of Weights to Indicators

Analytical Hierarchy Process (AHP) can be used to assign weights to the indicators (refer Box 3). A pair-wise comparison of the indicators under each component (exposure and vulnerability) should be carried out to understand significance of the indicator in expressing the City's vulnerability and exposure status. An online meeting can be conducted inviting experts from climate change domain and urban local body to compare the indicators and assign weights.

Box 3 Analytical Hierarchy Process

AHP is a method for organizing and analyzing complex decisions, using math and psychology (perception of the stakeholders). AHP is a technique for decision making in complex environments in which many variables or criteria are considered in the prioritization and selection of alternatives.

AHP was developed in 1970s and is still considered as a robust technique involving multi-criteria decision making in economics, politics, engineering, and climate change studies (including mitigation and adaptation). AHP's ability to hierarchically structure complexity into homogeneous clusters of factors renders it as an appropriate decision support tool allowing for the interconnectedness of climate change systems, the constraints in time, knowledge, and computational abilities.

Stakeholders compare the importance of criteria, two at a time, through pair-wise comparisons. AHP converts these evaluations into numbers, which can be compared to all the possible criteria. The AHP method has inbuilt checks and balances. These checks and balances ensure that logically consistent solutions are obtained when stakeholders compare the relative importance of the criteria in the process of assigning weights. A major advantage of AHP is that it is participative in nature and considers perceptions of different stakeholders in a project.

3.2.5 Calculation of Component Index

The next step is the calculation of indices for hazard, exposure, and vulnerability after the computation of indicators and their corresponding weights. Each of the component will be a function of their indicators and weights.

Box 4 Equation for Calculation of Component Index

$$X = f\ (C_i, w_i)$$

Where X can be sensitivity, adaptive capacity, hazard, or exposure
C_i is the criteria for indicator '*i*'
w_i is the weight of indicator '*i*'

3.2.6 Calculation of Risk Index

The scores of indices from each component will need to be aggregated using weights to obtain a unified risk index (See Box 1). The risk assessment can also be performed at a sub-city scale (Zone/Ward) for selected hazards. The final output may also be represented in the form of spatial risk maps on GIS for taking zone specific actions.

3.2.7 Identification of Risk-prone Zone/Ward

Based on the risk scores calculated at sub-city scale, the highly risk-prone areas can be demarcated like shown in Figure 9. Such identification can highlight areas that are susceptible to maximum damage under the influence of changing climate by addressing spatial variations in risk to natural hazards.

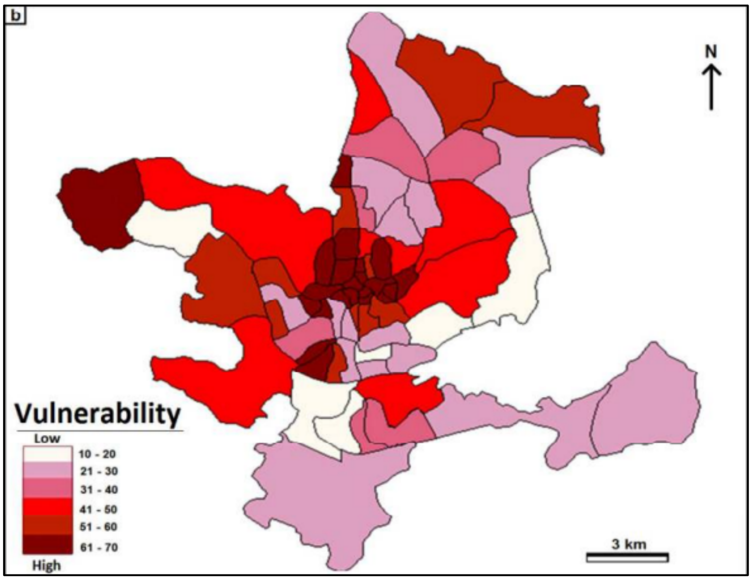


Figure 9 Illustrative map showing Vulnerability Map of City

3.2.8 Development of Habitat/Adaptation Strategies

The mitigation and adaptation strategies should be proposed as per the risk category or stressor on the basis of the climate change risk assessment. A compendium of such strategies will help in preparation of an outline risk management plan.

4 Way Forward

The Climate Change Risk Assessment Framework developed in this report will applied to Ahmedabad City.

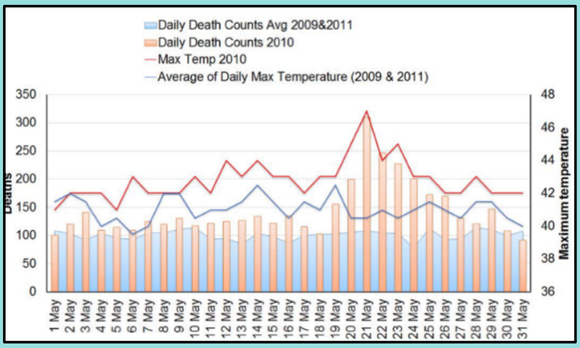
Climate change have caused adverse effects on Gujarat, both in terms of increasing frequency of extreme events and gradual increase in temperature. The result of these changes poses strong and different challenges for big urban centres such as Ahmedabad, Surat, and Rajkot. Climatic extremes are accompanied with several cascading effects causing failure of different infrastructure of the city one after the other. Poor coping mechanism worsen the situation casing social unrest and loss in terms of mortality at its worst.

Ahmedabad is one such urban centre in Gujarat that have experienced scorching high temperatures with increasing number of warmer days and nights (refer Box 5). In May 2016, the temperature rose as high as 50℃. Further, the narrowing gap between the maximum and minimum temperature is an alarming situation for the city. As it results usage of cooling devices like air conditioners which imposes a negative feedback mechanism on the climate causing further warming the City's temperature[30].

It is important understand historical and current trends to devise mitigation and adaptation plans for planning development in Ahmedabad city. The city experiences significant reduction in green cover which is expected to get reduced to 3 percentage by 2030[30]. As a result, the city has become more prone to further warming and extremes such as extreme precipitation, heatwaves, and droughts in near future. It is therefore, crucial to account for changes in future period for climate proofing the development plans and devising long-term adaptation strategies. This makes Ahmedabad City, a suitable pilot study for the application of the proposed integrated framework.

Box 5 Ahmedabad during Heatwave Episode of 2010

Ahmedabad Heatwaves 2010



In May 2010 (May 20-27th), Ahmedabad witnessed heatwaves with record-breaking temperatures that exacted a toll of 4,462 lives. This was excess deaths 800 in one week and 1,344 deaths more than the toll in May 2009. In 2010 itself, the city experienced 19 days of heatwaves, the highest in the state[29]

[29] https://timesofindia.indiatimes.com/city/ahmedabad/state-drowning-in-bigger-heatwaves-study/articleshow/52393420.cms ; https://thewire.in/environment/gujarat-cities-urban-planning-climate-change ; https://www.nrdc.org/sites/default/files/ahmedabad-heat-action-plan-2016.pdf

Annexure I : Comparison of Existing HVRA Tool with Proposed Integrated Climate Change Framework

Attribute	HVRA	Proposed Climate Change Risk Assessment Framework	Justification
Criteria for risk index	Based on 5 indicators: Exposure of area to hazard, Exposure of population to hazard, Susceptibility, Coping Capacity, Adaptive Capacity	Based on IPCC AR5 (2013) climate risk framework combined with Urban Ecosystem Health Assessment, classified into 3 categories: Hazard, Exposure, Vulnerability	HVRA lacks the climate change risk assessment component and ecosystem health assessment
Risk formula	R = E × V (classification of activity and living zone)	R = f (H, E, V) = H × E × V	As per IPCC AR5 climate risk assessment framework
Vulnerability formula	V = (S+(1-C) +(1-A))/3	V = f (S, AC) = S/AC or S×(1-AC) or $(S\times(1-AC))^{1/2}$	Additive or subtractive function clusters or shifts the overall score to the direction of higher component. Therefore, three possible multiplicative functions are selected.
Nature of indicators	Percentage scale normalized from 0 to 1	Variable scales normalized from 0 to 1	Different indicators have different units and nature. Therefore, converting every indicator into percentage in not feasible.
Aggregation of indicators	Averaging function	TOPSIS or similar approach	

Estimation of weights	Equal weights to all indicators within a component	Using AHP (experts' judgement)	It is important to understand the relative importance of indicators with respect to experts' opinion (scientific community, policymakers, academicians, end-users)
Selection of indicators	At village level (rural scale)	At sub-city (zones/wards) level (urban scale)	Framework is devised as per Indian cities
Estimation of hazard	Hazards are categorized as rapid or slow based on speed of onset and weighted as rapid events higher based on sudden impacts on the exposed system (0.8). Intensity of hazard is categorized into 3: High, medium, and low based on the criteria in literature. The return period is quantified by establishing relationship between frequency of past events and their magnitudes. Area fraction of affected or prone area is multiplied with the hazard coefficient. Hazard= area fraction of affected polygon * hazard significance (by considering RP and intensity) * hazard type score (based on rapid/slow)	Hazard is quantified based on frequency of past events, indicators derived from climatological variable time series, zonation based on GIS maps. Projection of three hydro-meteorological hazards (Extreme precipitation Index: proxy for floods; Heat Index: proxy for heatwaves; Dry Index: proxy for droughts)	No area fraction of affected area concept (data collection not feasible for large cities, towns, or districts) Climate change projections are needed to devise near-term mitigation, and medium and far-term adaptation strategies.
Normalization of final scores	RiskIndex (Village)=0.8× (Σ ($\boldsymbol{N_i}$=**0**RiskIndex (LivingZone$_i$) × Calibration Index$_i$)/N) +0.2×RiskIndex (ActivityZone) *Calibration Index$_i$ = Population (LivingZonei) / (Σ* (N_i=0 *Population* (*LivingZonei*)/N)	Min-max normalization with respect to all sub-units	Area of city administrative boundary is much more complex and larger in comparison to rural setting. Thus, it is difficult to classify city into living and activity zones as done in HVRA. The activity zone

	Where - *Calibration Index* is a derived index to calibrate initial living zone risk index based on population factor - *N* is total number of living zones of an activity zone - 0.8 & 0.2 indicates 80% & 20% weight given to risk of living & activity zone respectively		within a sub-city unit may have hundreds of living zones which may complicate the assessment framework and making it a tedious task.

Annexure II : Hazard Indicators

Type of Hazard	Hazard	Notation	Name of indicator	Indicator notation	Method	Description of indicator (with units)
Geological	Rockfall	RF	Rockfall susceptible zones	RSZ	Zonation	Hazard prone areas based on past events
	Landslide	LS	Landslide susceptible zones	LSZ	Zonation	Hazard prone areas based on past events
	Earthquake	EQ	Earthquake susceptible zones	ESZ	Zonation	Hazard prone areas based on past events
	Tsunami	TS	Distance to coastline	TDC	Zonation	Hazard prone areas based on past events
	Bank Erosion	BE	Maximum elevation of the active floodplain	R_(BH/BFH)	Ratio	Ratio of bank height to bank-full height
			Root depth/bank height	R_(RD/BH)	Ratio	Ratio of average root depth to bank height
			Root density %	R_rho	Percentage	Proportion of the streambank surface covered (and protected) by plant roots (e.g., a bank whose slope is half covered with roots = 50 percent); higher density of roots in a streambank the greater the stability and strength of that bank
			Bank angle (degrees)	R_Theta	Angle	Angle of the "lower bank" – the bank from the waterline at base flow to the top of the bank, as opposed to benches that are higher on the floodplain. Bank angles great than 90 percent occur on undercut banks.
			Surface protection %	R_surfP	Percentage	Percent of bank covered by vegetation, woody debris, etc.

Type of Hazard	Hazard	Notation	Name of indicator	Indicator notation	Method	Description of indicator (with units)
	Debris Flow	DF	Extremely high rainfall events	R99.9p	Frequency	Extremely high rainfall events function as a triggering event for occurrence of debris flow
	Avalanche	AL	Avalanche susceptible zones	ASZ	Zonation	Hazard prone areas based on past events
Hydro-meteorological	Flood	FL	Number of heavy precipitation days	R64.5	Frequency	Annual count of days when PRCP>=64.5mm
			Very wet day precipitation	R95p	Sum total	Annual total PRCP when RR>95th percentile
			Extremely wet day precipitation	R99p	Sum total	Annual total PRCP when RR>99th percentile
			Consecutive Wet Days	CWD	Frequency	Maximum number of consecutive days with RR>=1mm
			Max 1-day precipitation	Rx1	Maximum	Monthly maximum 1-day precipitation
			Max 5-day precipitation	Rx5	Maximum	Monthly maximum consecutive 5-day precipitation
	Flash Flood	FF	Frequency of flash flood events	FFF	Frequency	Calculated based on historical records of flash flood events
	Cyclone	CY	Frequency of cyclone events	CYF	Frequency	Calculated based on historical records of cyclonic events
	Heatwaves	**HW***	Warm nights	WTN	Frequency	Percentage of days when minimum temperature is greater than 90th percentile
			Warm Spell Duration Indicator	WSDI	Frequency	Annual count of days with at least 6 consecutive days when maximum temperature is greater than 90th percentile
			Frequency of HW events	HWF	Frequency	The number of heat wave events, which is greater than 45℃, that occur every year
			warm days	WTD	Frequency	Number of days greater than 90th percentile of max temp

Type of Hazard	Hazard	Notation	Name of indicator	Indicator notation	Method	Description of indicator (with units)
			max day time temperature	TXx	calculating average of maximum annual maximum temperature	Maximum day time max temperature
			max night time temperature	TNx	calculating average of maximum annual minimum temperature	Maximum night-time min temperature
	Droughts	**DR***	Standardized Precipitation Index	SPI-3,6,9,12	-1.5 < SPI <= -1.0 Moderately dry -2.0 < SPI <= -1.5 Very dry MIN <= SPI <= -2.0 Extremely dry	Most commonly used indicator worldwide for detecting and characterizing meteorological droughts
			Standardized Precipitation Evapotranspiration Index	SPEI-3,6,9,12	5 classes, namely: 1- non-Drought (in this class the value of SPEI greater than -0.5), 2- Mild (the value of SPEI is between -0.5 and -1), 3- Moderate (SPEI is between -1.5 and -1), 4- Severe (SPEI is between -2 and -1.5), and 5- Extreme (Less than -2)	Take into account both precipitation and potential evapotranspiration (PET) in determining drought.
			Keetch-Byram Drought Index	KBDI	Index value (hundredths of	Describe moisture deficiency in upper soil layer

Type of Hazard	Hazard	Notation	Name of indicator	Indicator notation	Method	Description of indicator (with units)
					inches) Index value (millimetres) Implications 0–200 0–50 Soil is moist. 0 represents a completely saturated soil.[6] 200–400 50–100 Leaf litter begins to dry. 400–600 100–150 Lower litter actively contributes to fire intensity and will burn actively. 600–800 150–200 Associated with severe drought and extreme fire behaviour.	

* Hazard not included in the previous HVRA framework.

Annexure III : Exposure Indicators

Theme	Sub-theme	Name of indicator	Method	Description of indicator (With units)	Justification	Hazard
Ecosystem	Flora and Fauna	Presence of Protected Areas	Yes/No	Protected areas or conservation areas are locations which receive protection because of their recognized natural, ecological, or cultural values	Protected areas in a city/area acts as a lung space and also aid in carbon sequestration.	RF, FL, LS, UF, CY, EQ, TS, FF, DF, AL, DR
		Occurrence of threatened species	Yes/No	Threatened species are any species which are vulnerable to endangerment in the near future	Population of threatened species is affected by the changes in climatic conditions; reducing chances of survival.	All hazards
Social	Demographic	Population density	Ratio	Total number of people living in a particular area. Pop. density = Total population divided by the area accommodating the population (persons / km2)	On occurrence of a disaster event the number of victims is high for a given high density area. Therefore, higher the density, greater is the exposure of a particular zone/ward.	All hazards
Infrastructure	Built	Number of industries in low lying or flood risk areas	Absolute	Total number of industrial establishments in flood prone areas in an urban area	Industries lying in the low-lying areas are subjected to flooding. During the events of floods, it is possible that the discharge of effluents from the industries might flow along with surface run off.	FL, TS
		No. of heritage sites/buildings	Absolute	Historic site or heritage site is an official location where pieces of political, military, cultural, or social history have been preserved due to their cultural heritage value. Total number of heritage buildings/ sites in an urban area.	Heritage Buildings are structure of socio-cultural significance. Onset of erratic climatic event may impact the structural stability and appearance of building and thus can lead of damage to cultural resources.	All hazards

Annexure IV: Vulnerability Indicators

Theme	Sub-theme	Name of indicator	Method	Description of indicator (with units)	Justification	Hazard
Sensitivity Indicators						
Ecosystem	Land	Slope	GIS	Defined as the rise over the run. In GIS, raster-based slope computation tools estimate the rate of change between each cell and its neighbours	Slopes are interlinked with active and inactive faults and give sufficient fault slip information. A higher slope value indicates a steeper incline. Runoff velocity increases with steep slope leading to flash floods.	RF,FL,LS,BE, TS, DF, AL
		Aspect	GIS	Represent compass direction that a topographic slope faces, usually measured in degrees from north.	Useful in identification of flat areas, direction of movement of runoff, debris, and snow during natural hazards.	RF, LS, DF, AL
		Elevation	GIS	Represents height above a fixed reference point of a geographic location, often the mean sea level (m)	Useful in demarcation of low-lying areas and identification of flow direction of runoff or sea water intrusion	FL, CY, TS, FF, DF, AL
		Distance to water body	GIS	Distance of locations from the water bodies (rivers, lakes, reservoirs) due to encroachment of flood plains	Vulnerability of the assets increases to natural hazards as the proximity to water body increases. Higher Chances of Encroachment of Public Land.	FL, UF, BE, EQ, DF
		Lithology	GIS	Represents chemistry, mineral composition, and	Unconsolidated sedimentary deposits in an economically developed land, a combination that may cause high ground	RF, LS, EQ, DF, AL

Theme	Sub-theme	Name of indicator	Method	Description of indicator (with units)	Justification	Hazard
				physical properties of rocks of the areas;	shaking and destruction during seismic activities	
		Peak Ground Acceleration density	GIS	Represents the maximum ground acceleration that occurred during earthquake shaking at a location; Derived from the catalogue using the equation: MI = 1/0.3 × (LOG 10(PGA × 980)–0.014)	Ground motion information can be understood from PGA associated with tectonic fractures or faults	LS, EQ, AL, TS
		Distance to fault	GIS	Distance of locations from the fault line (km)	High seismic activity is observed along the fault line. Spatial Vulnerability of zones is observed near active faults and the vulnerability decreases with an increase in distance to the fault line.	EQ
		Low-lying areas in flood prone zone	GIS	Low lying areas estimated using DEM	Low lying areas are more susceptible to water logging during floods	FL, UF, CY, TS, FF, DF
		Percentage change in green space	GIS	Green space (land that is partly or completely covered with grass, trees, shrubs, or other vegetation); includes parks, community gardens, and cemeteries; percentage change in green areas can be calculated using LULC map or NDVI.	Urban green spaces provide a number of environmental and social benefits, such as local climate stabilization and a decrease in energy demand. It is particularly important for ecosystem-based adaptation responses to climate change such as urban heat island effects, increased carbon capture and storage, water purification. Social benefits include improvements to mental and physical health and the availability of healthy food products.	RF, FL, LS, BE, HW, DR

Theme	Sub-theme	Name of indicator	Method	Description of indicator (with units)	Justification	Hazard
		Albedo	GIS	Measure of the diffuse reflection of solar radiation out of the total solar radiation	Urban areas have higher solar ingress and low albedo which therefore leads to formation of heat islands. Decrease in albedo also means more energy is absorbed, which causes further warming of the troposphere.	HW, DR
		Runoff potential	GIS	Proxy of soil permeability; refers to ability of soil to generate runoff based on its soil permeability which measures the ability to allow the rainwater infiltration through the soil by considering the runoff coefficient for different land cover types	Higher the runoff potential results to more vulnerability to floods; less likely for precipitation to infiltrate into the groundwater system and recharging aquifers.	FL, LS, UF, BE, DR
		Land Surface Temperature (LST)	GIS	Radiative skin temperature of the land surface, as measured in the direction of the remote sensor (℃)	Higher LST can enhance heatwave conditions over an urban area; may result into hydrological droughts and loss of soil moisture.	HW, DR
	Water	Increased fluctuation of groundwater levels	Absolute change	Ground water level (m)	Large variations in seasonal precipitation due to climate change can cause fluctuations of groundwater levels. This process could increase or decrease the groundwater level and create situations such as drought or flooding	FL, UF, DR
		Ground Water Extraction Status	Absolute	Represented by 4 categories, namely: 'Safe' - have ground water potential for development; 'Semi-critical':	Changes in groundwater availability directly impacts the groundwater extraction and usage; over-exploitation might accelerate the decrement in	DR

Theme	Sub-theme	Name of indicator	Method	Description of indicator (with units)	Justification	Hazard
				cautious groundwater development is recommended; 'Critical'; and 'Over-exploited': intensive monitoring and evaluation needed, and future ground development be linked with water conservation measures.	groundwater level due climate change even further	
		Percentage change in blue space/infrastructure	GIS	Blue space/infrastructure comprises all the areas dominated by surface waterbodies or watercourses; change in area under water bodies will be estimated through LULC change analysis in GIS.	Water bodies act like storage sinks and are crucial in reducing the magnitude and frequency of flash floods. Moreover, they also have a microclimatic effect on their immediate surroundings and aid in coping from heat stresses; relate to droughts and floods	FL, UF, DR
	Air	Changes in annual average concentration of NO_2 ($\mu g/m^3$)	Absolute	Changes in present annual average concentration of NO_2 with respect to a base year	Nitrogenous gases also play a key role in global climate change. Nitrous oxide is a particularly potent greenhouse gas as it is known to be more effective at trapping heat in the atmosphere than carbon dioxide	All hydro-meteorological hazards
		Changes in annual average concentration of O_3 ($\mu g/m^3$)	Absolute	Changes in present annual average concentration of O_3 with respect to a base year	Tropospheric ozone has a warming effect	All hydro-meteorological hazards
		Changes in annual average concentration of	Absolute	Changes in present annual average concentration of PM with respect to a base year	Tend to pose significant impact on urban microclimate as PM have both warming and cooling effects	All hydro-meteorological hazards

Theme	Sub-theme	Name of indicator	Method	Description of indicator (with units)	Justification	Hazard
		particulate matter (µg/m^3)				
Social	Demographic	Population growth rate	Percentage	Average annual rate of change of population size, for a given country, territory, or geographic area, during a specified period. Using the decadal population data, the growth rates of respective wards/zones will be estimated.	Rapid population growth lacks enough shelters, social services network and often results in unpredictable demand of relief supplies during disasters. Areas with higher growth rates – especially of dependent population – are likely to be more sensitive to climate change	All hazards
		Gender gap in literacy rate	Percentage	Gender gap in literacy occurs when there are systematic differences in schooling level between men and women. Calculated as male literacy rate minus female literacy rate.	Understanding how gender relations shape women's and men's lives is critical to disaster risk reduction. This is because women's and men's different roles, responsibilities, and access to resources such as education influence how each will be affected by different hazards, and how they will cope with and recover from disaster. Differences in vulnerability of women and men as a result of socially constructed gender roles.	All hazards

Theme	Sub-theme	Name of indicator	Method	Description of indicator (with units)	Justification	Hazard
		Sex ratio	Ratio	The sex ratio is the ratio of males to females in a population. Number of females per 1000 males	Vulnerability to climate change can be differentially defined on the basis of gender. Sex-ratio is an indicator of the gender distribution in a society. Ideally, the sex ratio should be 1. A low sex ratio in general represents a lesser social status of women, which creates conditions for discrimination at various levels. A lower sex ratio can add-on to the sensitivity to climate change increasing overall vulnerability.	All hazards
		Annual average deaths	Absolute	The estimated number of deaths due to natural disasters per 100 000 population averaged over the period. Deaths per 100 000 population	Increased Number of deaths can also be termed as a representative of vulnerability of population to various factors.	All hazards
		Migrant population	Percentage	Number of people migrated to cities for higher income or rate of migration to certain areas. Calculated as difference between the number of immigrants (people coming into an area) and the number of emigrants (people leaving an area) throughout the year.	Natural disasters are positively associated with emigration rates. Climate change-related natural disasters will cause an increase in human migration and forced displacement.	FL, LS, BE, CY, EQ, FF, TS, DF, AL, HW
		Dependency ratio	Ratio	Ratio of dependent population (non-working;	A combination of factors such as extreme temperatures and flooding is the primary	All hazards

Theme	Sub-theme	Name of indicator	Method	Description of indicator (with units)	Justification	Hazard
				children and old age people) to the working population. Dependent population is defined as that part of the population that does not work and relies on others for the goods and services they consume.	stressor for children and elderly people with regard to health and development. The percentage of children and elderly in the population is one of the key aspects of the system's sensitivity to various climate change events.	
		Infant mortality rate (IMR)	Percentage	Proxy indicator for health infrastructure; number of children dying at less than 1 year of age, divided by the number of live births that year	Compared with adults, infants and children are more vulnerable during and after natural disasters. There can also be inequality in the availability of medical resources for infants.	FL, EQ, FF, HW, DR
		Percent population with disabilities	Percentage	Percent population of physically or mentally impaired, disabled, etc.	People with physical disability are more likely to sustain injuries during disaster events or follow up the evacuation process.	All hazards
		Percentage of slum population	Percentage	Percent population residing in slum to total population	Increased Number of populations living in slums is a proxy of people exposed to climate adversities and poor access to basic services.	All hazards
	Economic	Unemployment rate	Percentage	Percentage of people unemployed or without a regular job including beggars, homeless, etc.	Unemployed population is highly sensitive to impacts of climate change in terms of their inability to overcome with post-disaster consequences	All hazards
		Gap in work participation rate	Percentage	Represents the difference between percent working male population and percent working female population	Greater difference in the male and female working population creates disparity within the society to adapt to the consequences of climate change	All hazards

Theme	Sub-theme	Name of indicator	Method	Description of indicator (with units)	Justification	Hazard
		Households below poverty line (BPL)	Percentage	Percentage of households below the poverty line as defined by government of India. It should be ₹32 in rural areas and ₹47 in urban areas (https://timesofindia.indiatimes.com/india/New-poverty-line-Rs-32-in-villages-Rs-47-in-cities/articleshow/37920441.cms)	BPL households have limited access to basic necessities of life. Being the vulnerable section of the society, their ability to cope with any natural disaster is minimal. Higher BPL population is likely to increase the sensitivity to climate change.	All hazards
Infrastructure	Social	Number of slums	Absolute	Urban form: the presence of poorly built and managed areas in particular has a wide variety of effects on the city, including increased greenhouse gas emissions, increased demand for resources and vulnerability to the effects of climate change	Slum encroachments come up in areas with lesser economic value and lesser access to basic amenities. Higher number of slums represent higher vulnerability to aftermath consequences of climate change as the area is favourable to ill-maintained inhabitable encroachments.	FL, CY, HW, DR
		Energy use per capita	Ratio	Ratio of the total annual use of energy to the mid-year population	Patterns of Energy Consumption changes during instances of extreme weather events and contributes to higher GHG Emissions and therefore adding to Climate Change.	
		Share of non-renewable energy	Ratio	Ratio of the total annual use of Non-Renewable energy to the mid-year population	Increased dependency on Non-Renewable Energy sources not just adds to resource crunch but also is a large contribute to GHG Emissions.	

Theme	Sub-theme	Name of indicator	Method	Description of indicator (with units)	Justification	Hazard
	Built	Building density	Ratio	Number of buildings per unit area.	Lack of sufficient buffer spaces in the built-up area can increase the scale/ impact of a disaster event. High-rise buildings with less surface area are more vulnerable to earthquakes than low-rise buildings with the large surface area. High Building Density also negatively impacts the microclimate of the surrounding area and reduces the access to emergency services.	All hazards
		Number of slum households	Absolute	Number of households in each slum	Slum dwellers are vulnerable to disasters because they live in congested and dilapidated houses lacking access to essential services.	
		Average height of buildings	Absolute	Vertical distance between finished grade and the highest point on the building.	High-rise buildings provide increased density of occupancy per structure, providing concentration of people in one building. Therefore, the consequence of damage due to disaster tends to be more severe than that of a low-rise. High-density high-rise buildings can increase surface temperatures.	FL, UF, EQ, TS, FF, HW
		Average age of building structures	Absolute	The average age of building structures in a particular area.	Older structures are more sensitive to hazards.	FL, CY, EQ, TS
		Average area of living per person	Ratio	Calculated by dividing built up area by the number of persons (m^2/person)	Higher the average area per person, lesser is the sensitivity. If the area available per person is more, higher is the thermal comfort due to less congestion. In case of disaster, evacuation will be more effective.	FL, CY, EQ, TS, HW

Theme	Sub-theme	Name of indicator	Method	Description of indicator (with units)	Justification	Hazard
		Percent built-up area	Percentage	Measured as the ratio between the built-up area (concrete) area and the total area; can be calculated using GIS (NDBI).	Increase in total urban built-up area can result in formation of urban heat islands. Increased built up, increases surface run off and reduces soil permeability leading to floods.	FL, UF, CY, EQ, TS, FF, HW, DR
	Municipal	Number of pollution causing industries	Absolute	Number of pollution causing industries (Red or Orange Category) falling under each zone	Presence of pollution causing industries within the city limits acts as potential source of climatic as well as health hazard to the nearby population.	All hazards
		Water demand supply gap	Ratio	Areas facing water shortage (demand-supply)	Water demand supply gap is a representative of acute water shortage existing in the city, which may further aggravate due to extreme climatic events.	FL, CY, TS, FF, HW, DR
Adaptive Capacity Indicators						
Ecosystem	Flora and Fauna	Percent change in extent of Mangrove Forest	Percentage	Percentage changes in area of mangroves; calculated using GIS	Mangroves acts as a barrier/shield to coastal flooding and habitat for wide variety of flora and fauna. Reduction in area under Mangrove cover reduces adaptive capacity and results in loss of biodiversity of the region.	FL, CY, TS, FF
Social	Demographic	Literacy rate	Percentage	Rate of literate population to the total population	The literacy rate and access to knowledge of an area is a clear indicator of the adaptive capacity of the people and how equipped they are in terms of knowledge and education. It indicates the degree to which a community can have access to the right kind of knowledge in understanding changes in the environment and in the	All hazards

Theme	Sub-theme	Name of indicator	Method	Description of indicator (with units)	Justification	Hazard
					management, practices required to deal with them.	
		Basic education or formal education for child population	Absolute	3-15 yrs. old; percentage of child population enrolled in school to total child population	Higher number of enrolment rate reflects higher dissemination of knowledge and awareness related to Climate Change.	All hazards
	Economic	Percentage of households who own their homes	Percentage	Percentage of total inhabited private homes to total liveable structures	The ownership of dwelling unit is a vital part of building people's resilience to climate change and providing coping capacity for various shocks.	All hazards
		Per capita income or Percent households earning average monthly cost of living in India	Absolute	Average income per person	A more optimal economic situation allows greater access to resources and consequently enables the protection of life, material, and subsistence assets, as well as a prompter recovery after a disaster.	All hazards
		Private vehicle population	Absolute	Number of private vehicles owned	Ownership of private vehicles signifies the financial stability of the people to withstand the impacts of climate change.	All hazards
		Households with access to banking facilities	Percentage	Access of households to banks, ATMs; calculated by dividing number of households with access to banking facilities within a specified radius to the total number of households	Households having access to financial services has better adaptive capacity in the event of disaster.	All hazards
Infrastructure	Social	Access to safe housing	Percentage	Percentage of liveable houses based on condition of housing (permanent structures)	Access to safe living conditions, especially housing, is vital to building the resilience of people under changing climate.	All hazards

Theme	Sub-theme	Name of indicator	Method	Description of indicator (with units)	Justification	Hazard
		Availability of educational institution	Ratio	Number of schools, colleges, universities, etc. per 1000 persons	Educations institutes per thousand students is a representative of adaptive capacity of a region. More number of literates in a city better is the chance of broadcast of awareness and information related to climate resilience.	All hazards
		Access to social security	Ratio	Number of police stations, fire stations, disaster management teams, etc. per 1000 persons	Proximity to emergency services like fire brigade, relief centres, etc. is crucial in an event of disaster. Better the access, better is the emergency response to disaster.	All hazards
		Access to healthcare	Ratio	Number of hospitals, dispensaries etc. per 1000 persons	Sufficient number of hospitals and health centres are a pre-requisite for providing proper medical services in a region. Climate Change may lead to increase in the spread of some diseases. Better access and capacity of medical facilities indicate better adaptive capacity.	All hazards
		Availability of beds	Ratio	Number of beds per 1000 persons	Availability of sufficient beds per thousand population is a method to enumerate the availability of required medical infrastructure during the time of climate crises in a city.	All hazards
	Built	Road density	Ratio	Road length per km^2	Reduction in the mobility during disaster arising due to lack of access to roads can lead to people being stranded during extreme events.	All hazards
		Access to electricity	Percentage	Percentage of households having electricity as main source of lighting	Households having access to electricity have better access to early warning systems and communication related to	All hazards

Theme	Sub-theme	Name of indicator	Method	Description of indicator (with units)	Justification	Hazard
					disaster. Access to electricity also helps people to better adapt to weather extremes.	
		Access to transport infrastructure (public transport)	Absolute	Access to more than 1 public transport in an area.	A well-structured transportation network acts as a means of providing access to facilities. Access to alternate means of public transport indicates better connectivity, adaptive capacity.	All hazards
	Municipal	Access to safe drinking water connection	Percentage	Percentage of households with safe drinking water connection	The lack of basic amenities can cause an area to become vulnerable to the effects of climate change and may later impose additional financial burdens on deprived people. In a scenario where there is a lack of access to safe drinking water, people will become more exposed to water stress. This may further lead to water conflicts. Better the access, higher will be the adaptive capacity.	All hazards
		Access to wastewater drainage connection	Percentage	Percentage of households having wastewater drainage connection	Lack of access to proper sewer/drainage systems reflects the inability of the local government to contain septage. This may lead to discharge of domestic wastewater into the natural water systems and thereby polluting the freshwater drinking source.	FL, CY, TS, FF
		Storm water drainage network density	Ratio	Length of storm water drainage per sq. km	Areas with higher density of storm water drain can accommodate more storm water leading to less instances of floods.	FL, UF, CY, FF

Theme	Sub-theme	Name of indicator	Method	Description of indicator (with units)	Justification	Hazard
		Efficiency of waste collection	Percentage	Percentage of waste collection by the corporation	The uncollected litter/waste gets chocked into the storm water drains leading to floods. The Zones having better percentage of waste collection provides better chances of runoff to drain into stormwater drainage system; no breeding ground; low chances of epidemic and flooding of drains.	FL, CY, EQ, TS, FF, HW, DR
		Percentage households with adequate sanitation	Percentage	Population with access to healthy sanitation	Access to proper sanitation facilities indicates hygienic living conditions. Additionally, it also helps in curbing the spread of water and vector borne diseases which are predicted to occur more frequently under changing climate.	All hazards
		Percentage of closed drains	Percentage	Percentage of closed drains in a locality	Open drains running across the city are an indication of increased probability of breeding ground of mosquito. litter from the streets can further clog the open drains, leading to overflow/flooding of lines.	FL, UF, CY, FF, TS, DF
Institutional Capacity	Policy	Adequate budget for disaster risk management per person	Ratio	Budget allocated (INR) for disaster management per 1000 person	Adequate financial allocation will aid in better disaster risk management. It will also help in recovery after the disaster. Having adequate budget for Disaster Risk Management will increase the adaptive capacity of the city.	All hazards
		Number of shelters and collection centres	Ratio	No. of shelters (schools, colleges, anganwadi, universities) per 1000 person	Having adequate number of Shelters in a City will aid in providing temporary shelter for the citizens. Having adequate number	All hazards

Theme	Sub-theme	Name of indicator	Method	Description of indicator (with units)	Justification	Hazard
					of shelters will increase the adaptive capacity of the City.	
		Number of trained officials	Ratio	Number of trained officials per 1000 person	Trained official will aid in proper planning and execution of disaster management plans. Having adequate number of trained officials will increase the adaptive capacity of the city.	All hazards
		Local volunteers for disaster management	Ratio	Number of volunteers per 1000 persons	Local volunteers will increase the adaptive capacity of the city as they will help citizens and businesses in managing disasters.	All hazards
		Education and campaign for disaster management	Number	Number of awareness programmes/campaign for disaster management in a year	Education and campaign will increase the awareness and prepare and sensitize the citizens to manage the disaster thereby increasing their adaptive capacity.	All hazards
		Early warning system/contingency plans, Mapping of risk areas	Yes/No	Presence of Early Warning System/Contingency Plans, Mapping of risk areas	In the event of a disaster, the early warning systems play a crucial role safeguarding people's lives. Having a prediction and early warning system in place indicates better preparedness.	All hazards