Cyclone risk assessment of the Cox’s Bazar district (CBD) in SE Bangladesh

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Cyclone hazard in Bangladesh

- Bangladesh experiences cyclones almost each year during early summer and retreating rainy season; as a result, cyclone related deaths have been recorded as more than one million since 1877 (Paul and Dutt, 2010).

- In fact, most of the world's catastrophic cyclones have been those hitting Bangladesh e.g., the episodes of 1584, 1737, 1942, 1876, 1897 and 1970.

- Among the historical extreme storm events, the Bhola (1970) that killed 0.3 - 0.5 million people is considered as deadliest ever cyclone.

- The event of 29 April 1991 is also one of the deadliest in the series; the storm struck the eastern coast of the country with wind speeds exceeding 240 km/h, generating storm surge of more than 9 m above mean sea level, killing 138,000–145,000 people and resulting in economic loss of $2.07 billion.

- Another cyclone in 2007 (Sidr) caused death of 3,406 people (Paul, 2009) and economic loss of $1.67 billion (Dasgupta et al.,2010).

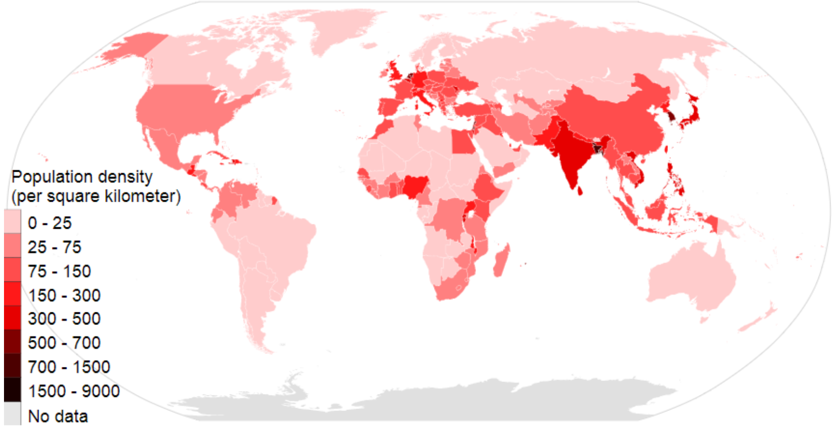
Why do unprecedented losses take place in Bangladesh?

Physical Environment
e.g., frequency of the cyclones
location and topography

Underdevelopment
e.g., housing pattern and poverty

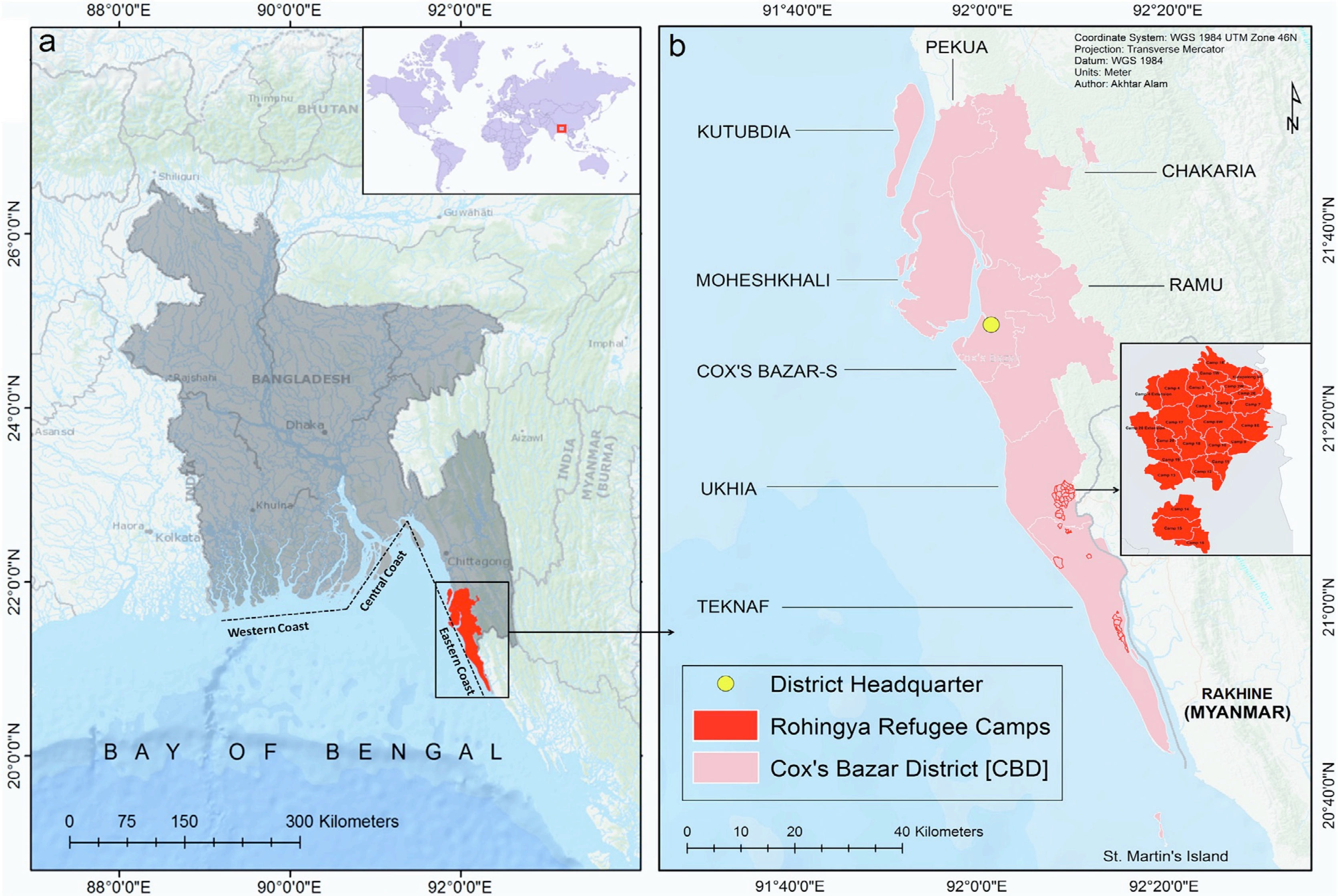
Demography
e.g., population density

Management
e.g., Policy and early waning system



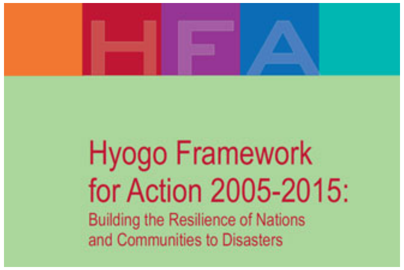
Population density (people per km²) by country in 2018

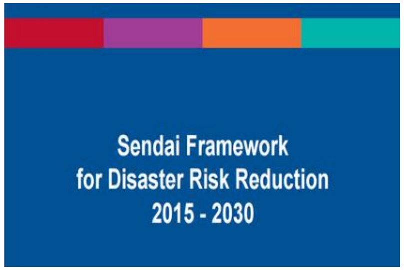
Study area:



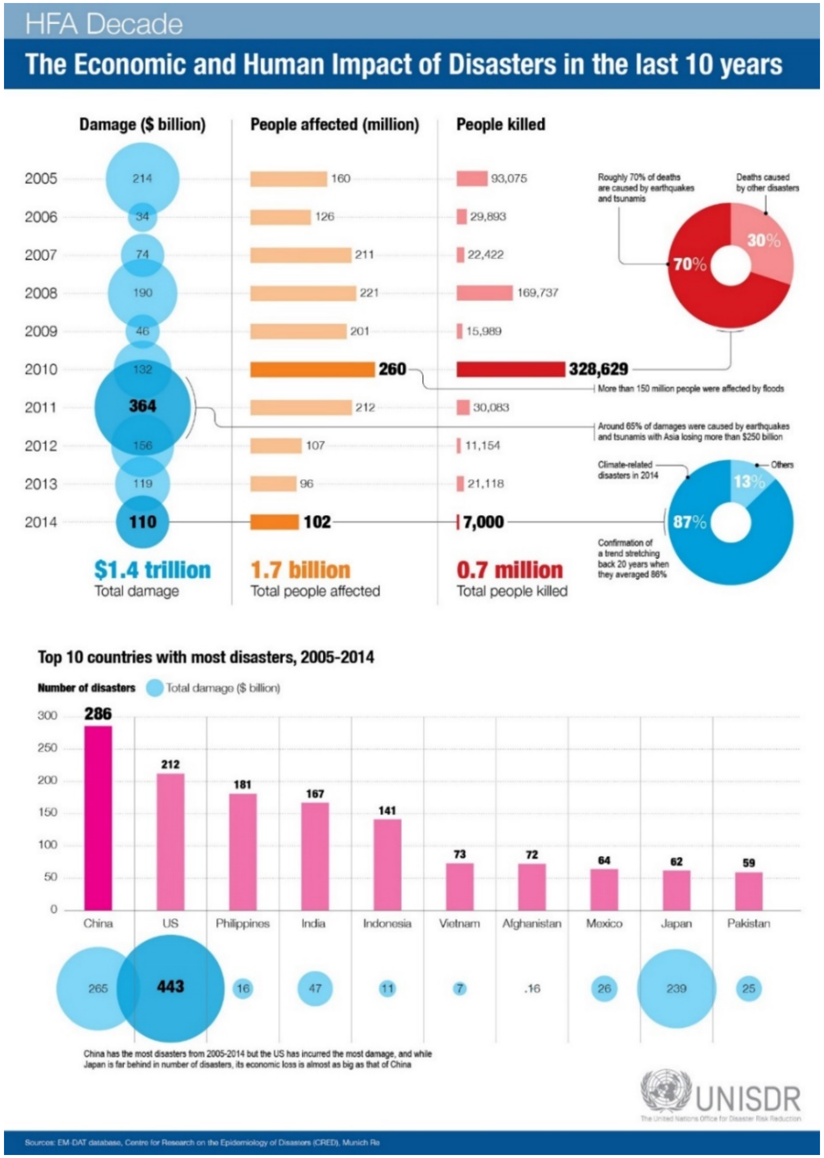
(a) Relief map showing the location of the Cox's Bazar district (Red) in Bangladesh; (b) different administrative units (*Upazilas*) of the district and location of the Rohingya refugee camps in the district.

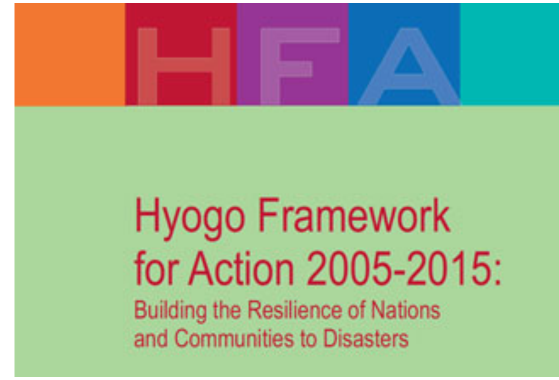
Why to assess the disaster risk?





www.unisdr.org





Hyogo Framework for Action (HFA) 2005-2015

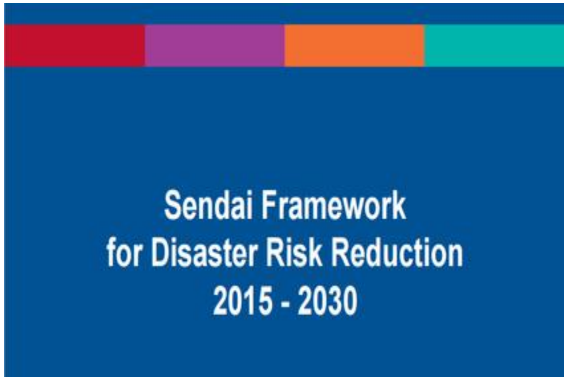
Priority Action 1: Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation.

Priority Action 2: Identify, assess and monitor disaster risks and enhance early warning.

Priority Action 3: Use knowledge, innovation and education to build a culture of safety and resilience at all levels.

Priority Action 4: Reduce the underlying risk factors.

Priority Action 5: Strengthen disaster preparedness for effective response at all levels.



The Sendai Framework for Disaster Risk Reduction 2015-2030

Priority 1. Understanding disaster risk.

Priority 2. Strengthening disaster risk governance to manage disaster risk.

Priority 3. Investing in disaster risk reduction for resilience.

Priority 4. Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction.

<u>Approaches:</u>

Disaster Risk

The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community **<u>in a specific period of time</u>**, **determined probabilistically as a function of <u>hazard</u>, <u>exposure</u>, <u>vulnerability</u> and <u>capacity</u> (UNDRR, 2017)**.

Annotation: The definition of disaster risk reflects the concept of hazardous events and disasters as the outcome of continuously present conditions of risk. **Disaster risk comprises different types of potential losses which are often difficult to quantify. Nevertheless, with knowledge of the prevailing hazards and the patterns of population and socioeconomic development, disaster risks can be assessed and mapped, in broad terms at least (UNDRR, 2017)**.

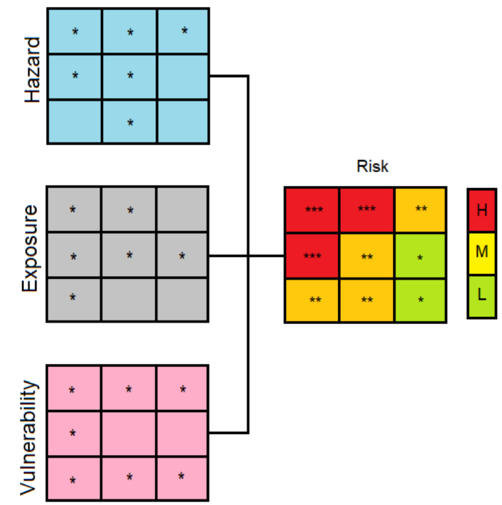
www.un-spider.org

Crichton, 1999

$$\text{Risk} = \text{Hazard (H)} \times \text{Exposure (E)} \times \text{Vulnerability (V)}$$

or

$$\text{Risk} = \frac{\text{Hazard (H)} \times \text{Exposure (E)} \times \text{Vulnerability (V)}}{\text{Capacity (C)}}$$

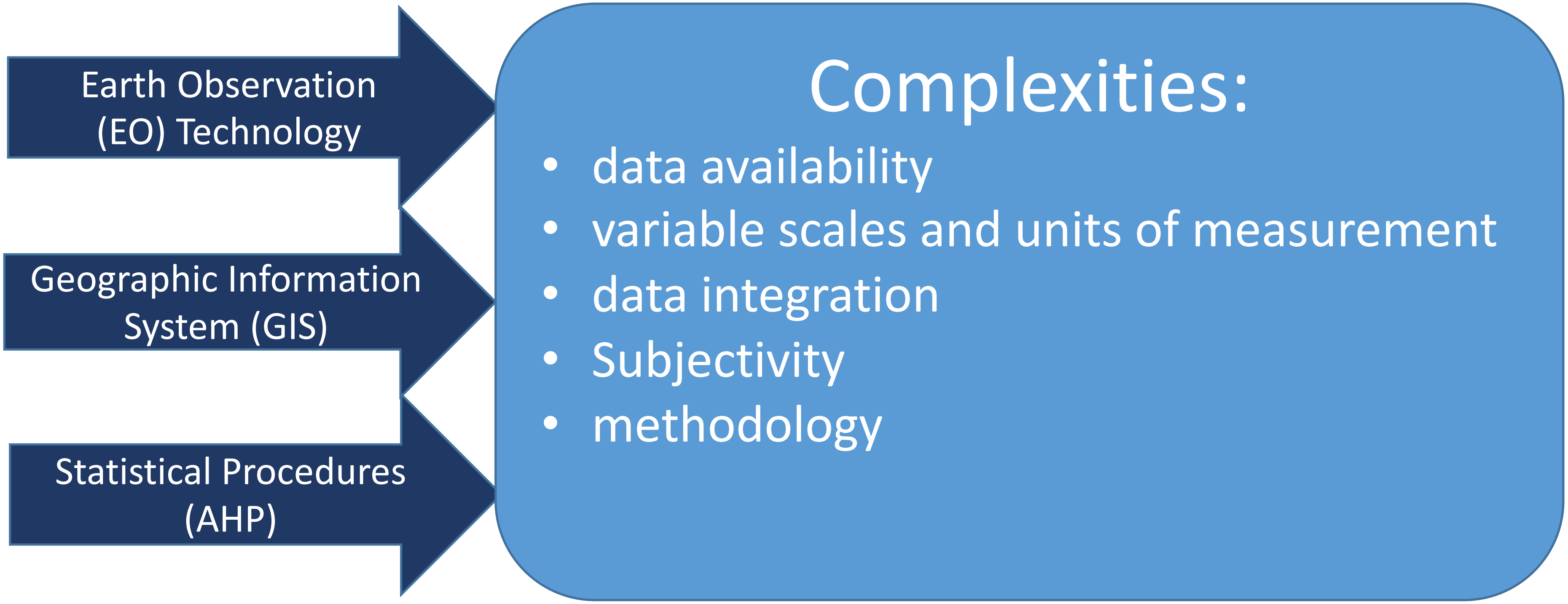


<u>Disaster Risk Assessment:</u>

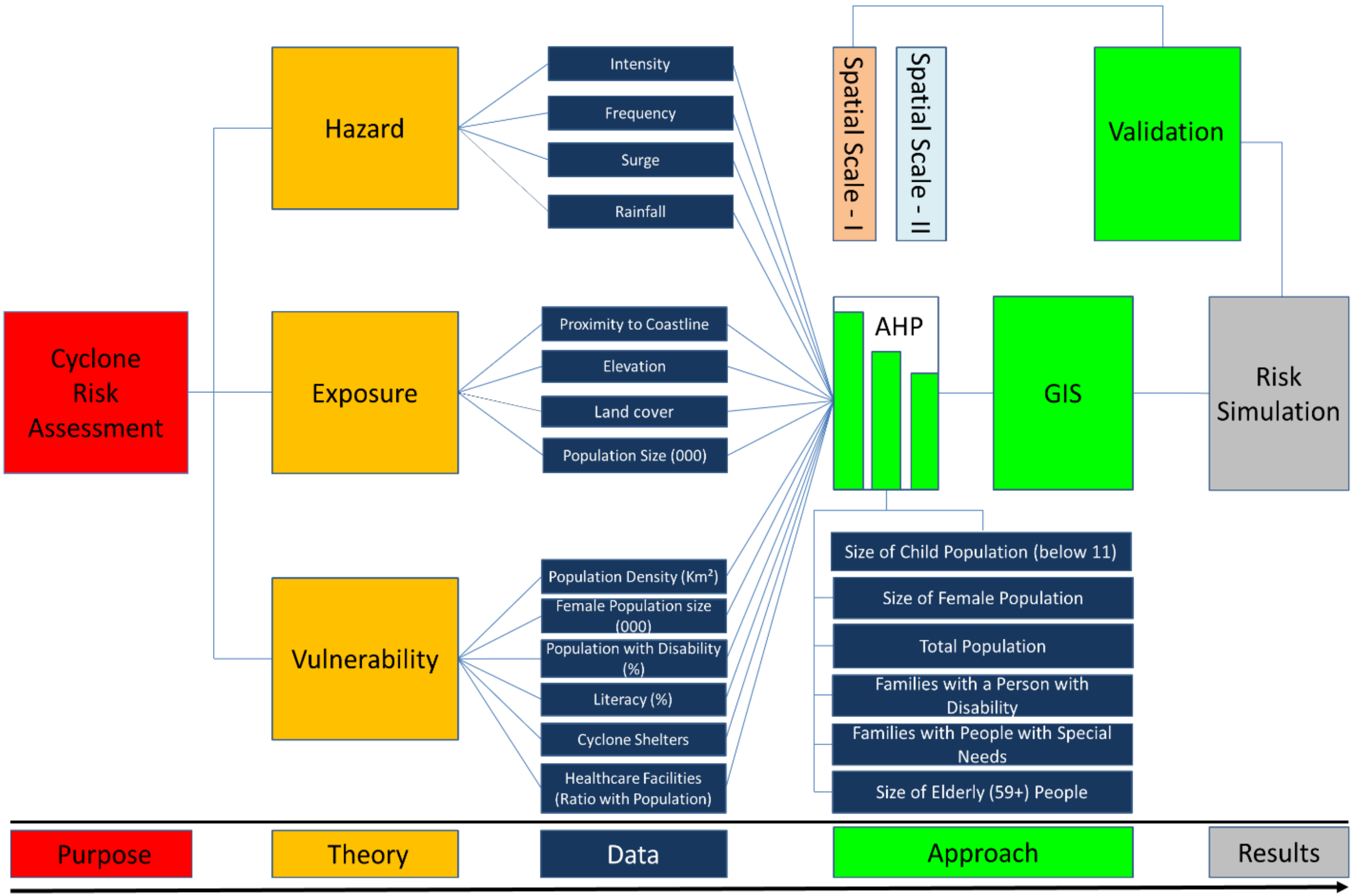
A qualitative or quantitative approach to determine the nature and extent of disaster risk by analyzing <u>potential hazards and evaluating existing conditions of exposure and vulnerability that together could harm</u> people, property, services, livelihoods and the environment on which they depend **(UNDRR, 2017)**.

Annotation: Disaster risk assessments include: the identification of hazards; a review of the technical characteristics of hazards such as their <u>location</u>, <u>intensity</u>, <u>frequency</u> and <u>probability</u>; the analysis of exposure and vulnerability, including the physical, social, health, environmental and economic dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities with respect to likely risk scenarios **(UNDRR, 2017)**.

Risk assessment:



Outline of the methodology:



Details of the data products:

Parameter	Product	Source
Cyclone intensity (TS-H4)	Wind speed of the storms (NOAA)	https://www.coast.noaa.gov/
Cyclone frequency (number)	Total number of the storms (NOAA)	https://www.coast.noaa.gov/
Storm Surge (m)	Projected surge height of 20 year storm and observed 1991 cyclone (~10m)	Dasgupta et al., 2010; Khalil, 1993
Rainfall (mm)	Mean Annual	www.bmd.gov.bd
Proximity to coastline (km)	Distance calculated using Landsat 8 satellite image as a base in ArcGIS 10.2.	https://glovis.usgs.gov/
Elevation (m)	ALOS World 3D – 30m Version 2.1, Digital Surface Model (DSM).	http://www.eorc.jaxa.jp/
Land Cover (category)	Satellite Image (Landsat 8 (OLI), date of acquisition 2019/02/01), UTM zone 46	https://glovis.usgs.gov/
Population size (000)	District Statistics (2011)	Bangladesh Bureau of Statistics (BBS), 2013
Population density (km²)	District Statistics (2011)	Bangladesh Bureau of Statistics (BBS), 2013
Female population size (000)	District Statistics (2011)	Bangladesh Bureau of Statistics (BBS), 2013
Population with disability (%)	District Statistics (2011)	Bangladesh Bureau of Statistics (BBS), 2013
Literacy (%)	District Statistics (2011)	Bangladesh Bureau of Statistics (BBS), 2013
Cyclone shelters (number)	District Statistics (2011)	Bangladesh Bureau of Statistics (BBS), 2013
Healthcare facilities (ratio to 000)	District Statistics (2011)	Bangladesh Bureau of Statistics (BBS), 2013
Demographic data of the Rohingya refugees	Population factsheet (15 April, 2019)	https://data2.unhcr.org/ https://data.humdata.org/

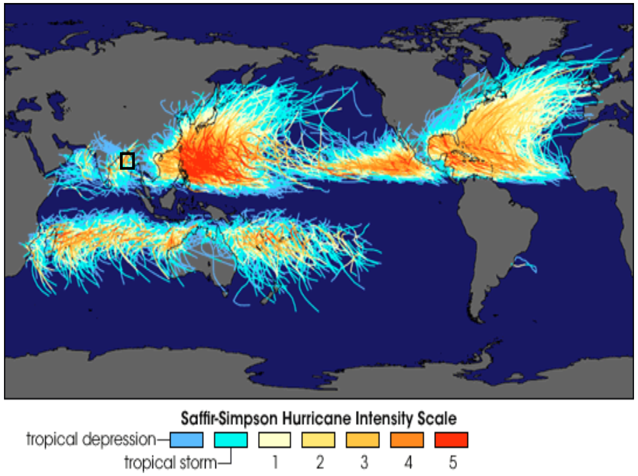
HAZARD (H):

Storm Intensity:

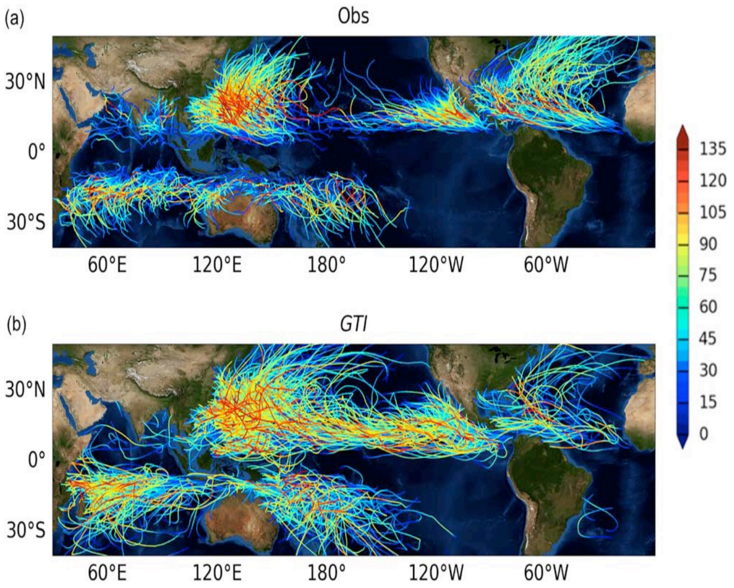
Maximum sustained wind speed defines the intensity of a Cyclone. This analysis used National Oceanic and Atmospheric Administration (NOAA) storm data to understand the historical pattern of the cyclone intensity in the CBD. Storm records spanning over a period of more than 110 years (1904–2016) from the NOAA archive were filtered to retrieve the cyclones with track over the Cox's Bazar district.

Cyclone frequency:

Frequency is described as the number of tropical cyclones in a given period or it may be illustrated as the return period of a storm of specific intensity. Our analysis reveals that on an average the Cox's Bazar district is directly hit by a cyclone storm of varying intensities after every 5 years.

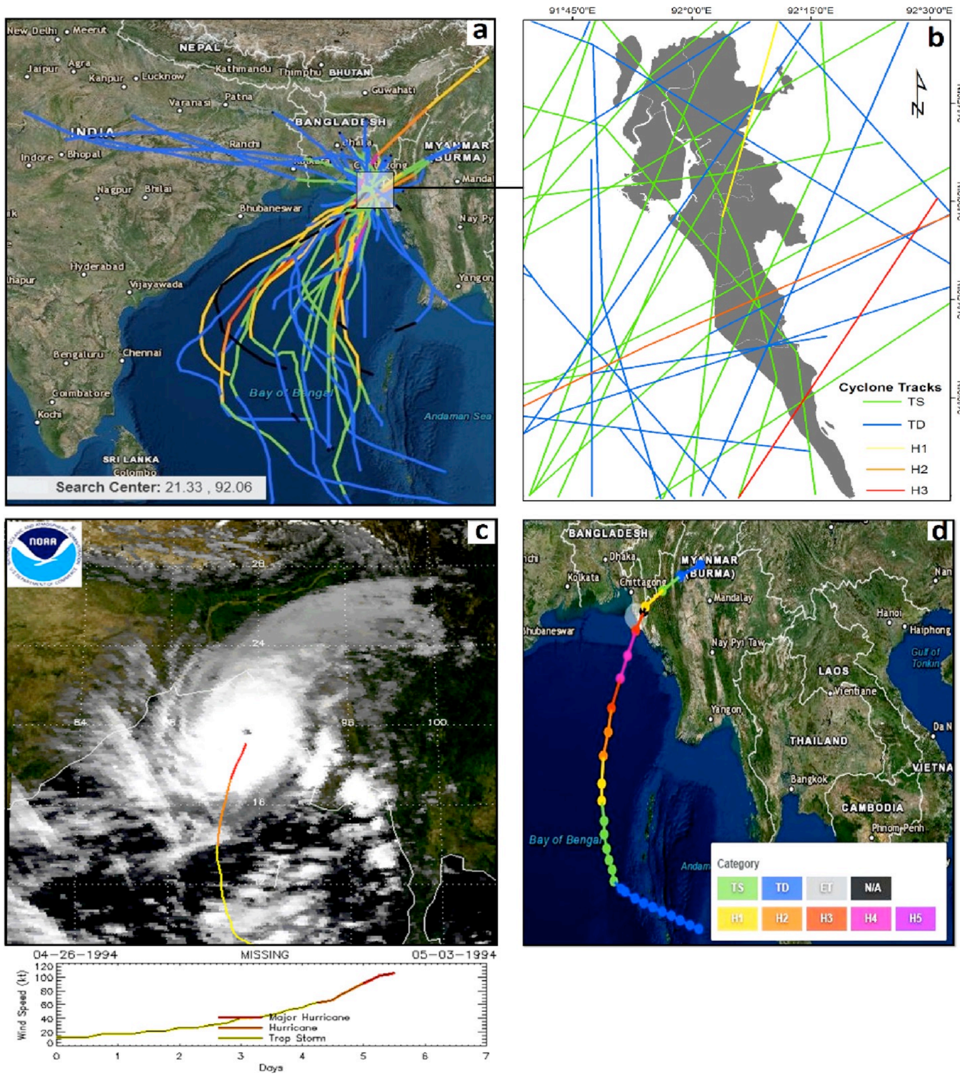


https://earthobservatory.nasa.gov/images/7079/historic-tropical-cyclone-tracks



2000–2012 historical tracks color-coded by intensity (a) observed, (b) simulated for the same period (Lee et al., 2018)

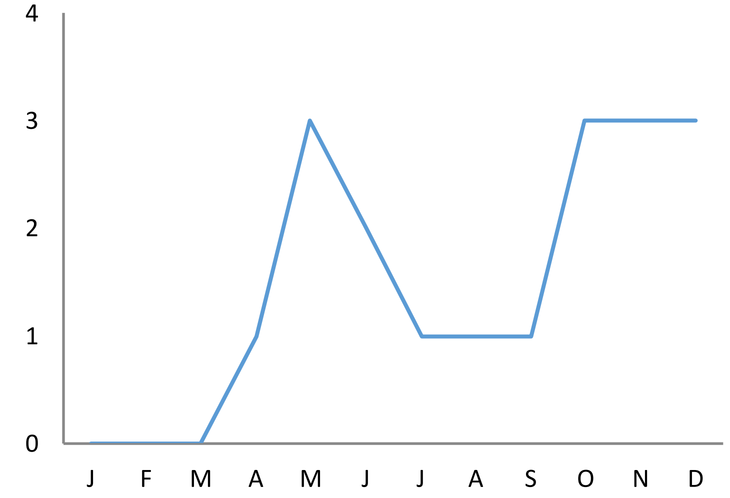
Cyclone storms of different intensities with track over the Cox's Bazar district from 1904-2016.

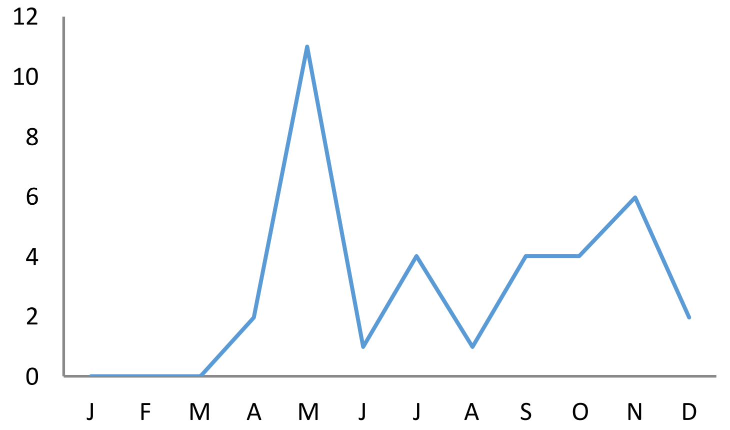


(a) Tracks of the cyclones originating from the Indian Ocean, (b) closer view of the storm tracks through the Cox's Bazar district, (c) satellite image of the wind field, track and timing of 1994 cyclone (d) intensity of the 1994 storm (Saffir–Simpson Scale).

Details of the cyclone events considered for the present analysis (1904-2016).

Year	Month	Days		Category
		From	To	(Max. attained)
1904	November	21	23	TS
1909	December	02	05	H1
1918	May	24	25	TS
1923	May	02	05	H1
1924	June	14	16	TS
1929	June	02	03	TD
1930	July	15	21	TD
1941	August	15	19	TD
1965	October	07	08	TD
1965	December	06	14	H1
1967	October	20	23	H1
1969	September	23	25	TD
1981	November	17	20	H1
1983	November	05	09	TD
1990	December	13	19	TD
1992	October	14	22	TD
1994	April/May	26 April	03 May	H4
1995	November	18	25	H3
1996	May	01	07	TD
2007	May	13	15	H1
2011	October	17	19	TS
2016	November	03	06	TS





Temporal pattern of the cyclone occurrence. (a) All the events of the Cox’s Bazar district from1904-2016 (Upper); (b) H1 to H5 category cyclones in Bangladesh from 1893-2007 (lower).

Storm surge:

- Storm surge is a phenomenon of rising water height of the waves because of high speed winds and low pressure associated with the cyclones resulting in coastal floods.

- Previous experiences reveal that most of cyclone related deaths in Bangladesh were due to surges associated with the storms.

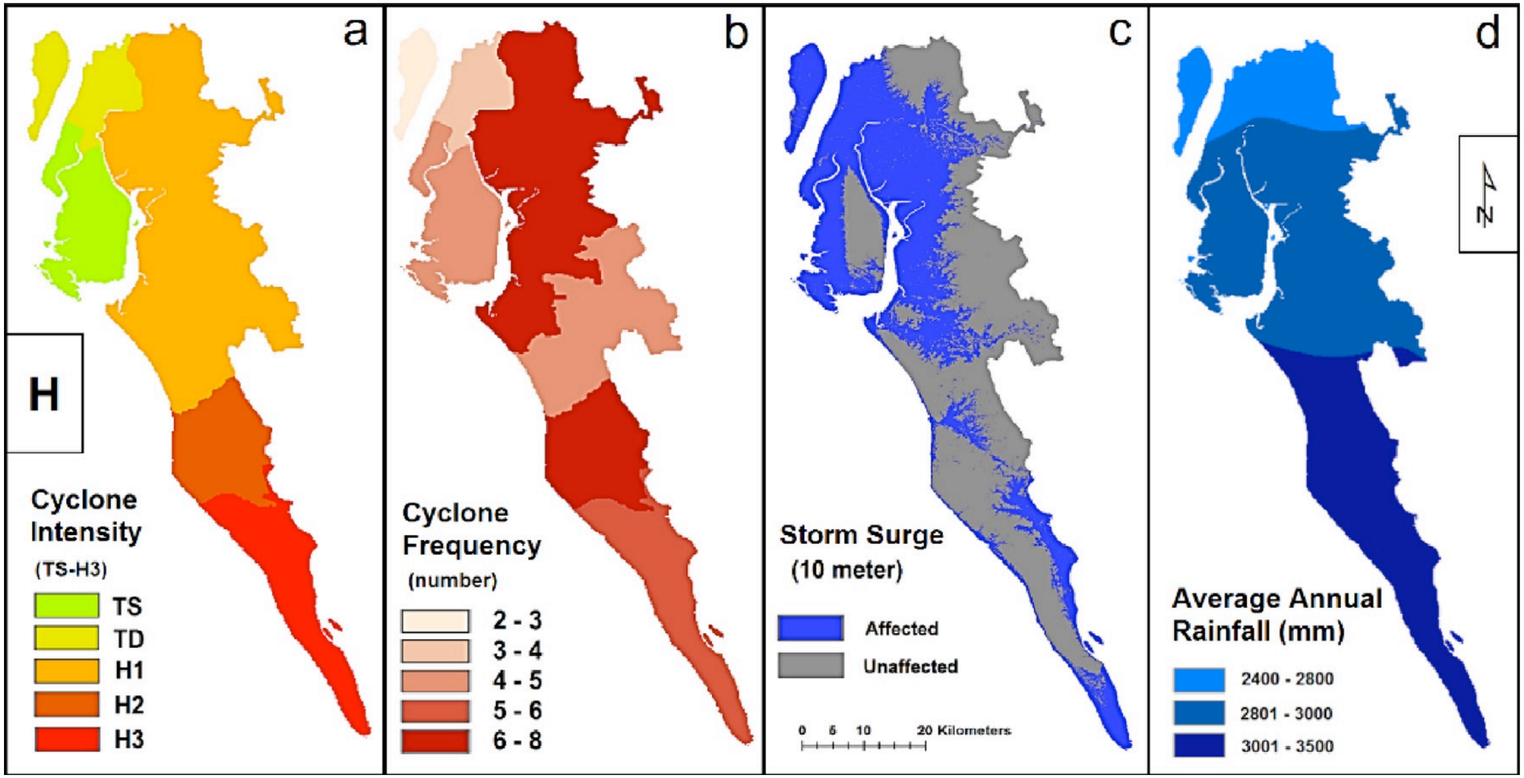
- UNICEF (1993) cyclone evaluation team during their post cyclone (1991) survey observed that almost all deaths have been as a result of drowning from the tidal wave that accompanied the cyclone.

- With continuous sea level rise in the wake of climate change, the cyclone storm surges are likely to enter deep into land and effect populated areas.

- In general, the frequency of 7m and 10m surge is 5 years and 20 years respectively during high tide along the coast of Bangladesh (Dasgupta et al., 2014). The surge height of the 1991 cyclone has also been reported more than 9 m (Khalil, 1993).

- We use the projected storm surge height and observed surge height during 1991 cyclone as a reference to identify the areas of Cox's Bazar district that are likely to get effected by a surge of this height (10 m). The scenario has beendeveloped using Advanced Land Observing Satellite (ALOS) Digital Surface Model (DSM).

Cyclone hazard (H):

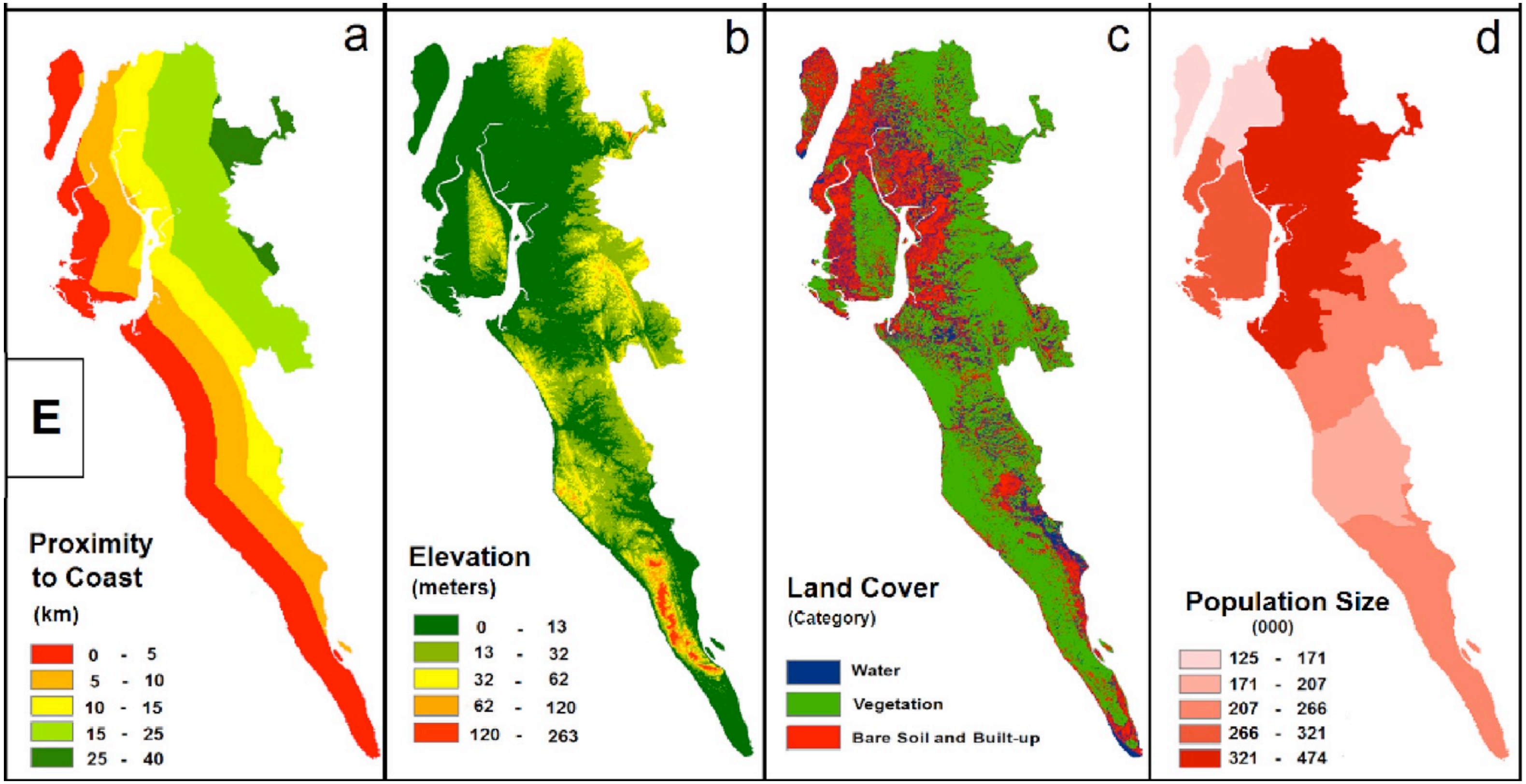


Parameters used for the cyclone risk assessment. [H-hazard]: (a) Intensity of the previous storms—TS-tropical storm, TD-tropical depression, H1, H2, H3 cyclone intensity on the Saffir–Simpson Scale, (b) frequency of the cyclone storms with track over the various Upazilas of the district (c) areas likely to be effected by a 10-meter-high surge (blue), and (d) pattern of the average annual rainfall (mm);

Land cover classification scheme

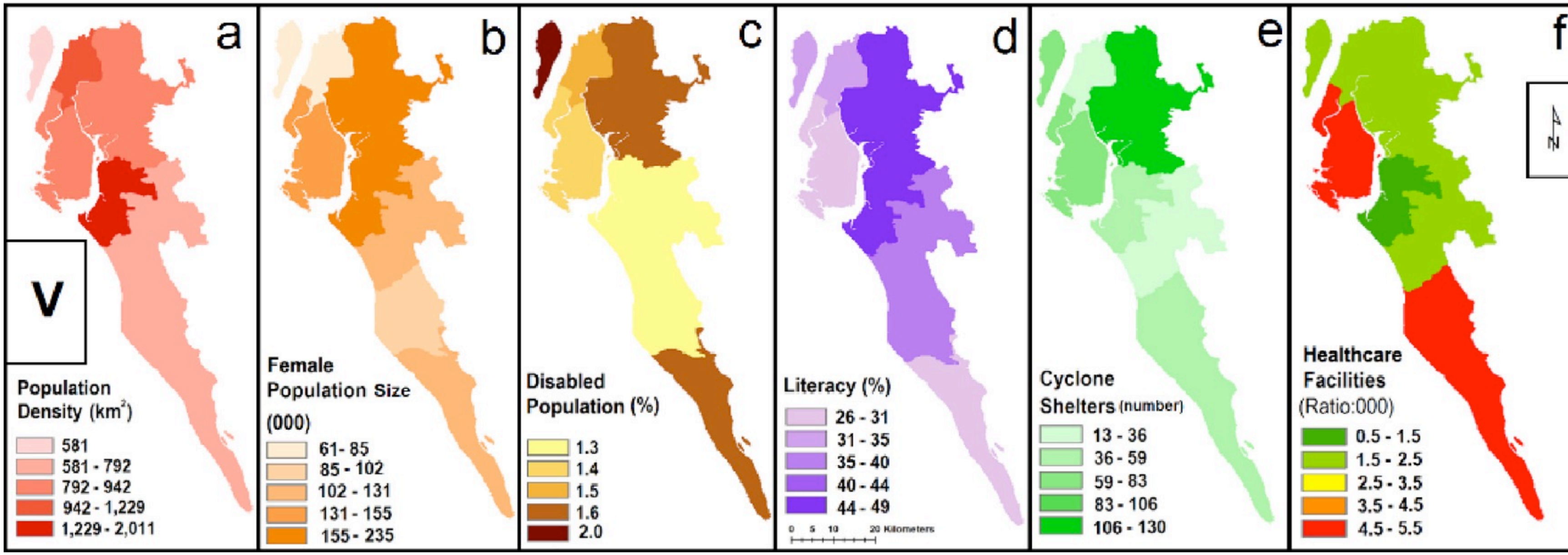
Land cover	Description
Water	Rivers, canals, ponds, swamps, and other water logged areas.
Vegetation	Forests, standing crops, mangroves, aquatic plants and other shrubbery.
Bare soil and Built-up	Agriculture land without standing crops, barren land, rocky outcrops, sandy and muddy coasts, residential areas, commercial establishments, roads and other paved surfaces.

Exposure to cyclones (E):



[E-exposure]: (a) zoning on the basis of distance from the coast, (b) elevation ranges derived from the ALOS DSM, (c) land cover classes obtained using Landsat 8 (OLI) imagery, and (d) population size.

Vulnerability to cyclones (V):



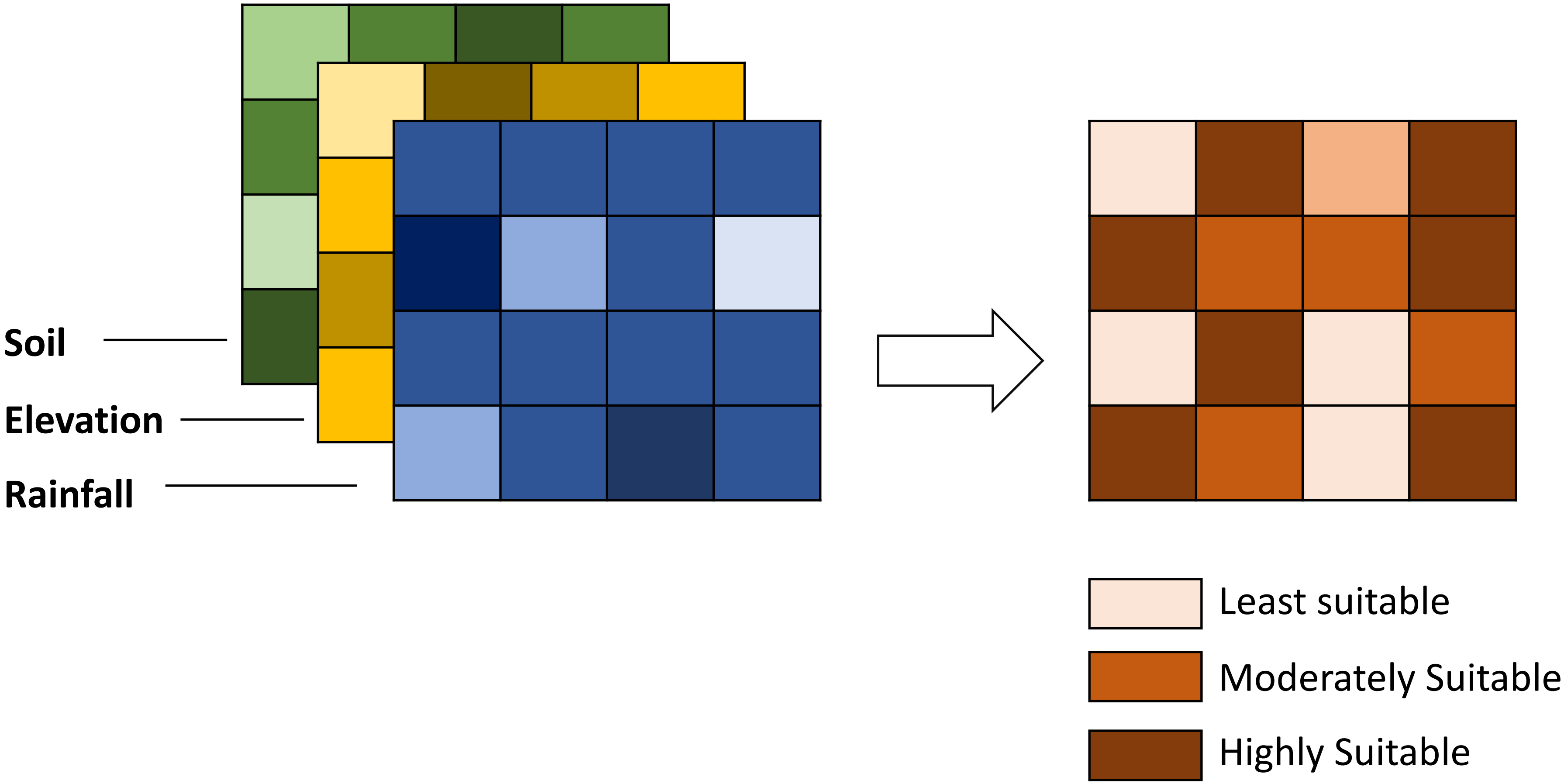
[V-vulnerability]: (a) density of the population, (b) total female population, (c) percentage of the population with disability, (d) percentage of the literate population, (e) number of cyclone shelters, and (f) availability of healthcare facilities per thousand of the population in each Upazila of the Cox's Bazar district.

Overlay analysis for depicting composite picture:

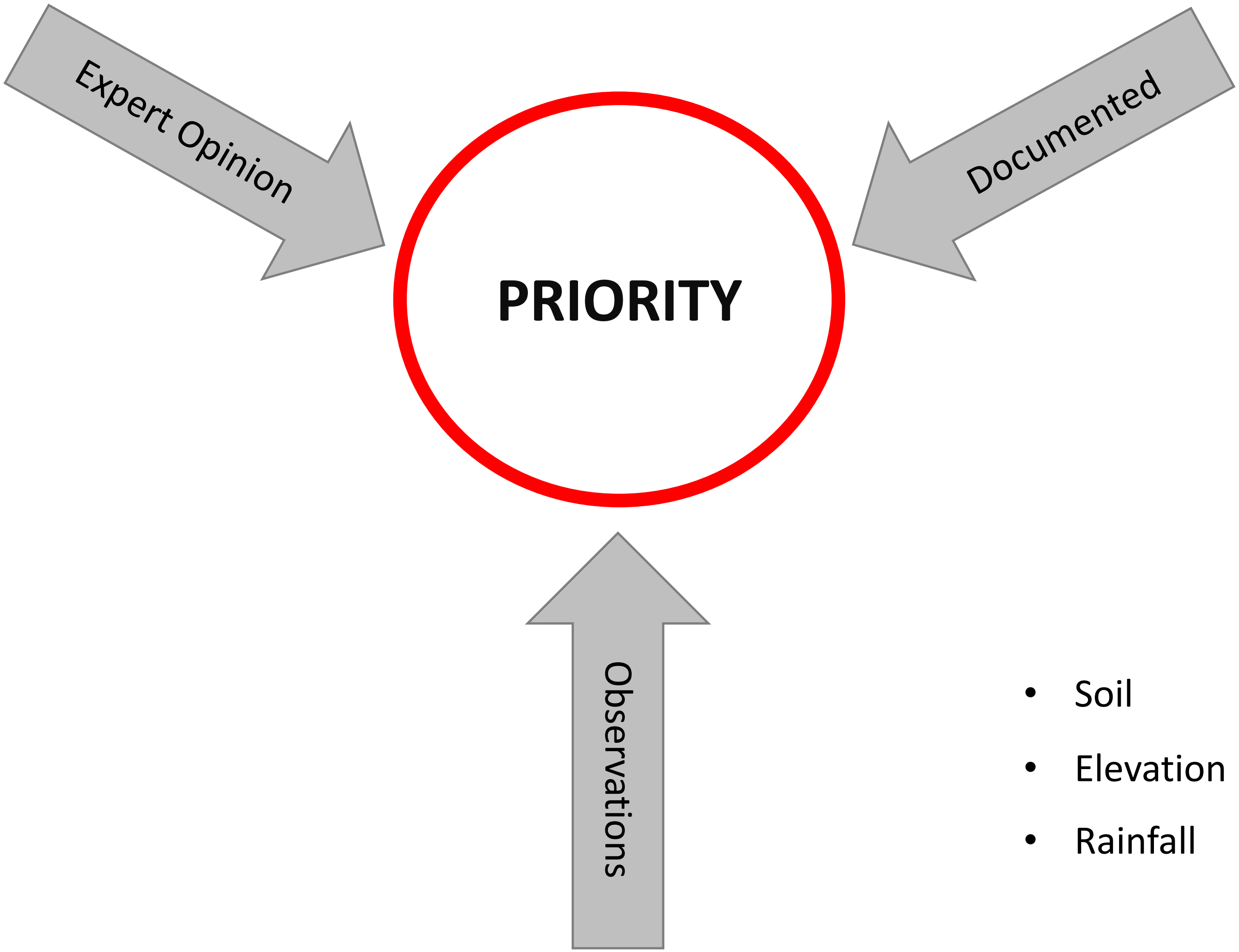
- Define the problem.
- Break the problem into submodels.
- Determine significant layers.
- Reclassify or transform the data within a layer.
- Weight the input layers.
- Add or combine the layers.
- Analyze.

Source: 

Example: Finding suitable sites for the cultivation of a particular crop.



How to determine the relative weightage or priority?



- Soil
- Elevation
- Rainfall

Challenges in pre-event risk assessment:

Each extreme event creates a unique damage and loss scenario, determined by various factors such as hazard severity, physical environment, social construction, capacity elements and many other real-time conditions; all these factors are dynamic in nature; consequently, predicting the role of contributing factors and forecasting the expected loss precisely is a complex task (Alam et al., 2019).

Multiple criteria decision making (MCDM) provides an ideal environment to accommodate the uncertainties and speculate the role of various contributing factors for simulating the disaster risk (Alam et al., 2019).

Multiple Criteria Decision Making (MCDM):

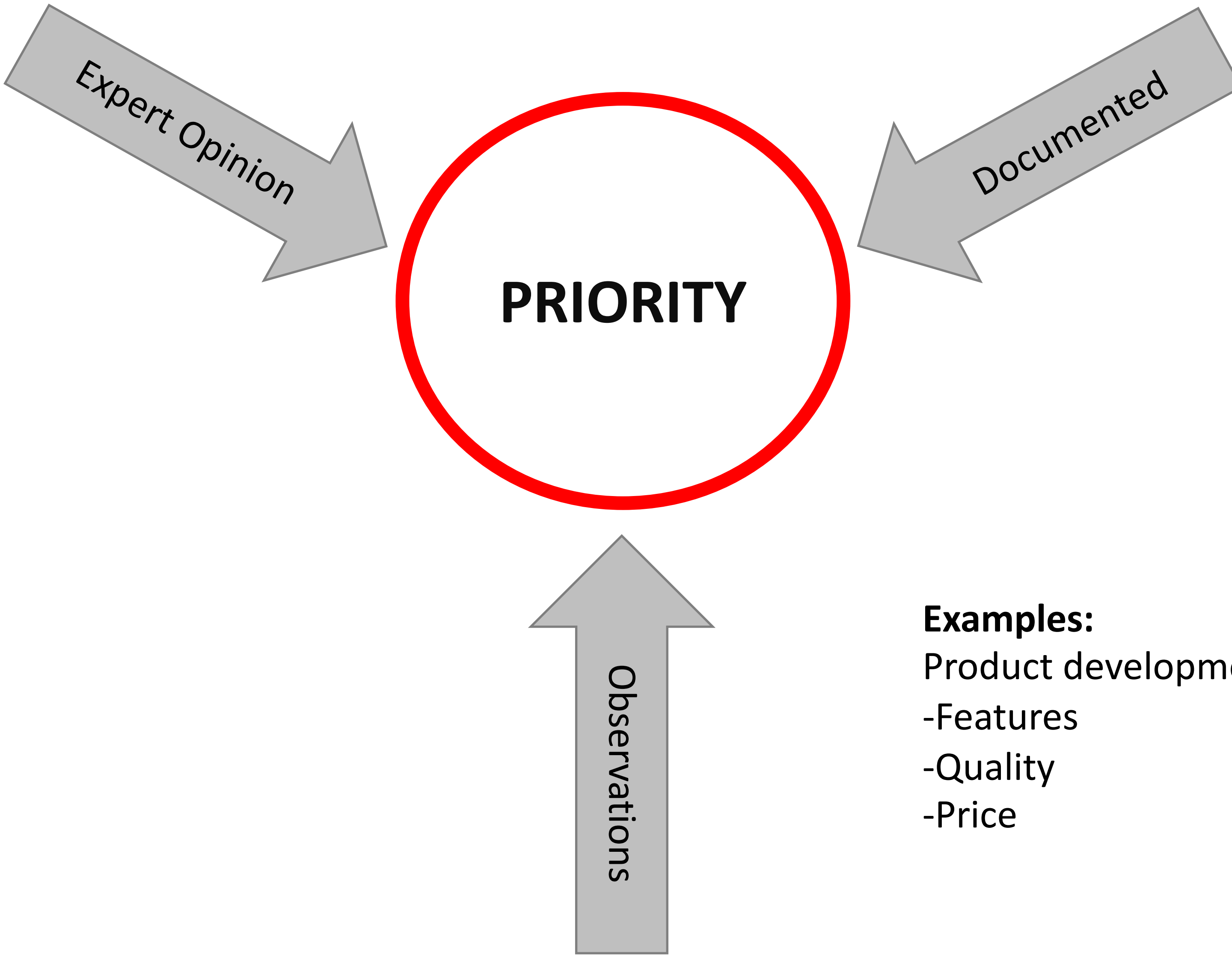
e.g., Decision theory based Analytic Hierarchy Process (AHP)

- AHP is a statistical measure to support complex decisions involving the comparison of elements that are difficult to quantify.
- The first step in the Analytic Hierarchy Process (AHP) is to develop a structure of the model.
- Followed by pairwise comparison of the model components; this gives weight to each element within a model.
- The process also involves determination of consistency ratio (CR): a consistency check of the comparisons.

Intensity of Importance	Definition	Explanation
1	Equal importance	Two variables contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one variable over another
5	Strong importance	Experience and judgement strongly favour one variable over another
7	Very strong or demonstrated importance	A variable is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one variable over another is of the highest possible order of affirmation
2, 4, 6,8	Intermediate Importance	When compromise is needed

Scale of relative importance (Saaty, 2008)

How to determine the relative weightage?

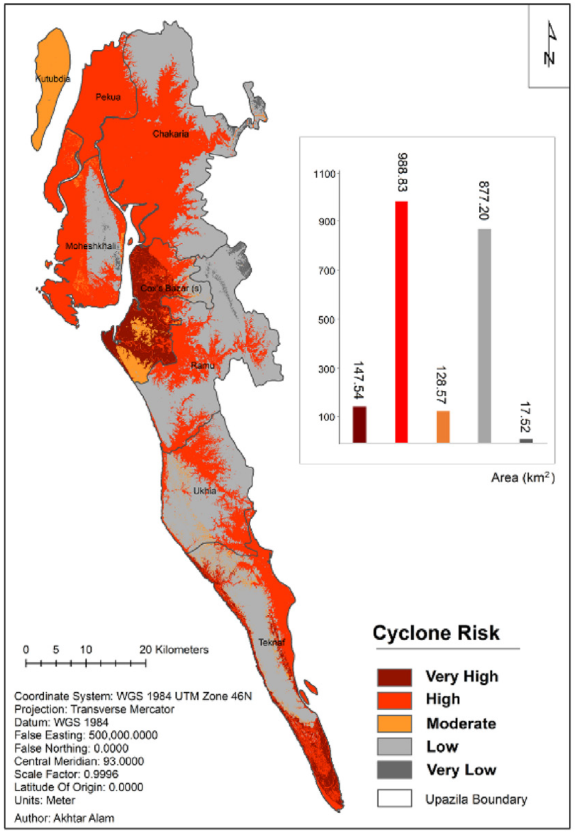


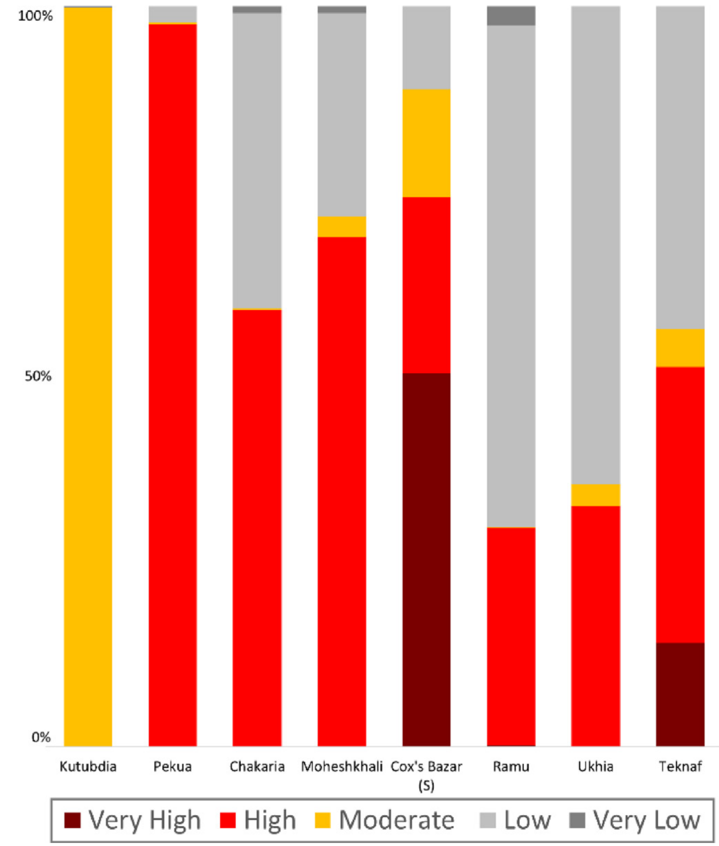
Examples:
Product development
-Features
-Quality
-Price

Relative importance of the selected parameters derived through AHP.

Risk Component	Criterion	Priority	Rank
Hazard	Cyclone intensity (TS-H3)	17.6%	1
	Cyclone frequency (number)	14.5%	3
	Storm surge (m)	16.2%	2
	Rainfall (mm)	3.0%	9
Exposure	Proximity to coastline (km)	8.6%	5
	Elevation (m)	9.9%	4
	Land cover (category)	2.5%	11
	Population Size (000)	2.5%	12
Vulnerability	Population density (km^2)	7.4%	7
	Female population size (000)	3.0%	8
	Population with disability (%)	2.2%	13
	Literacy (%)	2.1%	14
	Cyclone shelters (number)	7.9%	6
	Healthcare facilities (ratio: 000)	2.5%	10

Simulated cyclone risk of the Cox’s Bazar district.



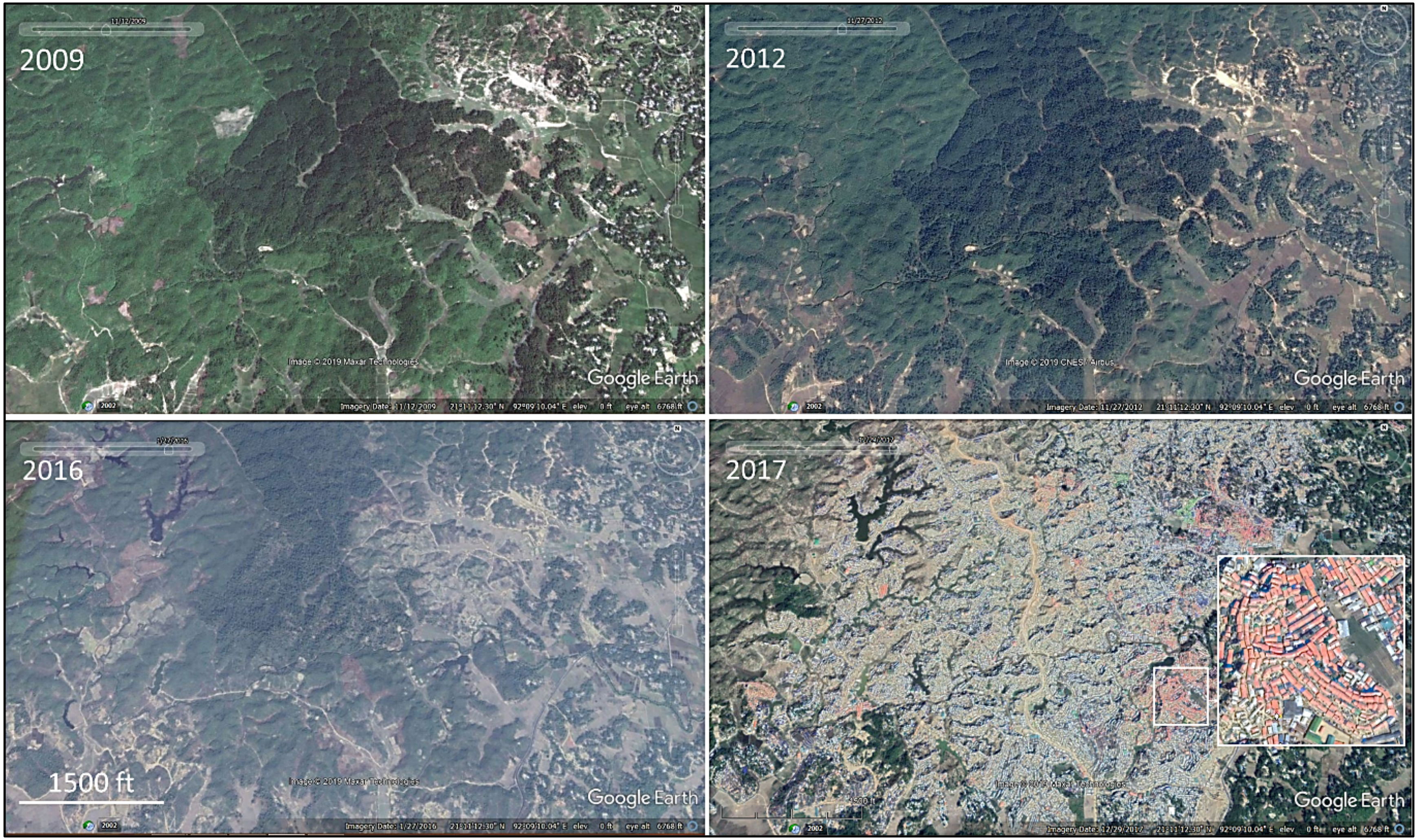


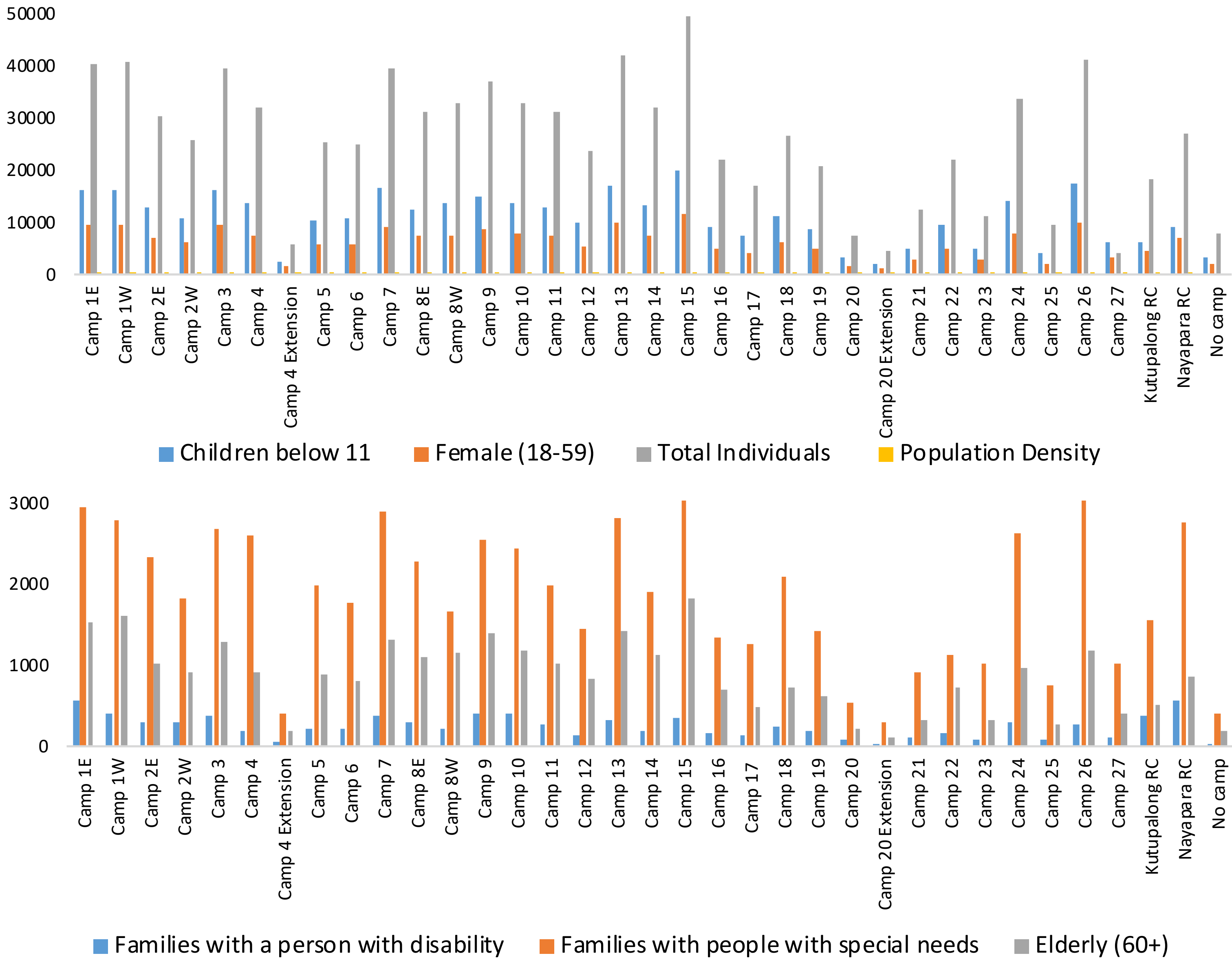
With the weighted overlay analysis of all the parameters representing hazard, exposure, and vulnerability, we simulated the cyclone risk in the Cox’s Bazar district.

The influence of few parameters such as intensity and frequency of the storms, inundation from the surge, population density, and availability of the cyclone shelters has been dominant in determining the overall risk of a particular location.

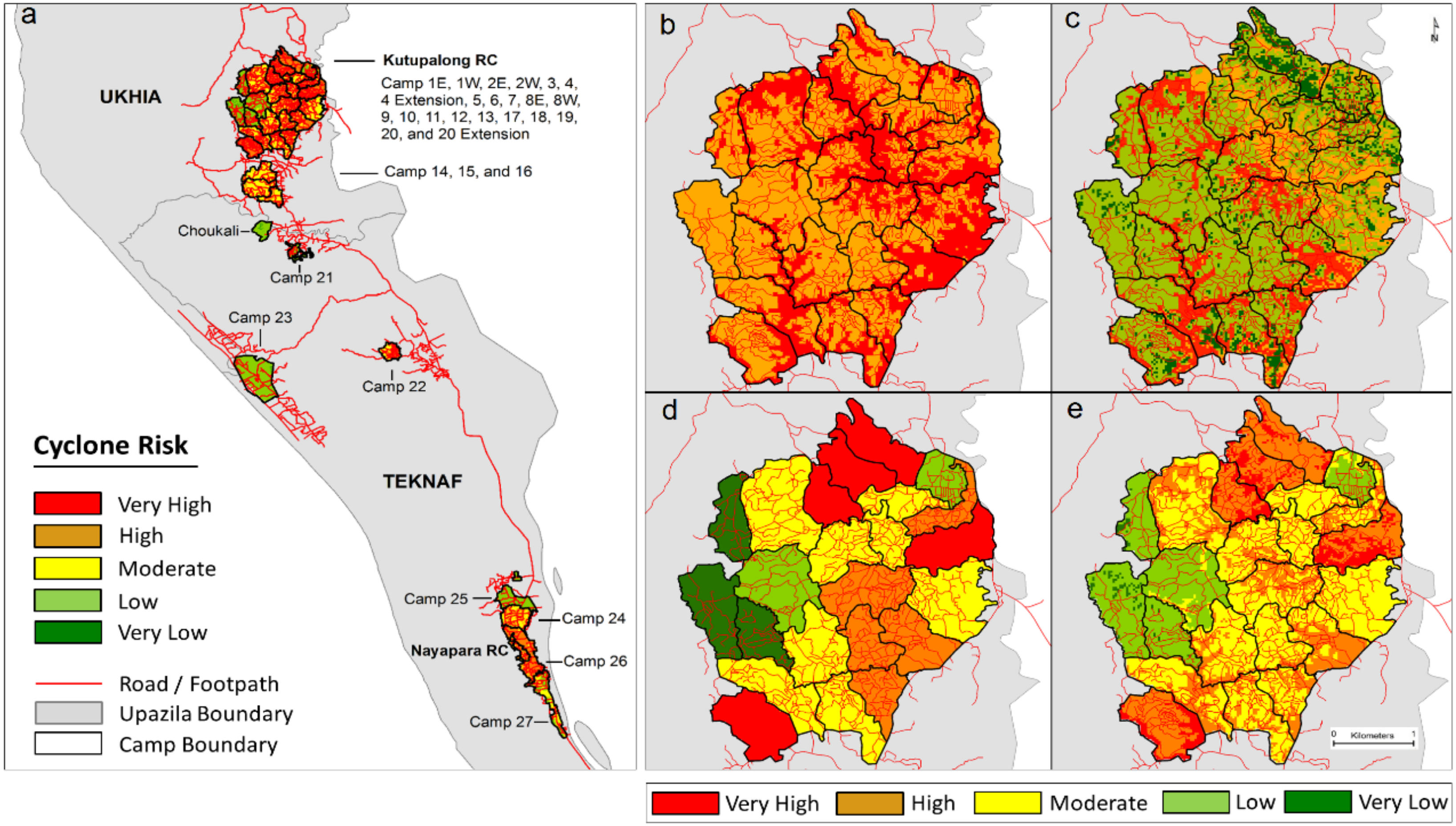
Rohingya:

- Largest stateless
- Most persecuted
- Violence against them: A textbook example of ethnic cleansing
- One of the world's largest and fastest exodus





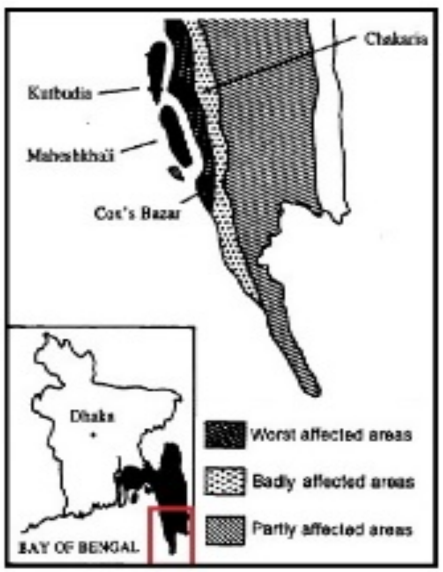
Demographic attributes of the Rohingya refugees that make them vulnerable.

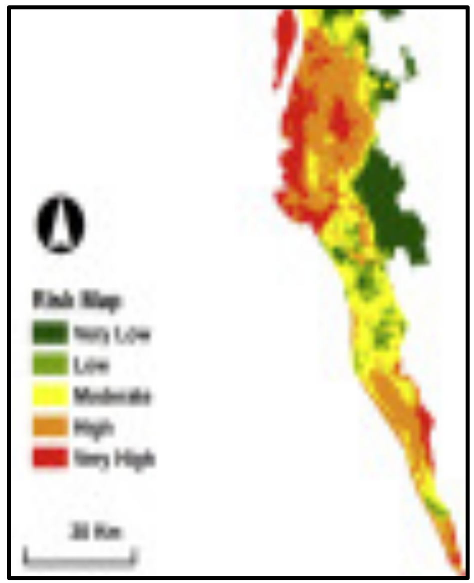


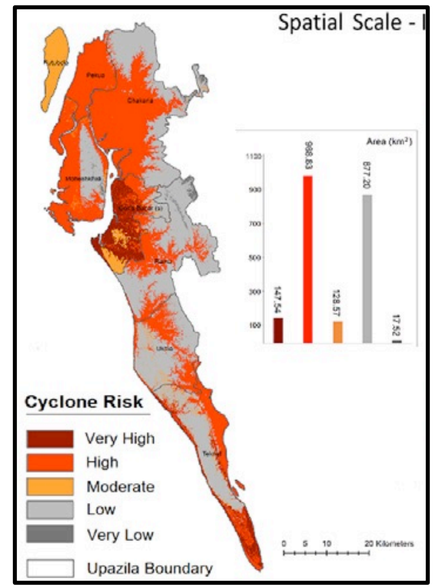
Simulated cyclone risk scenario of the Rohingya refugee camps; (b) hazard, (c) exposure, (d) vulnerability and (e) risk — scenario of the Kutupalong-RC cluster.

Correlation of the simulated risk:

Eastern coast of Bangladesh was worst hit during the deadly cyclone in 1991. Cox's Bazar was one of the districts where maximum deaths were reported because of this cyclone (Hoque et al., 1993).







Observed Impacts (1993) **Hoque et al., 2019** **Alam et al., 2019**

Limitations and uncertainties

There are some **inherent limitations** of the data and the uncertainties involved in the pre-event risk assessment that may influence the results of the analysis and future use of the deliverables.

The principal limitation of the study is that it assumes the components of the risk as static; however, in real world almost all of the **selected parameters are dynamic in nature.**

The **quality of data** is another important issue that influences the results; e.g., in this analysis we used **ALOS DSM** which is a low resolution data for developing the depth scenario of the storm surge; hence, we had to assume the depth of the storm surge as constant (10 m). In reality the water depth would decrease with increasing distance towards the land area, consequently the impacts of the surge cannot be expected as constant for the whole area.

Moreover, use of the **administrative boundaries** to represent a phenomenon is often a generalization that distorts in-situ information.

Another important aspect is the use of statistical method (**AHP**) where the relative weightage of the chosen parameters is **subjective**. The relative weight assigned to each parameter selected for a particular study may differ from one researcher to another; it is therefore likely that the results of the **studies even with similar objectives may be inconsistent**.

In spite of the various limitations and uncertainties, the deliverables of this analysis are useful from the functional and academic point of view because the multiple criteria decision making (MCDM) is logically flexible, **allowing incorporation of the maximum possible conditions and factors for replicating a process; as a result the derived scenarios often match considerably with the real world conditions.**

Google Scholar

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Decision Making AHP ANP

ARTICLES CITED BY

TITLE	CITED BY	YEAR
What is the analytic hierarchy process? TL Saaty Mathematical models for decision support, 109-121	60339 *	1988

What is the analytic hierarchy process? 40658
TL Saaty
Mathematical models for decision support, 109-121, 1988

Steps to follow:

1. Define the objective
2. Select the criterions
3. Set up a criteria comparison matrix (n x n)
4. Assign relative importance
5. Derive weights
6. Check consistency

Scale	Numerical Rating	Reciprocal
Extremely Preferred	**9**	**1/9**
Very strong to extremely	8	1/8
Very strongly preferred	**7**	**1/7**
Strongly to very strongly	6	1/6
Strongly preferred	**5**	**1/5**
Moderately to strongly	4	1/4
Moderately preferred	**3**	**1/3**
Equally to moderately	2	1/2
Equally preferred	**1**	**1**

	A	**B**	**C**	**D**	**E**	**F**
A	1	0.33	0.2	0.11	0.14	3
B	3	1	0.33	0.14	0.33	3
C	5	3	1	0.2	0.2	3
D	9	7	5	1	3	7
E	7	3	5	0.33	1	9
F	0.33	0.33	0.33	0.14	0.11	1

4. Sum up the columns

	A	B	C	D	E	F
A	1	0.33	0.2	0.11	0.14	3
B	3	1	0.33	0.14	0.33	3
C	5	3	1	0.2	0.2	3
D	9	7	5	1	3	7
E	7	3	5	0.33	1	9
F	0.33	0.33	0.33	0.14	0.11	1
SUM	25.33	14.66	11.86	1.92	4.78	26

5. Normalize the comparison matrix: dividing each criterion in each column by the sum of that column.

	A	B	C	D	E	F
A	0.04	0.02	0.02	0.06	0.03	0.12
B	0.12	0.07	0.03	0.07	0.07	0.12
C	0.2	0.2	0.08	0.1	0.04	0.12
D	0.36	0.48	0.42	0.52	0.63	0.27
E	0.28	0.2	0.42	0.17	0.21	0.35
F	0.01	0.02	0.03	0.07	0.02	0.04
SUM	1	1	1	1	1	1

6. Sum and average each row in the normalized matrix (W).

	A	B	C	D	E	F	SUM	SUM/6 Weight (W)	%
A	0.04	0.02	0.02	0.06	0.03	0.12	0.280818	0.046803	4.680292
B	0.12	0.07	0.03	0.07	0.07	0.12	0.471813	0.078636	7.86355
C	0.2	0.2	0.08	0.1	0.04	0.12	0.747742	0.124624	12.46237
D	0.36	0.48	0.42	0.52	0.63	0.27	2.672064	0.445344	44.5344
E	0.28	0.2	0.42	0.17	0.21	0.35	1.62981	0.271635	27.16349
F	0.01	0.02	0.03	0.07	0.02	0.04	0.197754	0.032959	3.295894

Consistency Ratio (CR):

Since the decisions made about the priorities of the criterions may not be perfect, the AHP requires a consistency check of the pairwise comparison matrix, which is being done by calculating the consistency ratio (CR).

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}$$

where CI is the consistency index (CI), calculated as:

$$\mathrm{CI} = \frac{(\lambda max - \mathrm{n})}{\mathrm{n} - 1}$$

where λmax is the average eigenvalue of the matrix and *n* represents the size of the matrix; RI is the random index representing the consistency of a randomly generated pairwise comparison matrix.

Multiply each column in comparison matrix (original) with preference Vector (Weight-W) of the corresponding row.

	A	B	C	D	E	F
A	1	0.33	0.2	0.11	0.14	3
B	3	1	0.33	0.14	0.33	3
C	5	3	1	0.2	0.2	3
D	9	7	5	1	3	7
E	7	3	5	0.33	1	9
F	0.33	0.33	0.33	0.14	0.11	1

X

SUM/6 Weight (W)
0.046803
0.078636
0.124624
0.445344
0.271635
0.032959

Average value of the SUM/W gives the λ (Eigenvalue).

	A	B	C	D	E	F	SUM	SUM/W
A	0.046	0.02574	0.0248	0.04895	0.03794	0.096	0.27943	5.970344
B	0.138	0.078	0.04092	0.0623	0.08943	0.096	0.50465	6.417544
C	0.23	0.234	0.124	0.089	0.0542	0.096	0.8272	6.637566
D	0.414	0.546	0.62	0.445	0.813	0.224	3.062	6.875584
E	0.322	0.234	0.62	0.14685	0.271	0.288	1.88185	6.927863
F	0.01518	0.02574	0.04092	0.0623	0.02981	0.032	0.20595	6.248673

Size of matrix	1	2	3	4	5	6	7	8
Random consistency	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41

Size of matrix	9	10	11	12	13	14	15
Random consistency	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Average 6.512929

(λ) Eigenvalue

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}$$

(Consistency Ratio)

0.1024

$$\mathrm{CI} = \frac{(\lambda max - \mathrm{n})}{\mathrm{n} - 1}$$

(Consistency Index)

1.24

RI

Random Index

CR = 0.08258

Thank you