Special session SS 49, 'Nature-based Solutions for water-related disaster prevention and mitigation'

Performance Evaluation of Potential Structural, Socio-economic and Nature-based Solutions for Flood Risk Reduction

Subhankar Karmakar

Professor & Head, Environmental Science and Engineering Department,
Vinaya & Samir Kapoor Chair in Climate Studies, Interdisciplinary Program in Climate Studies
Associate Faculty, Centre for Urban Science and Engineering,
Indian Institute of Technology Bombay, Mumbai 400 076, India

Global flood perspective

- The average annual maximum precipitation amount in a day as well as daily mean precipitation intensities have increased since the mid-20th century in a majority of land regions (Seneviratne, 2021), leading to rise in flooding events
- ‘Floods have the greatest damage potential of all natural disasters and affect the largest number of people’ (UNDP, 2004)
- Flood risk management essential to minimize the potential harmful impacts as much as possible
- Flood inundation mapping, flood risk forecasting and warning systems plays a crucial role in managerial decisions and timely evacuation during the time of floods
- Advances in flood risk forecasting based on precipitation forecasts, topography, and socio-economic aspects of a region to prioritize emergency response measures, beyond the current state of the art, are yet to be explored.

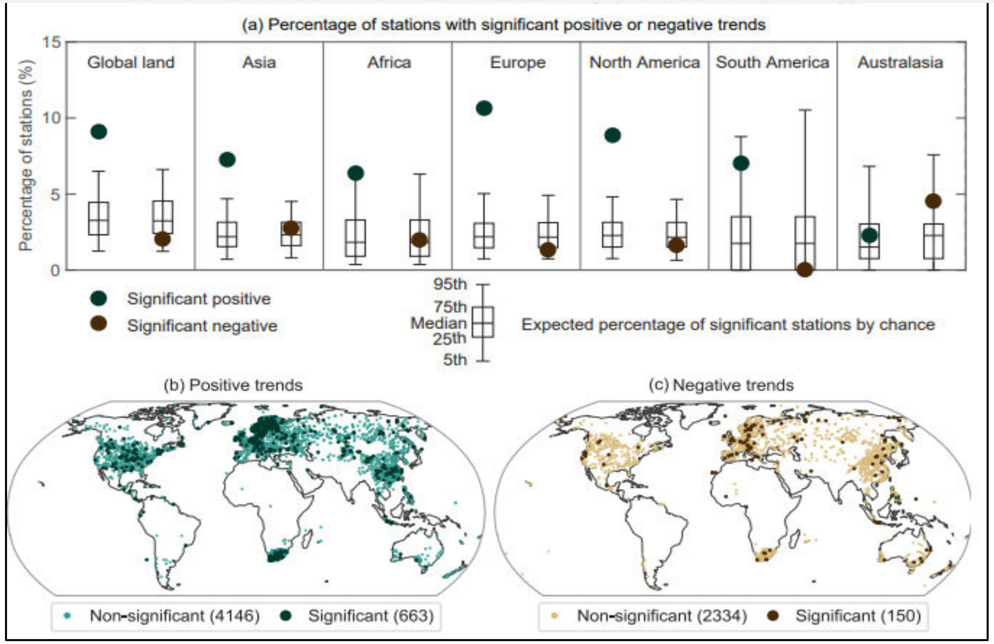
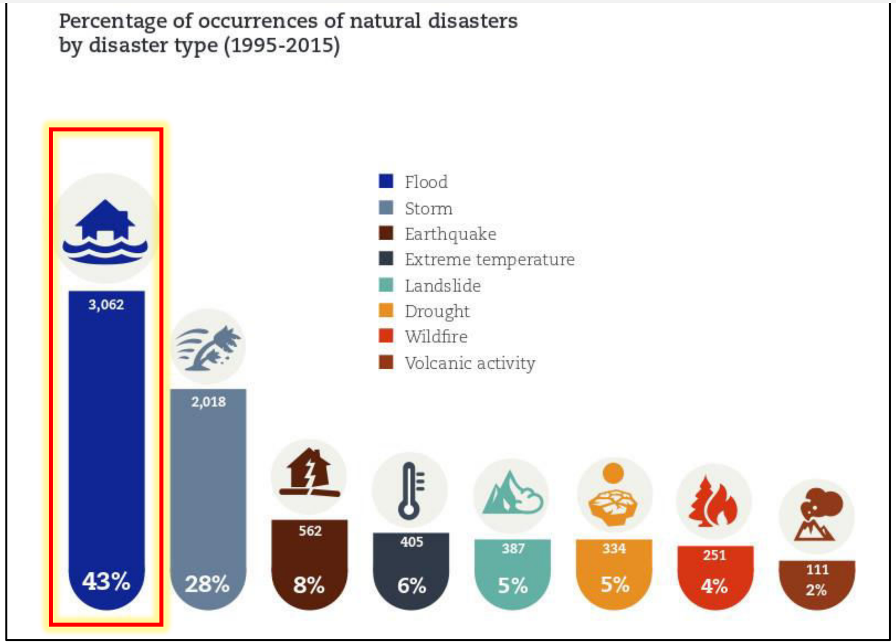
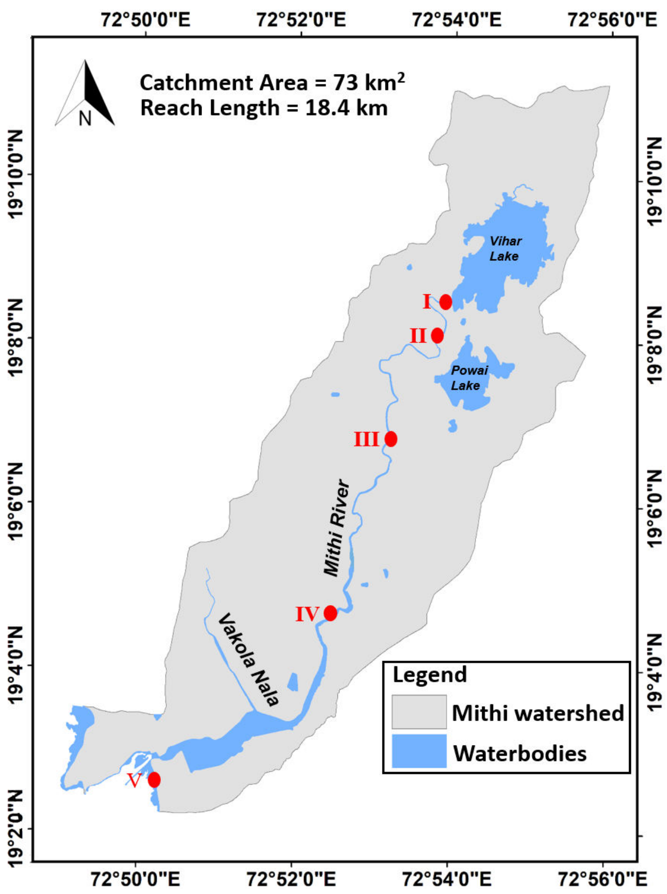


Figure: Signs and significance of the observed trends in annual maximum daily precipitation (Rx1day) during 1950–2018 at 8345 stations with sufficient data (Source: IPCC 2021, AR6, Working Group I, Chapter 11)



Source: United Nations Office for Disaster Risk Reduction

Performance evaluation of potential inland flood management options through a 3-way coupled hydrodynamic modelling for a coastal urban catchment



Four distinct reaches:

- **I-II: Origin to Jogeshwari Vikhroli Link Road (JVLR): Bed Gradient is 1:200 (Very Steep Gradient).**
- **II-III: JVLR to MV Road: Bed Gradient is 1:450 (Steep Gradient).**
- **III-IV: MV Road to CST Bridge: Bed Gradient is 1:850 (Moderate Gradient)**
- **IV-V: CST Bridge to Mahim causeway in BKC area: Bed Gradient is 1:4000 (Flat gradient) (Khan et al., 2014, Zope et al., 2015)**

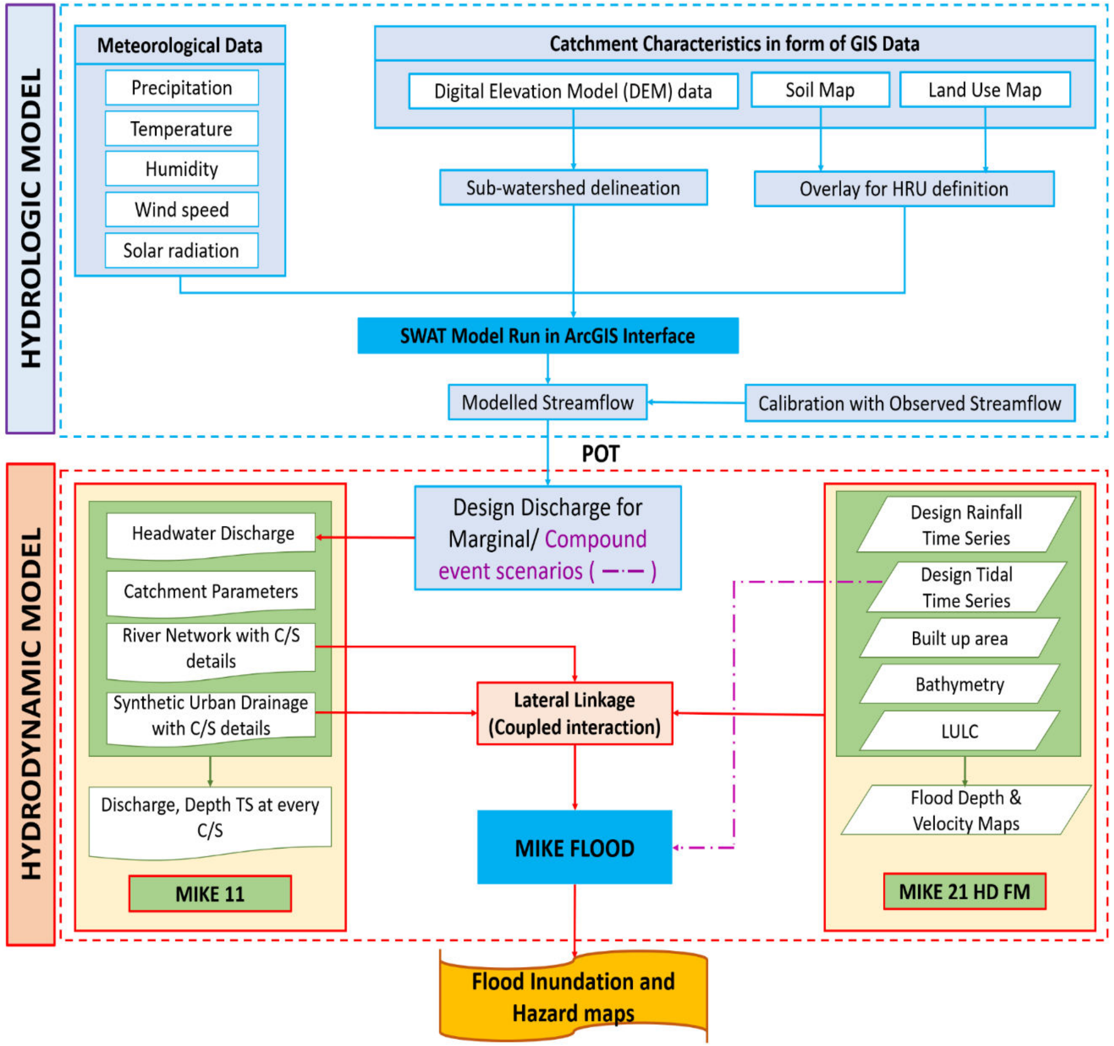


Figure: Framework adopted in the development of 3-way coupled hydrodynamic flood model

Subhankar Karmakar, IIT Bombay, Mumbai, India

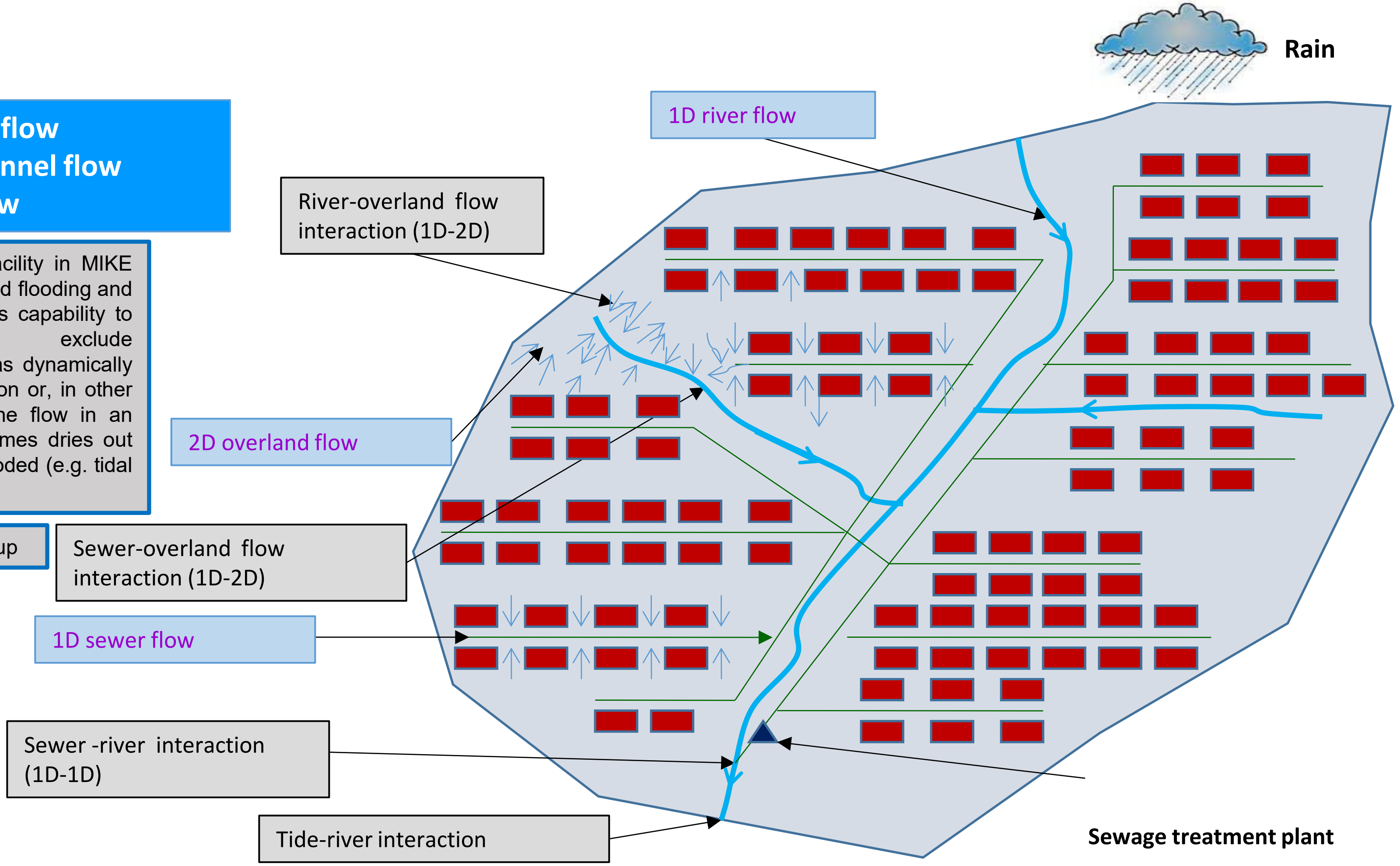
Modeling Framework *A complete three-way hydrodynamic flood modeling in a coastal urban catchment (considering tidal impact)*

1. **Overland flow**
2. **River/channel flow**
3. **Sewer flow**

- ❖ A very valuable facility in MIKE FLOOD is advanced flooding and drying condition: its capability to include and exclude computational areas dynamically during the simulation or, in other words, compute the flow in an area which sometimes dries out and sometimes flooded (e.g. tidal flats).

- ❖ Flexible mesh Set-up

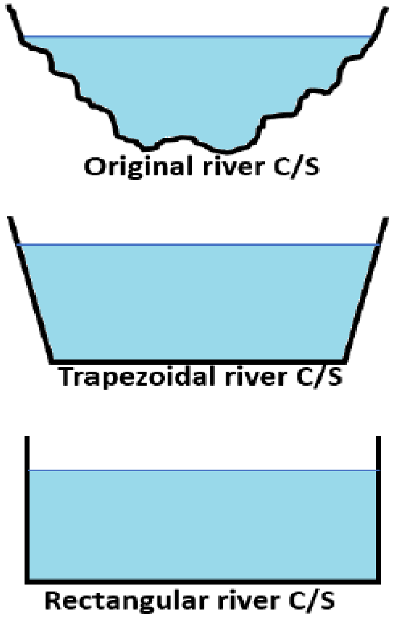
- ❖ Steep slope
- ❖ module



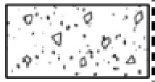
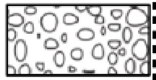
Schematic diagram of a coastal urban catchment

Different scenarios considered (for flood mitigation as per the plan of MMRDA – apex civic body)

Cross-sections considered in the flood model



Manning's N considered in the flood model

- River C/S with default Manning's N value
- Concrete lining material 
- Gravel lining material 

Sl.No.	Description of Hydraulic Options
I	Original C/S with river bed channel having default manning's n value of 0.04
II	Trapezoidal C/S with river bed channel having default manning's n value of 0.04
II (A)	Trapezoidal C/S with river bed channel completely lined with concrete (manning's n value of 0.012)
II (B)	Trapezoidal C/S with river bed channel completely lined with gravel (manning's n value of 0.02)
II (C)	Trapezoidal C/S with river bed channel lined with concrete after Qube hotel (manning's n value of 0.012)
II (D)	Trapezoidal C/S with river bed channel lined with gravel after Qube hotel (manning's n value of 0.02)
II (E)	Original C/S with river bed channel having default Manning's n value of 0.04 till Qube hotel but trapezoidal C/S with river bed channel lined with concrete (Manning's n=0.012) after Qube hotel
II (F)	Original C/S with river bed channel having default Manning's n value of 0.04 till Qube hotel but trapezoidal C/S with river bed channel lined with gravel (Manning's n=0.02) after Qube hotel
III	Rectangular C/S with river bed channel having default manning's n value of 0.04
III (A)	Rectangular C/S with river bed channel completely lined with concrete (manning's n value of 0.012)
III (B)	Rectangular C/S with river bed channel completely lined with gravel (manning's n value of 0.02)
III (C)	Rectangular C/S with river bed channel lined with concrete after Qube hotel (manning's n value of 0.012)
III (D)	Rectangular C/S with river bed channel lined with gravel after Qube hotel (manning's n value of 0.02)
III (E)	Original C/S with river bed channel having default Manning's n value of 0.04 till Qube hotel but rectangular C/S with river bed channel lined with concrete (Manning's n=0.012) after Qube hotel
III (F)	Original C/S with river bed channel having default Manning's n value of 0.04 till Qube hotel but rectangular C/S with river bed channel lined with gravel (Manning's n=0.02) after Qube hotel

Figure: Description of various hydraulic options developed through utilization of different cross-sections and lining materials

Ghosh, Mousumi, Mohit Prakash Mohanty, Pushpendra Kishore, and Subhankar Karmakar. "Performance evaluation of potential inland flood management options through a three-way linked hydrodynamic modelling framework for a coastal urban watershed." *Hydrology Research* 52, no. 1 (2021): 61-77.

Flood inundation maps

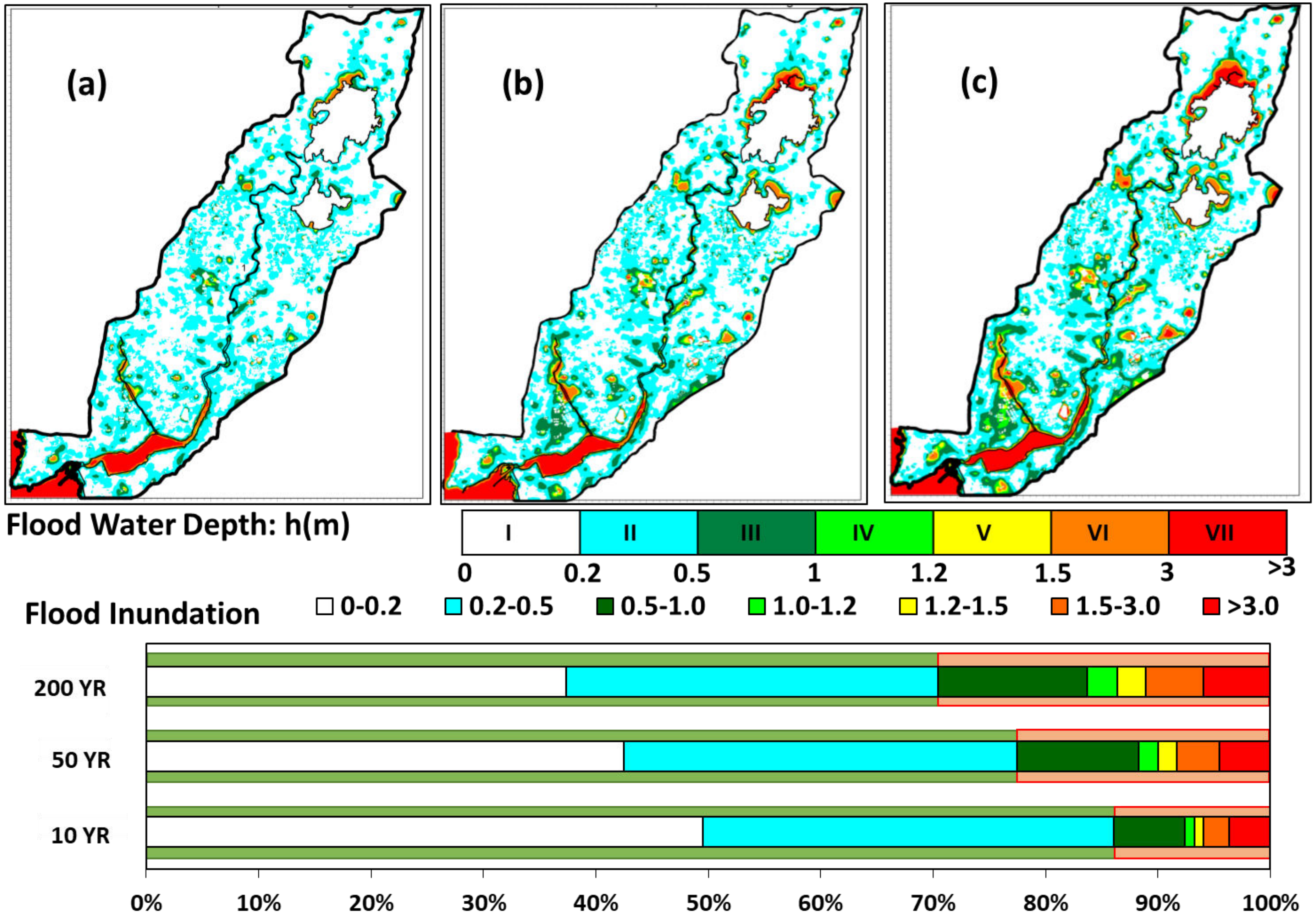


Figure: Flood inundation maps for (a) 10 YR, (b) 50 YR and (c) 200 YR return period for original C/S

Flood hazard maps

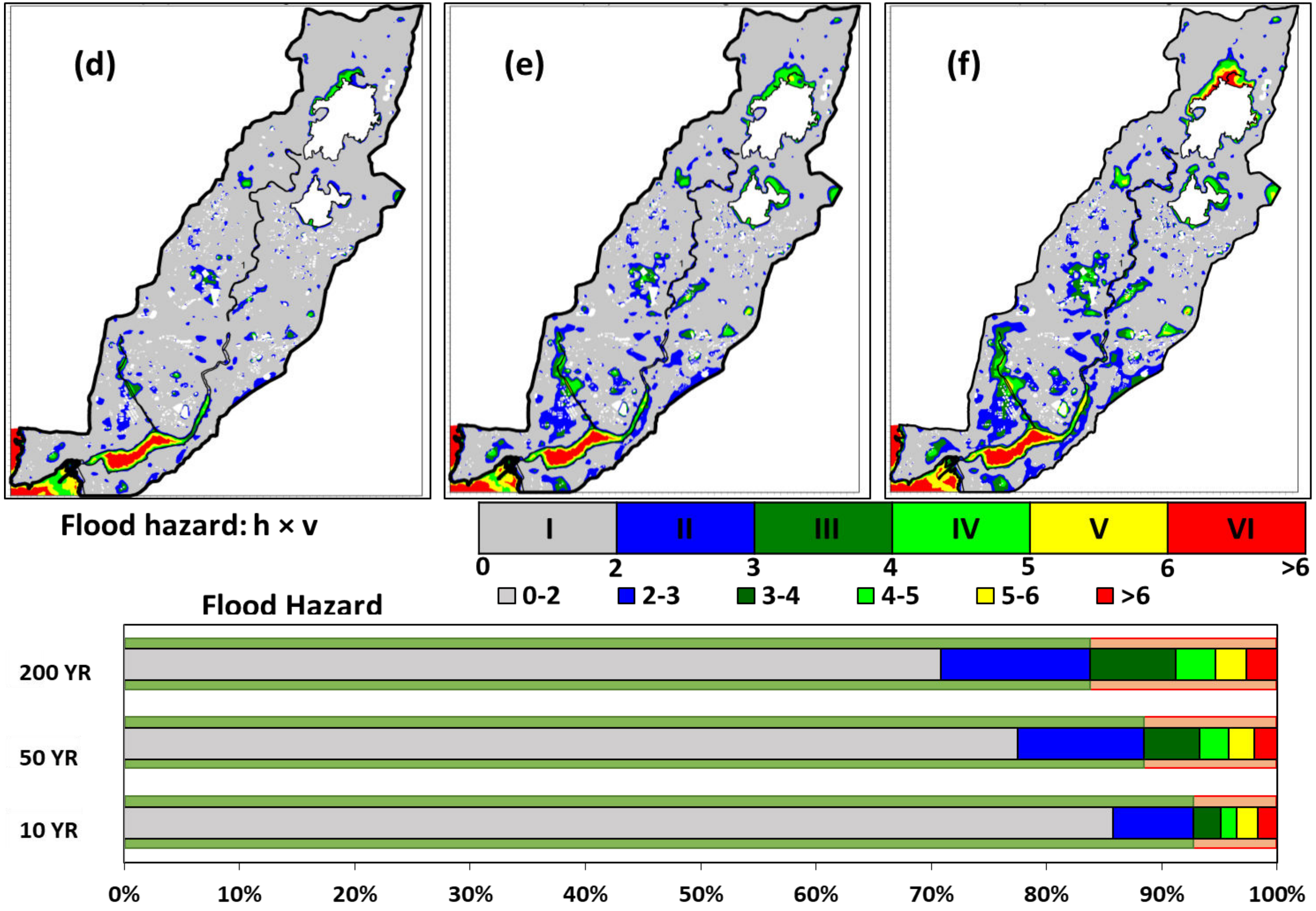
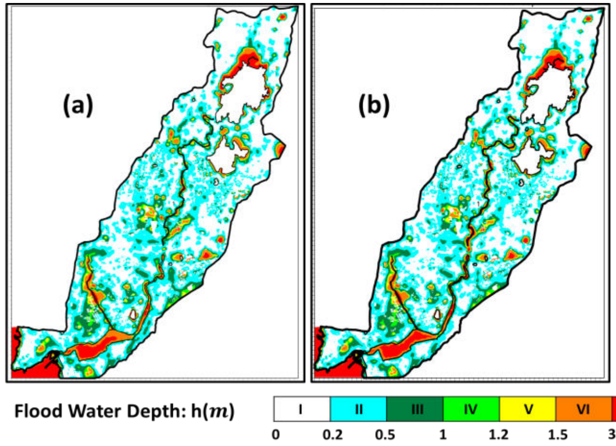


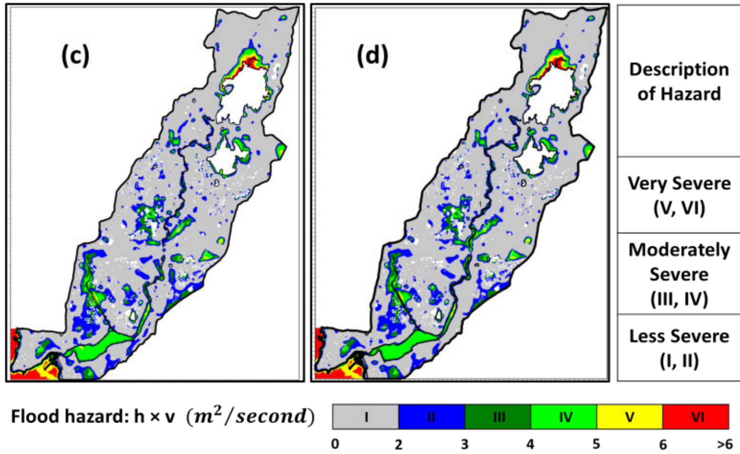
Figure: Flood hazard maps for (d) 10 YR, (e) 50 YR and (f) 200 YR return period for original C/S

Flood inundation and hazard maps

The ‘trapezoidal C/S lined with concrete was found to be the best possible scenario for flood control adaptation strategy, based on the reduction of ‘very severe’, and ‘moderately severe’ flooded cells in inundation and hazard maps when compared with maps of original scenario.



Description of Inundation	Number of cells under each index		
	Original C/S Scenario I	Scenario II (E)	Scenario III (E)
Very Severe (V, VI, VII)	94717	90159	91657
Moderately Severe (III, IV)	110916	109198	104943
Less Severe (I, II)	490777	497053	499790



Description of Hazard	Number of cells under each index		
	Original C/S Scenario I	Scenario II (E)	Scenario III (E)
Very Severe (V, VI)	37047	30538	31236
Moderately Severe (III, IV)	75785	77834	79868
Less Severe (I, II)	583578	588038	585306

Figure: Flood Inundation maps (a) scenario II(E), (b) scenario III (E) and hazard maps (c) scenario II(E), (d) scenario III (E) for best-performing scenarios for 200 YR RP

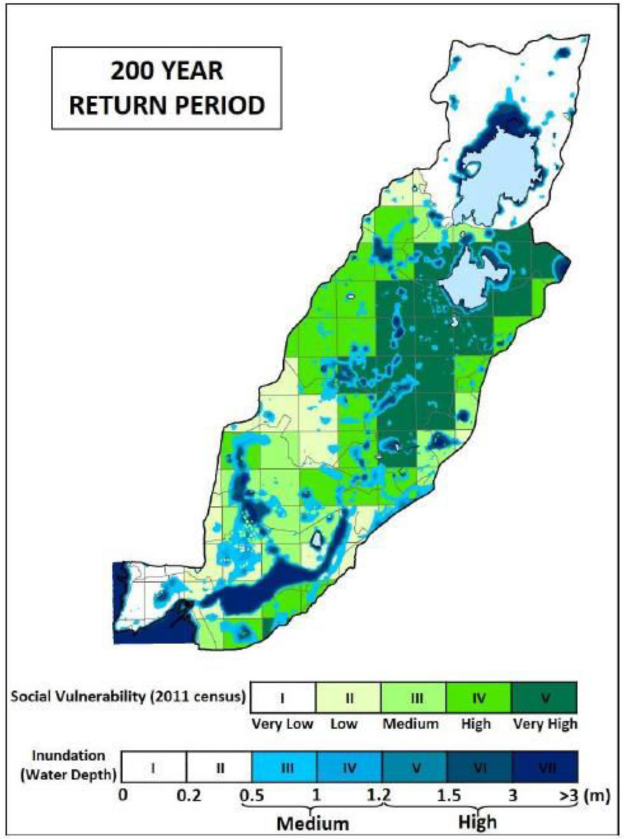


Figure: Flood inundation map for Mithi catchment for 200-yr RP overlaid on the social vulnerability map derived from 2011 census data

Uncertainty analysis

1) Uncertainty in water depth of flood

$$ADD = \left| DW_{mesh(2500m^2),CN(0.7)} - DW_{mesh(i),CN(j)} \right|$$

where ADD is the mean absolute difference in depth of water, $DW_{mesh(2500m^2),\ CN(0.7)}$ is the maximum water depth simulated by a combination of mesh size 2500 m^2 and courant number 0.7, and $DW_{mesh(i),\ CN(j)}$ is the water depth simulated by the corresponding combination of mesh and Courant number.

2) Uncertainty in the spatial extent of flood

$$SI = \frac{A_{mesh(2500m^2),\ CN(0.7)} \cap A_{mesh(i),\ CN(j)}}{A_{mesh(2500m^2),\ CN(0.7)} \cup A_{mesh(i),\ CN(j)}}$$

where SI is the measure of similarity index, $A_{mesh(2500m^2),\ CN(0.7)}$ is the inundation area simulated with the combination of mesh size 2500 m^2 and courant number 0.7, $A_{mesh(i),\ CN(j)}$ is the inundation area simulated with other combinations of mesh sizes and courant numbers.

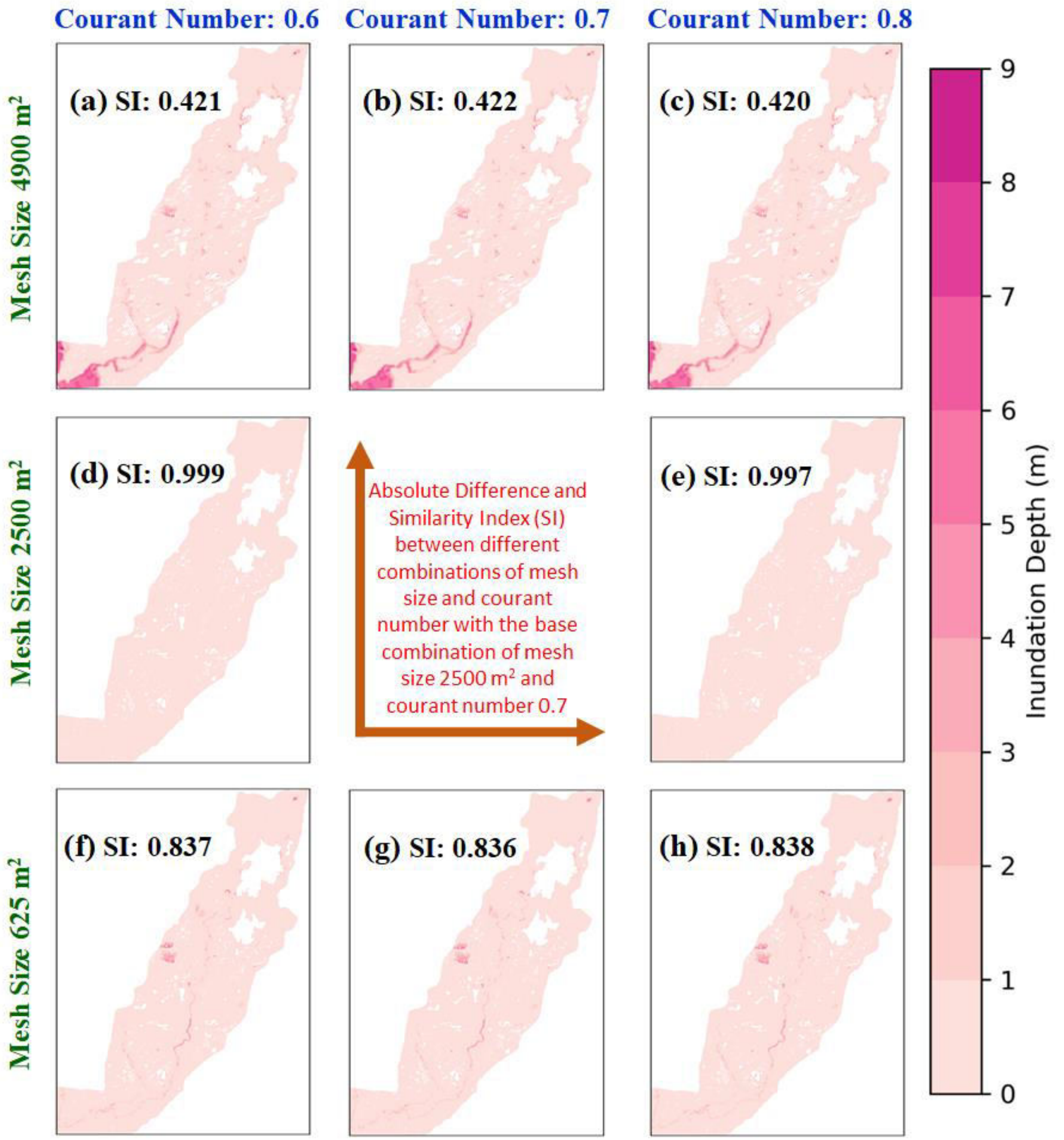


Fig: Uncertainty analysis for various combinations of mesh size and courant number

Assessment of various <u>socio-economic alternatives</u> to alleviate flood-risk

- ❑ Flood risk assessment is an important non-structural flood management strategy that warrants global attention
- ❑ Flood risk (*R*) consists of two major components (Koks et al., 2015)
  - (i) Hazard (***H***) - Probability of occurrence of flood at a specific location in space and time
  - (ii) Vulnerability (***V***) - Susceptibility and degree to which various physical, social, economic and environmental conditions might be affected during floods(UNISDR, 2009; Boudou et al. 2016)
- ❑ It is expressed as the combination of *H* and *V*.

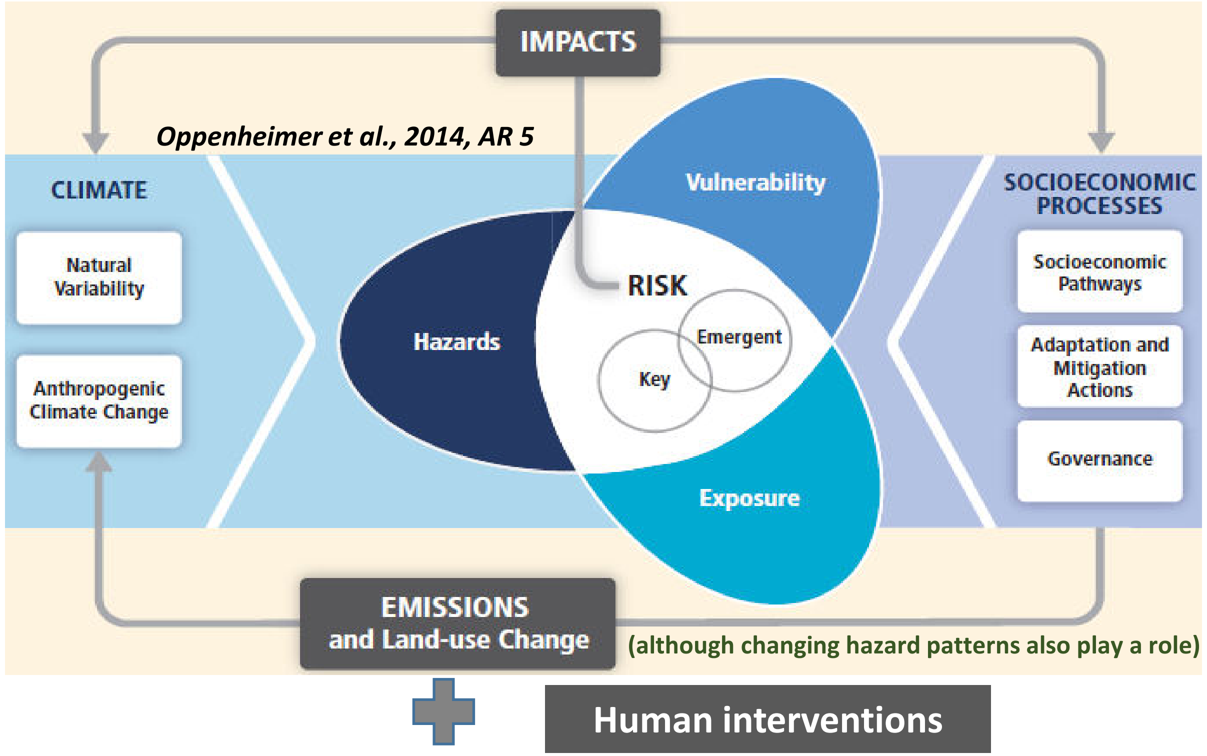


Figure: Schematic of the interaction among the physical climate system, exposure, and vulnerability producing risk

Socio-economic vulnerability mapping

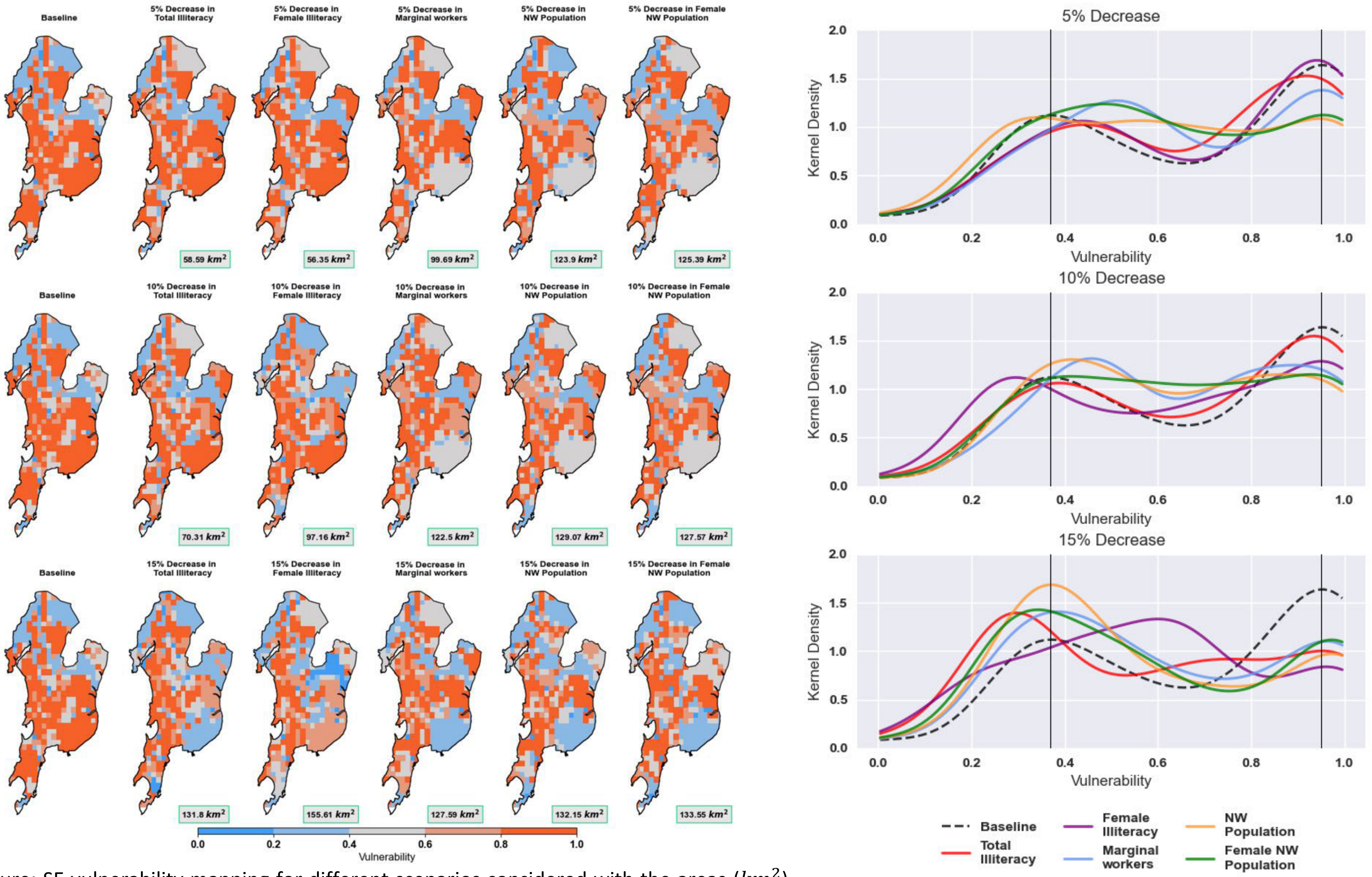


Figure: SE vulnerability mapping for different scenarios considered with the areas (km^2) having a decrease in vulnerability mentioned at the bottom right of each subplot

Hazard mapping (Flood inundation mapping)

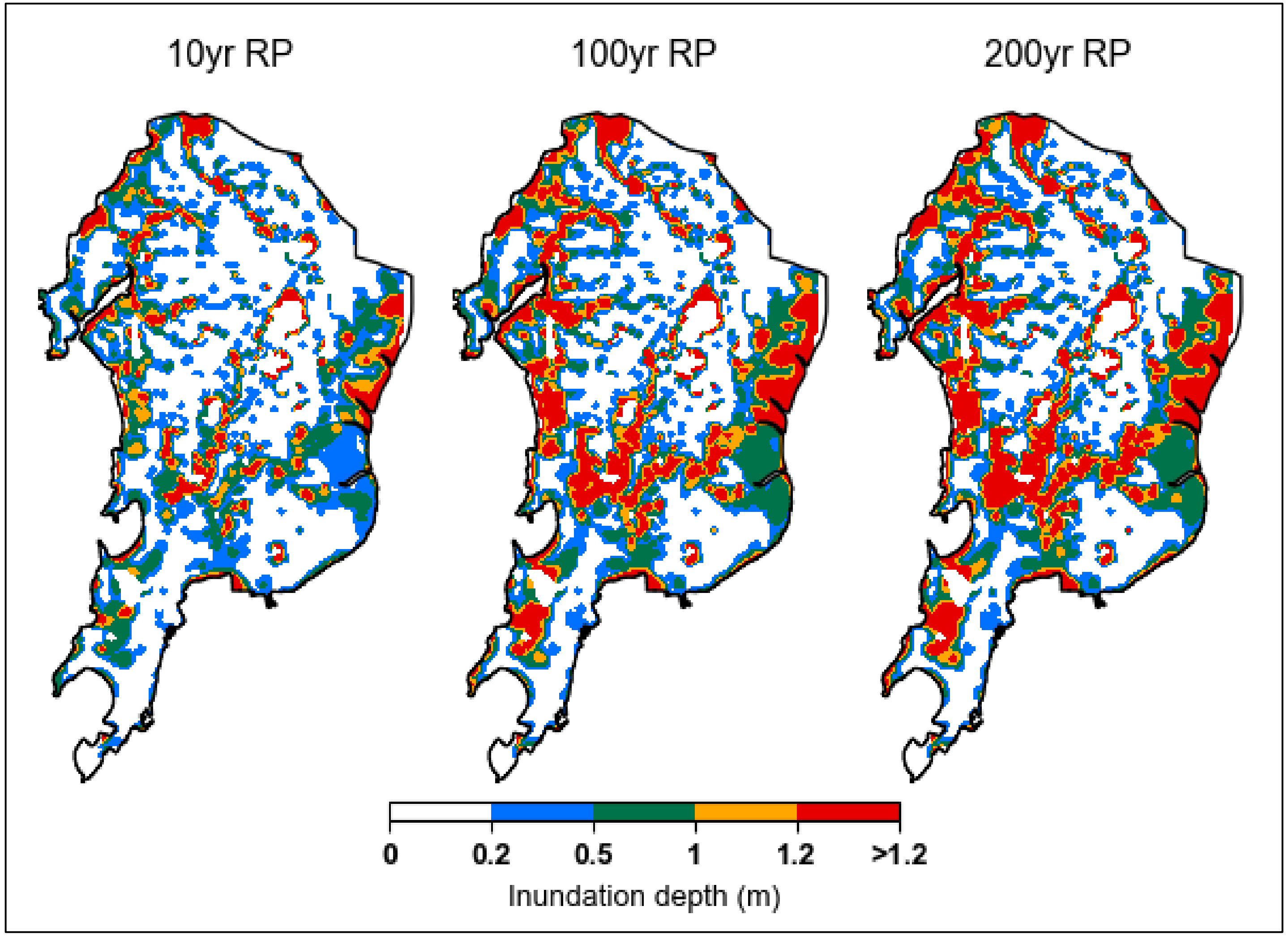


Figure: Inundation maps for (a) 10 year (b) 100 year (c) 200-year return period

Bivariate risk mapping

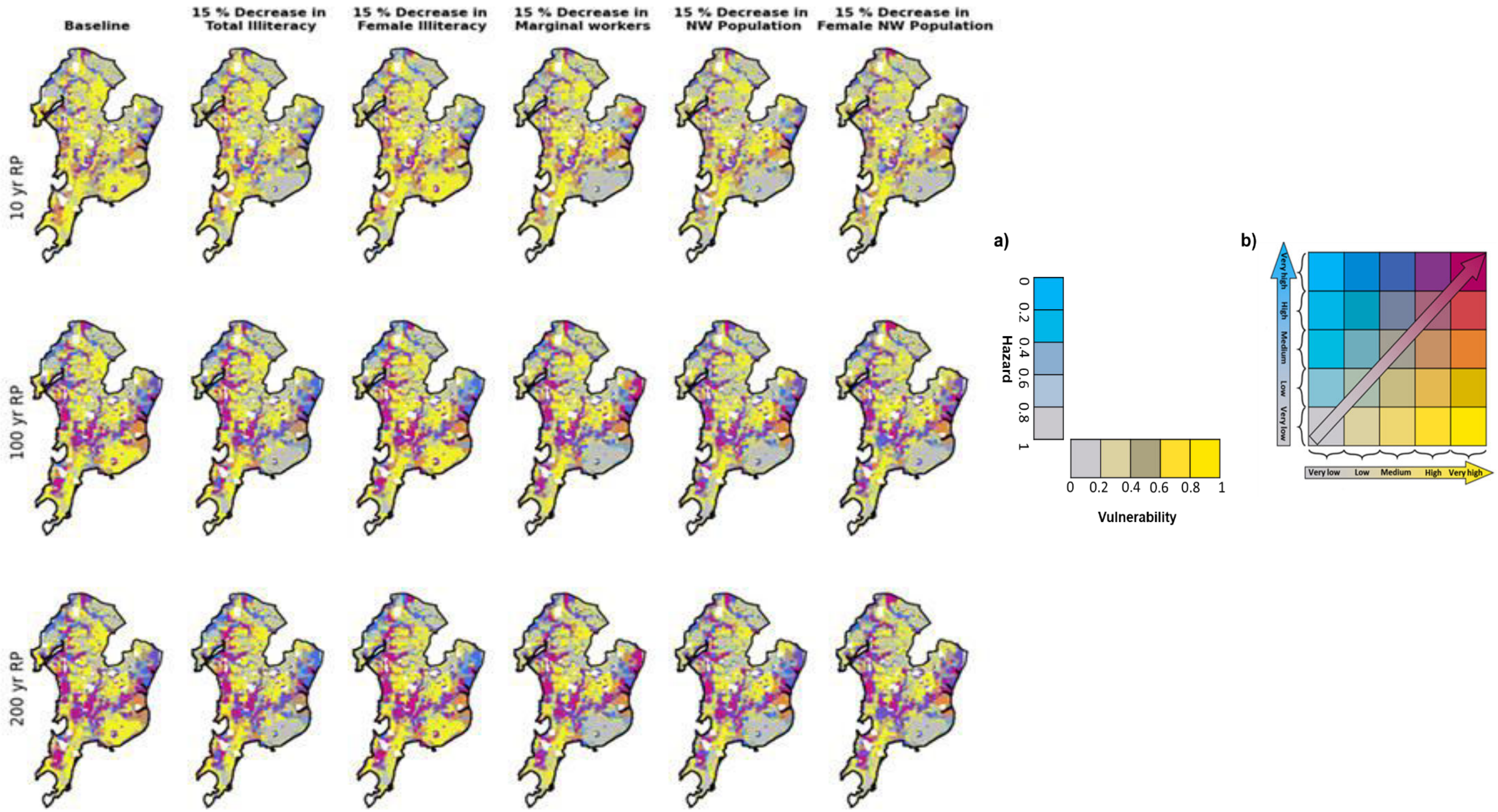


Figure: Bivariate risk maps derived for 10-, 100- and 200-year return periods socio-economic vulnerability scenarios considering for 15% reduction

Nature-based solutions: A way forward on flood management strategies

Nature-based solutions (NBS): The concept of nature-based flood management involves utilizing natural processes and features to mitigate the impacts of flooding. The solutions used to manage water and reduce flooding risk work in harmony with the natural environment, rather than against it.

In flood management, nature-based solutions can be highly effective as they leverage natural systems and processes to reduce flood risks, enhance resilience, and minimize damage caused by floods.

NBS offers several advantages over conventional, engineered approaches for addressing flood risks and managing water resources environmentally and sustainably. Some of the key aspects are:

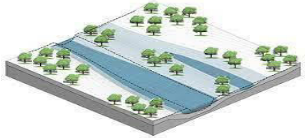
1) Ecosystem Services: enhance and preserve multiple ecosystem services they provide.
2) Resilience: adapt and evolve over time and resilient to changing climate
3) Cost-effectiveness: lower initial investments and maintenance costs over long-term than conventional approaches
4) Biodiversity conservation: create and restore habitats for several species
5) Community engagement: involve local communities in planning and implementation which fosters sense of stewardship and enhance social cohesion
6) Reduced energy consumption: lower energy requirements than conventional structural measures of flood management.

Sources: IUCN NbS Standard webpage

Types of NBS for flood management

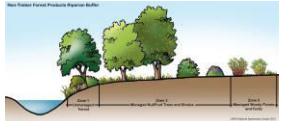
- Wetland restoration

- Floodplain restoration

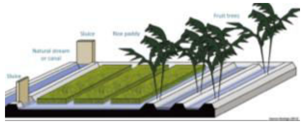


- Riverbank stabilization

- Riparian Buffer Zones

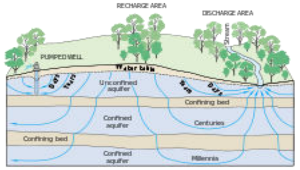


- Flood-resilient landscaping



- Erosion Control Measures

- Managed Aquifer Recharge



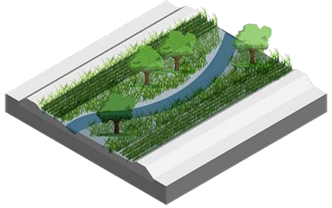
- Urban green infrastructure

- Natural Flood Barriers

- Restoring Urban Waterways

- Regenerative Agriculture

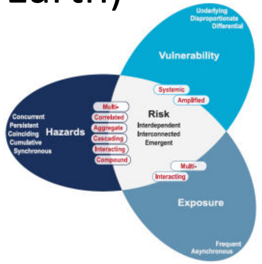
- Levee Setbacks



Conclusions

- A novel comprehensive framework is proposed to reduce the inundation extent by incorporation of different inland hydraulic scenarios into a 3-way coupled hydrodynamic flood model, considering various combinations of cross-sections and lining material options.
- A vulnerability and subsequently risk mapping framework addressing the socio-economic aspects (total population. illiterate population, households, elderly people and children, etc.) has been proposed to identify the key indicators which contribute in significant change in vulnerability and overall risk.
- The nature-based solutions can be used in combination with other flood management measures to reduce the risk of flooding in a cost-effective and sustainable manner.
- Some concerns in NBS may deserve our attention
    - Public acceptance
    - Lack of knowledge and understanding
    - Longer time frame
    - Space consumption in urban setups
    - Ecosystem disservices

Risk function: Triplet → Quadruplet (derived from IPCC, 2014 and Simpson et al., 2021, One Earth)



Conventional risk triplet of IPCC, AR5

New risk quadruplet integrating 'response' as a determinant of risk

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Thank you