Identification of Optimal Hydraulic Flood Management Scenarios for a Socially Vulnerable Urban Coastal Catchment: A 3-way Coupled Hydrodynamic Approach

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Abstract

With the rapid rise in flooding events induced by climate change across the globe, effective flood management strategies through modelling have garnered attention over the years. In the present study, we propose a holistic hydrodynamic flood modelling framework to derive the flooding extent. Various hydraulic scenarios are integrated into the framework which consider different combinations of cross-section and lining material options along the river channel for this purpose. A 3-way coupled flood model has been developed in MIKE FLOOD platform, over Mithi river catchment an extremely flood-prone area in Mumbai, the financial capital of India. Flood influencers such as precipitation, flows through the channel, overland, storm-water drains, and tidal influences are considered to generate flood inundation and hazard maps for the scenarios. The dearth of data in the model is met by implementing alternate robust procedures to compute the design values of the influencers. Subsequently, the maps are derived for different return periods of design precipitation, tidal elevation and streamflow values to identify the most desirable scenario. The proposed framework efficiently determines that the scenario having trapezoidal river cross-section with concrete lining material maximizes the decrease in spatial extent of flood in comparison to the other scenarios. This user-friendly generic approach can be potentially executed as an effective flood mitigation option in thickly populated and socially vulnerable regions where lack of space limit the implementation of structural measures for flood management. The framework can prove instrumental particularly for the developing and under-developed countries where application of these strategies is hindered by inadequacy of data.

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Research motivation and Objective

- The coastal cities across the globe have been facing increased flood risk due to high urbanisation and dense population, climate-change induced extreme rainfall and sea-level rise.
- The research community and the administrative bodies are continuously working towards development of scientific technologies and problem-oriented solutions in order to lessen the severe impacts caused by the heavy flooding events.
- However, the conventional implementation of structural measures such as the development of flood storage structures, reservoirs etc. often becomes difficult in urban areas owing to space constraints and rapidly thriving population.
- This study proposes a novel and comprehensive **hydrodynamic flood modelling framework** to reduce the flooding extent by **incorporation of various hydraulic scenarios** which involves combination of different cross-sections and lining materials along the rivel channel.

Framework for hydrodynamic flood modelling

- The MIKE11 (1-D) model (considering river streamflow with stormwater drainage network) and MIKE 21 (2-D) model (considering overland flow) are integrated in the MIKE FLOOD platform to develop a 3-way coupled hydrodynamic flood model (Figure 1).

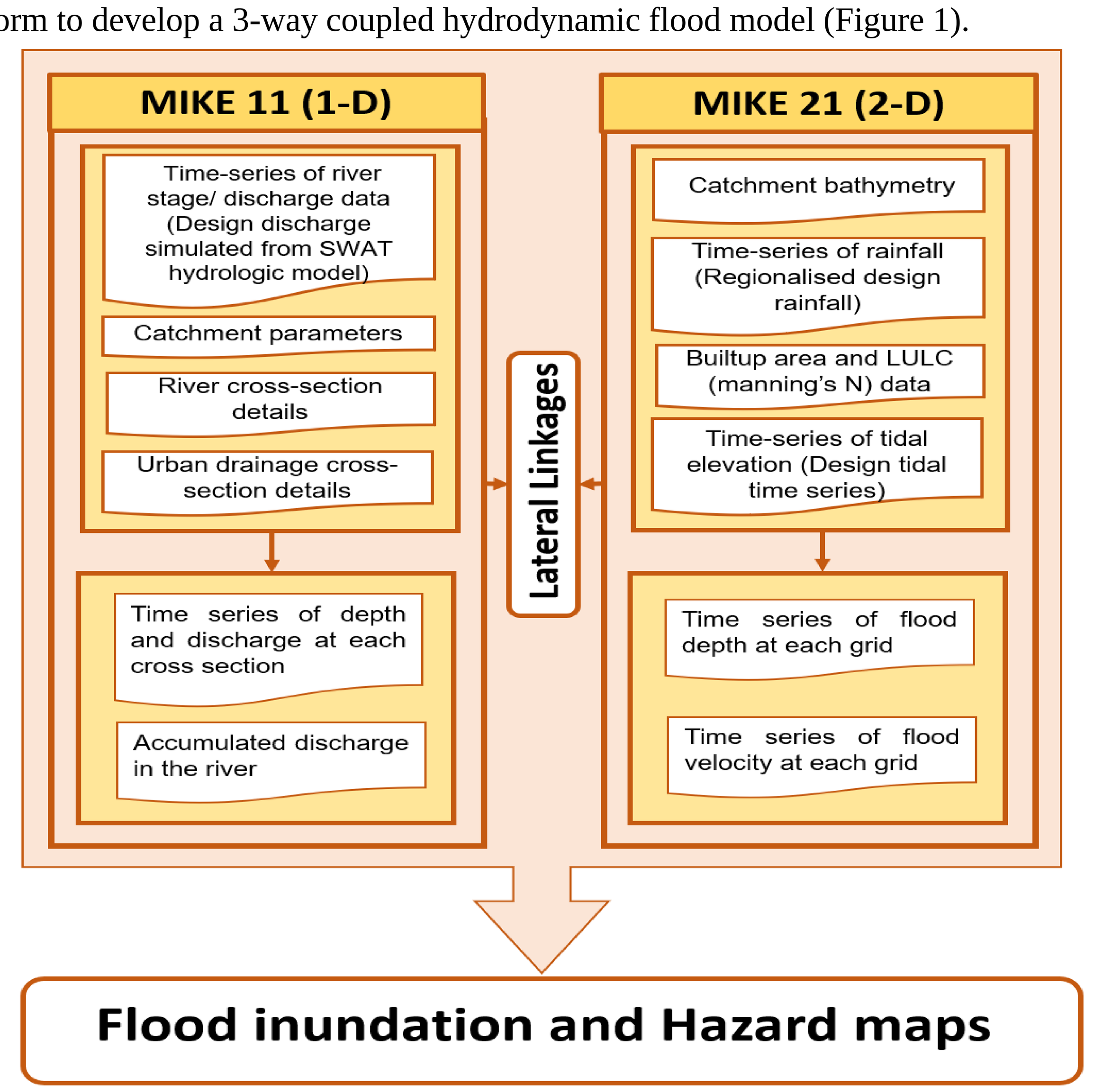


Figure 1: Framework adapted for the development of 3-way coupled MIKE FLOOD model

- Design rainfall was computed by implementing the Peak-over-Threshold (PoT) analysis (in extreme value analysis) by selecting a suitable threshold and fitting Generalized Pareto Distribution (GPD) on a single long term observed rainfall data set.
- The design discharge at the mouth of the river, used as an upstream flow boundary condition, was computed by simulating it from hydrological model SWAT (Arnold et al. 1998) corresponding the observed rainfall time series.
- The astronomical tide height for different return periods is calculated by fitting a synthetic time series for tidal elevation into a generalized extreme value model.
- The design values of rainfall, discharge and tidal impact were computed for 10-, 50-, and 200- year return periods and were provided as inputs into the flood model. The flooding parameters derived were translated into flood inundation maps (based on depth) and flood hazard maps (based on both depth and velocity).

Study area

- The study area considered to demonstrate the proposed framework comprises of the **Mithi river catchment** (geographical area 72.95 km^2).
- The Mithi river, which originates from Vihar lake plays a crucial part in the drainage network of Mumbai, India and influences the flooding in **Mumbai** to a great extent (Figure 2).
- There is a rapid change in gradient along the 18.4 Km length of the river.
- Mumbai city, the business capital of India, lies along the south-west monsoon belt spatially and is subjected to flood disasters almost annually.

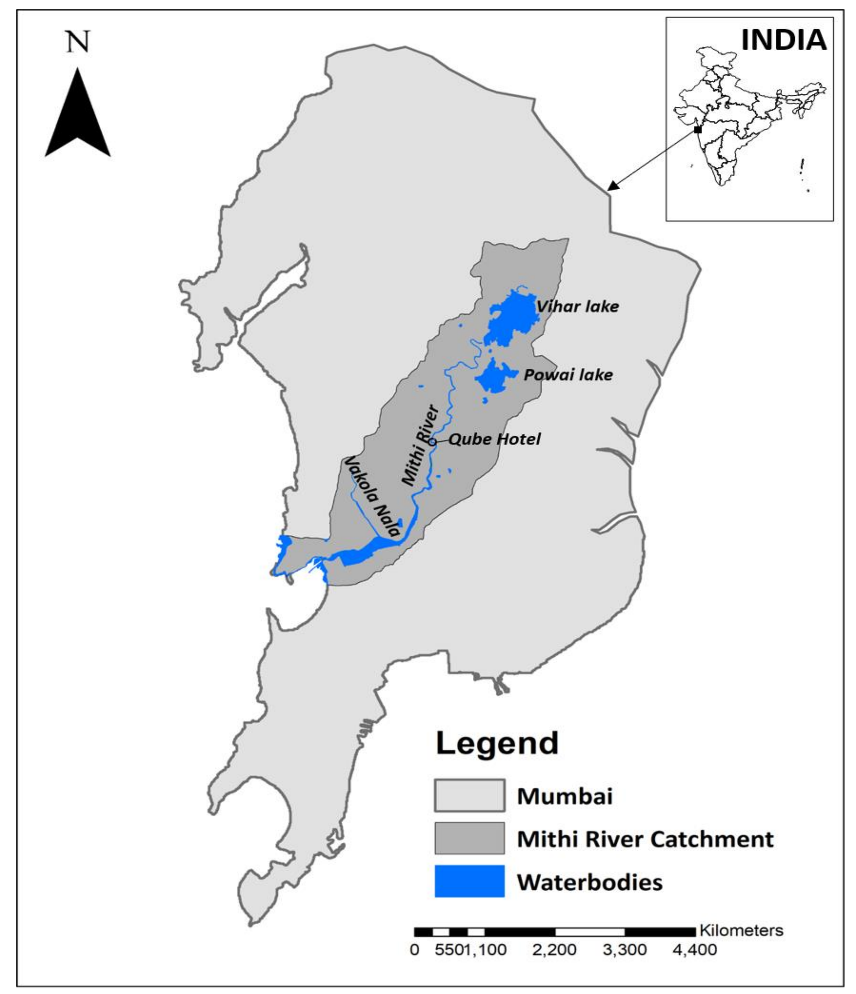
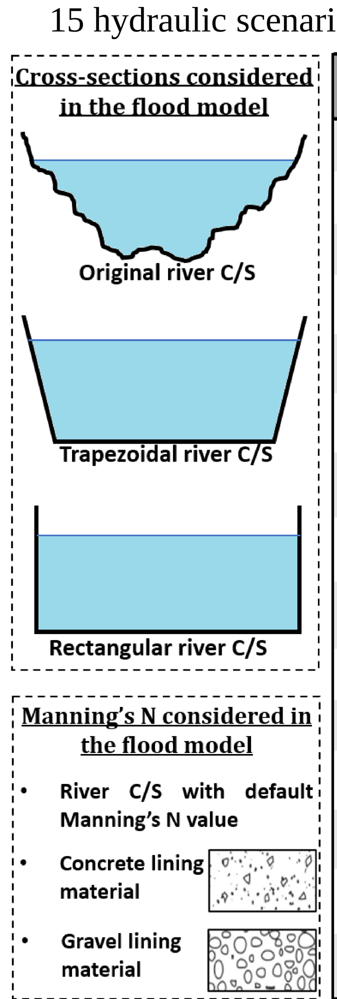


Figure 2: Location of Mithi catchment in Mumbai city (India)

Proposed hydraulic options for the river channel

- Three sets of cross-sections, i.e., original, rectangular and trapezoidal along with three sets of lining materials, i.e., default, concrete and gravel, were utilised to account for 15 hydraulic scenarios (Figure 3) as discussed with the primary civic body of Mumbai.



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 3: Description of various hydraulic options developed through utilization of different cross-sections are lining materials

- Further, 45 (15 x 3) simulations were performed in the developed flood modelling framework where 15 stands for hydraulic options and 3 stands for different return periods (10, 50, and 200-yr).
- Finally, the best option is identified based on the ability of the model to reduce extent of flood inundation and severity of hazard.

Results and Discussion

- The flood inundation and hazard maps obtained from MIKE FLOOD modelling framework for different return periods for the original cross-section depict that there is a rise in percentage of high flood inundation and hazard areas with increase in return period of rainfall, discharge and streamflow.
- Scenario II (E) and scenario III (E) are found to be the best ones amongst all the scenarios for all the return periods considered in this study. Figure 4 represents the inundation and hazard maps for 200-yr return period for the original scenario, scenario II (E) and III (E) respectively.

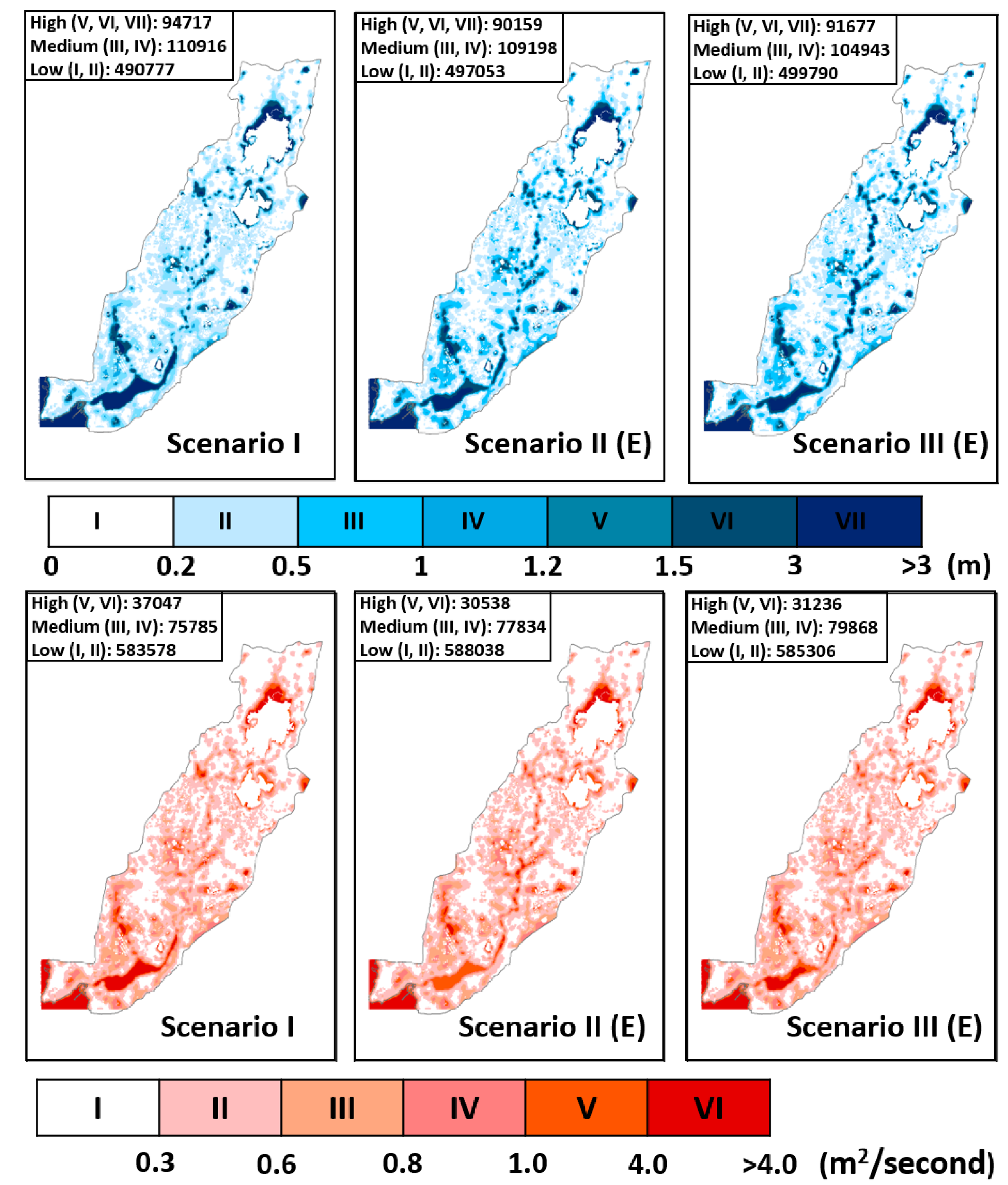


Figure 4: Flood inundation maps (top row) for Scenario I, Scenario II(E) and Scenario III(E) and hazard maps (bottom row) for Scenario I, Scenario II(E) and Scenario III(E) for 200 YR return period

- It is further evaluated through the proposed network that the scenario with trapezoidal river cross-section and concrete lining material is found to have a maximum decrease in flood inundation as compared to the other scenarios.
- This can be attributed to the fact that the water carrying capacity of a trapezoidal cross-section is greater than the others which results in higher storage of water in the river channel and lesser spilling of river water across the banks.
- The concrete also has higher roughness value than gravel which increases the friction of water against the surface and lessens the speed of stormwater flow thus minimizing the adverse impact of floodwater.
- A noticeable difference between the inundation extent does not exist amongst the proposed scenarios which can be attributed to the fact that the area considered is small in this study. Although, there is a significant reduction in the percentage of medium and high flooded areas when compared to the original one.
- Further, the social vulnerability map of the study area (utilising the 2011 census data which is the latest data) derived by Sherly et al. 2015 towards heavy flooding events (Figure 5) indicates that most of the high inundated areas fall within the medium to very high vulnerable zones.
- Therefore, the reduction in very severe inundation zone in the highly vulnerable area will provide tangible benefits in terms of reduced economic and human losses.

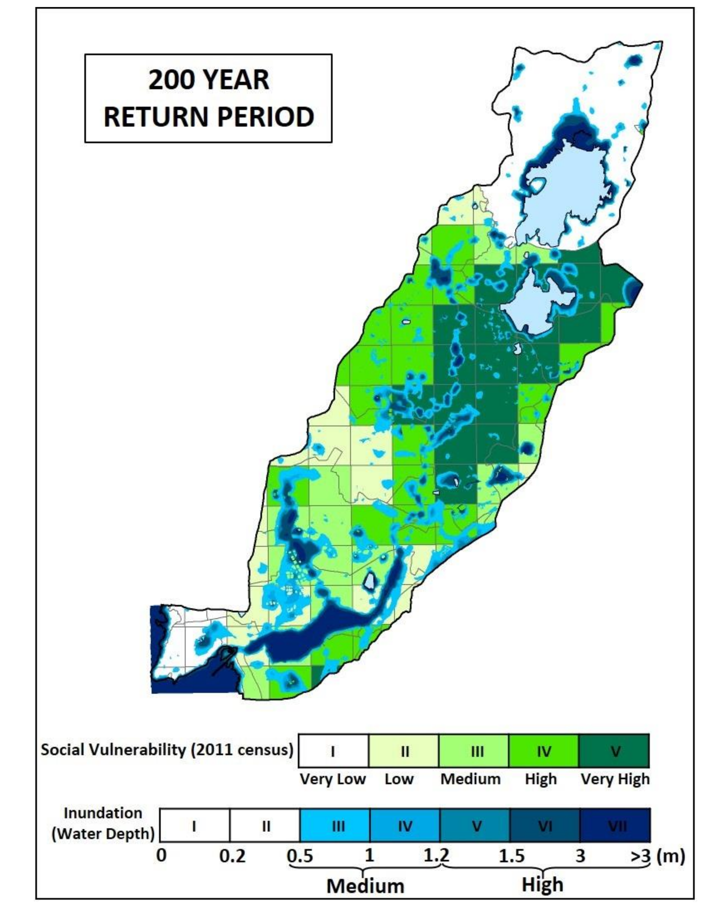


Figure 4: Flood inundation map for Mithi catchment for 200-yr return period overlaid on the social vulnerability map derived from 2011 census by Sherly et al. 2015

Conclusions and future recommendations

- Therefore, the reduction in very severe inundation zone in the highly vulnerable area will provide tangible benefits in terms of reduced economic and human losses.
- This generic user-friendly framework can be executed as a potential flood alleviation option which considers an integration of structural and non-structural measures.
- This can be particularly beneficial in data-scarce areas, socially-relevant set-ups, and densely populated and space- constrained areas where implementing structural measures like construction of dams, reservoirs etc., are no simple panacea.
- Preservation of wetlands should also be adapted as they provide protection against high tides along the coastal belts.
- Web-based flood information system can be developed for the city in the future to inform the civic bodies and citizens on the flood risk hot-spots under different scenarios.

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