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Impact of Climate Change and Land Use on Urban Flooding: Insights from Hydrological Modelling

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Abstract

Urban flooding is a rising concern globally due to climate change, urbanization, and anthropogenic activities. Rising temperatures and altered rainfall and temperature patterns have led to increased flood frequency and intensity. In India, 12% of the land area and over 5161 urban local bodies are flood-prone, with annual losses exceeding $3 billion. Urbanization exacerbates flooding by increasing impervious surfaces, accelerating runoff, and overwhelming drainage systems. The loss of green spaces and poor waste management further contribute to waterlogging and drainage blockage. Climate change intensifies these challenges by increasing the severity of extreme weather events, while urban heat islands amplify rainfall. Hydrological modeling, including 1D, 2D, and coupled 1D-2D models, is crucial for simulating flood behavior. These models predict water levels, flood depths, and flow velocities using equations based on physical laws. Coupled 1D-2D models provide a balanced approach for large floodplains, offering both computational efficiency and detailed flow dynamics. The study underscores the need for advanced modeling and climate adaptation strategies to mitigate urban flood risks effectively.

Introduction: Floods place a major risk to urban regions due to the change in climate, land use, and anthropogenic activities. Intense increase in urban areas leads to floods in all over the world. increase

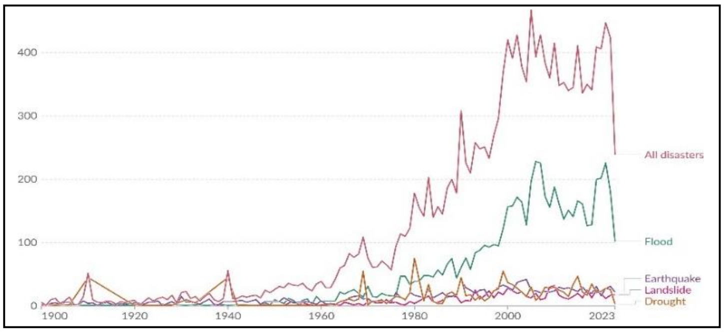

Fig. 1: Number of recorded natural disaster events, 1900 to 2023

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in temperatures and changing monsoon patterns contribute to rise in flood events . Annexure I countries, with their fast urban growth,leads to augmented susceptibility, resulting in human fatalities and considerable economic lossfrom flood incidences. In India, most of the cities have experienced flood related disasters, which leads to significant loss to countries economy. In India, 12% of land area and about 5161 urban local bodies are vulnerable to flood. Every year flood events occurring due to climatic frontiers alone incur losses to the alter of 3 billion US dollars to Indian economy which is 10% of worldwide economy losses due to flood.

As from figure 1 it depicts the natural hazards are increasing from the year 1900 to present scenario. When compared to all the natural hazards flood is one of the major events which causing more hazard with more frequency.

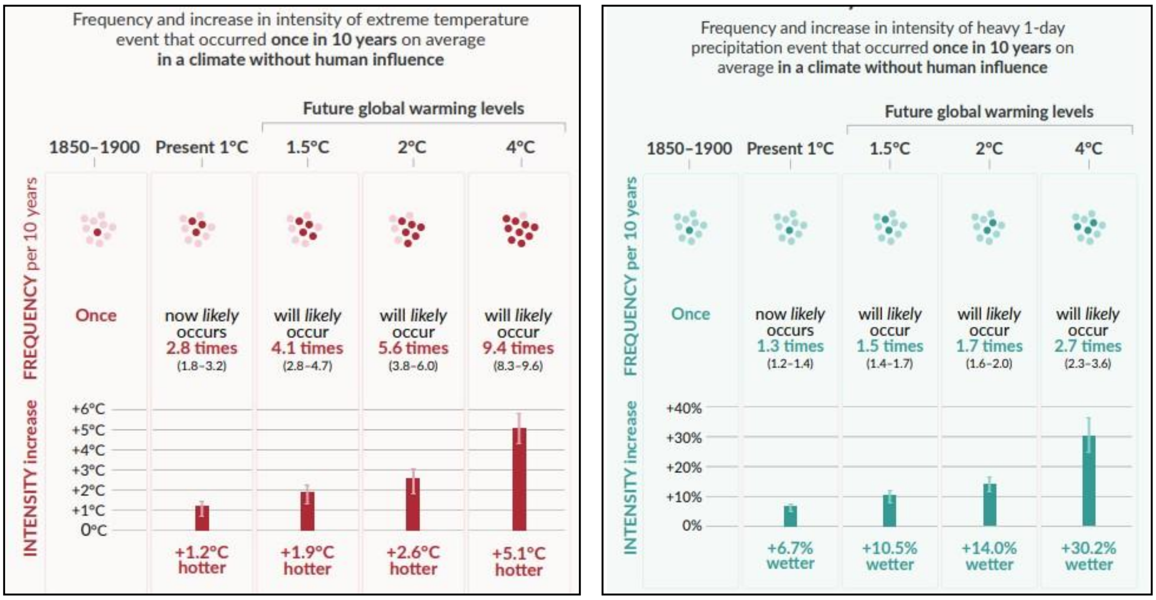

Fig 2: Projected changes in the intensity and frequency of hot temperature extremes overland, extreme precipitation over land

With increase in frequency and intensity of very high temperature event that usually occurred once in 10-year interval on average in a climate without anthropogenic impact. If the global warming levels of 1.5°C, 2°C and 4°C increases it leads to increase the rainfall and temperature all over the land as shown in the figure 2**.**

Causes for urban flood.

Urban flooding is increasingly driven by various interconnected factors, many of which are exacerbated by human activity and climate change. Altered weather patterns, such as more intense rainfall events, exceed the capacity of existing drainage systems, leading to frequent and severe floods. Deforestation and the loss of green spaces further aggravate the issue by reducing the land's ability to absorb water and degrading wetlands, resulting in rapid surface runoff in urban areas. Improper disposal of debris and solid waste, especially non-biodegradable materials like plastics, clogs drain, contributing to waterlogging and flood risks. Public unawareness of sustainable waste disposal practices, ethical construction methods, and flood preparedness heightens the vulnerability to floods, as it hinders both preventive measures and effective responses during flood events. Moreover, many Indian cities suffer from outdated or insufficient drainage systems, which cannot handle the high volumes of water during heavy rainfall. Encroachment on natural drainage channels, due to unchecked urbanization, obstructs the natural flow of water, compounding the flood risk. Inadequate urban planning, where infrastructure is developed without consideration for natural water drainage patterns, further exacerbates flooding by disrupting the water flow and contributing to water accumulation in flood-prone areas.

Impact of Urbanization & LULC on Flooding

Urbanization brings two significant issues to the natural surfaces in urban areas: land use/land cover changes and imperviousness. Assessment of urbanization's effects on hydrological study, which results in a decrease in flow time, an increase in volume, peak flow,and overall discharge. Urban development alters the natural hydrologic regime, resulting in an altered hydrologic equilibrium, alteration of peak flow distribution, and changing the period and magnitude of both low and high flows. Base flow, interflow, and evaporation reduce with urbanization, while stream flow, surface runoff, and raised peak streamflow.

As imperviousness increases, water infiltration decreases and runoff increases. In densely populated places, more than half of the rainfall produces surface runoff, and deep penetration is only a portion of what it was originally. It causes flooding and reduces deep infiltration, lowering groundwater levels for wetlands and wells.

Impact of Climate Change on Flooding

Floods in cities do not occur in discrete, isolated incidents. They exist as part of the largerurban context, causing landslides and interacting with other concurrent dangers such as cyclonestorm surge or tsunami. Increases in mean atmospheric temperatures are some of the projectedconsequences of climate change. A rise in air temperature raises the volume of water that the atmosphere can hold, making more water accessible for precipitation. Large cities can act as "heat islands," boosting air temperature in a specific area. The ensuing microclimate could enhance the amount and severity of rainfall in the metropolitan region. Global warming is likely to raise both the intensity and the incidence of extreme weather events.

Traditional flood management strategies, such as drainage improvements and flood barriers, are often insufficient to handle the complexity of modern flood dynamics. As rainfall patterns become more unpredictable, the need for advanced tools to predict and manage flood risks has become critical. This is where flood modelling plays a vital role. Hydrological and hydraulic flood models allow for the simulation of flood events. By simulating various scenarios, these models help assess vulnerabilities, optimize flood mitigation measures, and inform urban planning. Effective flood modelling is essential to minimize the socio-economic and environmental impacts of future flood

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events.

Flood modelling: The process to simulate/predict water level, flood depth, flow velocity using mathematical modelling or hydrodynamic models. Hydrodynamic Models replicate the flow of water by solving equations based on physical laws.

Depending on the geographical representation of the floodplain, models can be dimensionally classified into the following categories:

- ✓ 1 dimensional modelling
- ✓ 2-dimensional modelling
- ✓ 1D-2D Modelling (coupled approach)

1D Flood modelling

The most basic way to depict floodplain flow is by considering it as one-dimensional along the center of the river channel. Many hydraulic situations can justify the 1D the assumption, either because a broader approach is unnecessary or if the flow is mostly 1D.1D models can also be used to describe open surface floodplain flow; floodplain flow is part of one-dimensional channel flow and is considered to be in one direction parallel to the main channel, with one cross-section averaged velocity used to represent wide changes in velocity throughout the floodplain.

2D Flood modelling

The 2D models depict floodplain flows as a two-dimensional field, with a belief that the third-dimension depth of water is shallower than the other two dimensions. It calculates waterdepth and depth-averaged velocity over a grid or mesh and it require digital elevation model.

1D-2D Coupled flood modelling

1D models require less computational resource, however, cannot be utilized to study the flood propagation in larger flood plains. 2D models can simulate the flooding in largefloodplains but they need more computational power. Unlike 1D models, 2D models are poorat bridge/weirs/sluice & other 'point' effect. The inadequacy of 1D models for offering detailsabout the flow field, along with the significant computer time needs of 2D models, led to a creation of coupled 1D-2D models.

General methodology for urban hydrological modelling

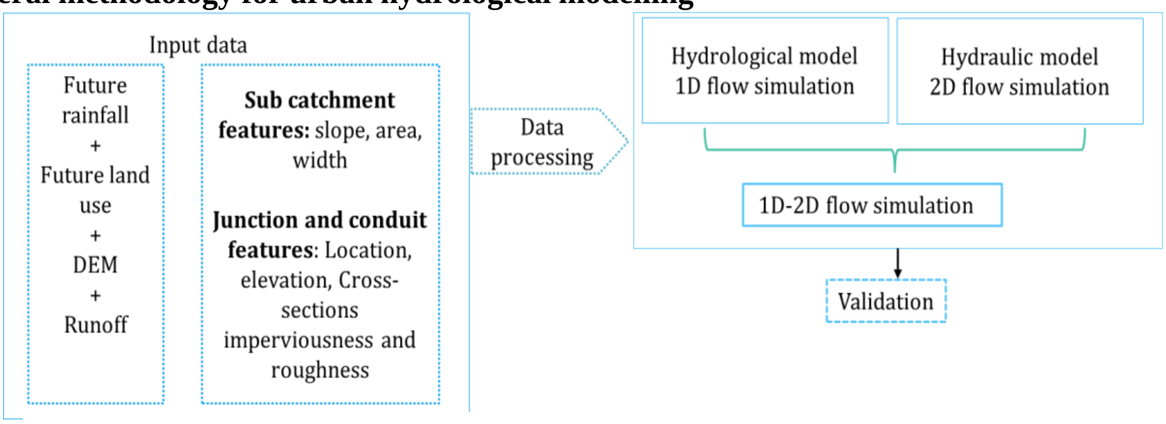

Fig. 3: Flowchart for urban hydrological modelling

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input data for hydrological modeling need to collect rainfall data, runoff, boundary condition like flood prone distance from river channel and extent of water spread water level in the river during flood, soil and slope, DEM data is required. (figure 3)

Conclusion:

Urban flooding is a growing global challenge, primarily driven by climate change, rapid urbanization, and land use changes. This study highlights the severe impacts of these factors on flood frequency, intensity, and damage, particularly in highly vulnerable regions like India. Inadequate drainage systems, deforestation, poor urban planning, and encroachment on natural drainage channels have worsened urban flood risks. Hydrological modeling, using advanced 1D, 2D, and coupled 1D-2D models, provides valuable insights into flood dynamics, aiding in risk assessment and mitigation. These models simulate water flow, flood depth, and velocity, allowing for better planning and decision-making in urban flood management. Climate projections indicate an increase in extreme weather events, making it crucial to implement sustainable land-use practices, resilient infrastructure, and effective urban planning. To combat the rising threats of urban flooding, a multidisciplinary approach involving improved urban planning, community awareness, and policy interventions is essential. Incorporating advanced hydrodynamic models in flood risk management will enhance preparedness, minimize damage, and build resilient urban environments in the face of future climate challenges.

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