IISc Sustainable Transportation Lab (IST Lab)
Celebrating 15 Years of Contribution to Sustainable Development

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Quantifying the Impact of Hydrological and Infrastructure Uncertainties on Urban Transport Resilience

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Presentation Outline

Introduction

Background

Methodology

Sources of Uncertainty

Case Study

Results

Summary, Conclusion and Future Directions

Introduction

- Transportation systems are vital for economic and social connectivity.
- Yet, they face increasing pressure from climate-related hazards.
- Long-term planning often overlooks resilience as a design principle.

Why Resilience Matters?

- Rising vulnerability due to climate change.
- Intensifying weather events causing system-wide losses.
- Resilience ensures recovery with minimum loss of function.

What is Resilience?

- A multidimensional concept.
- The system’s ability to adapt, absorb shocks, and recover quickly.
- Involves adaptability, robustness, and redundancy (Faturechi & Miller-Hooks, 2014; Gu et al., 2020).

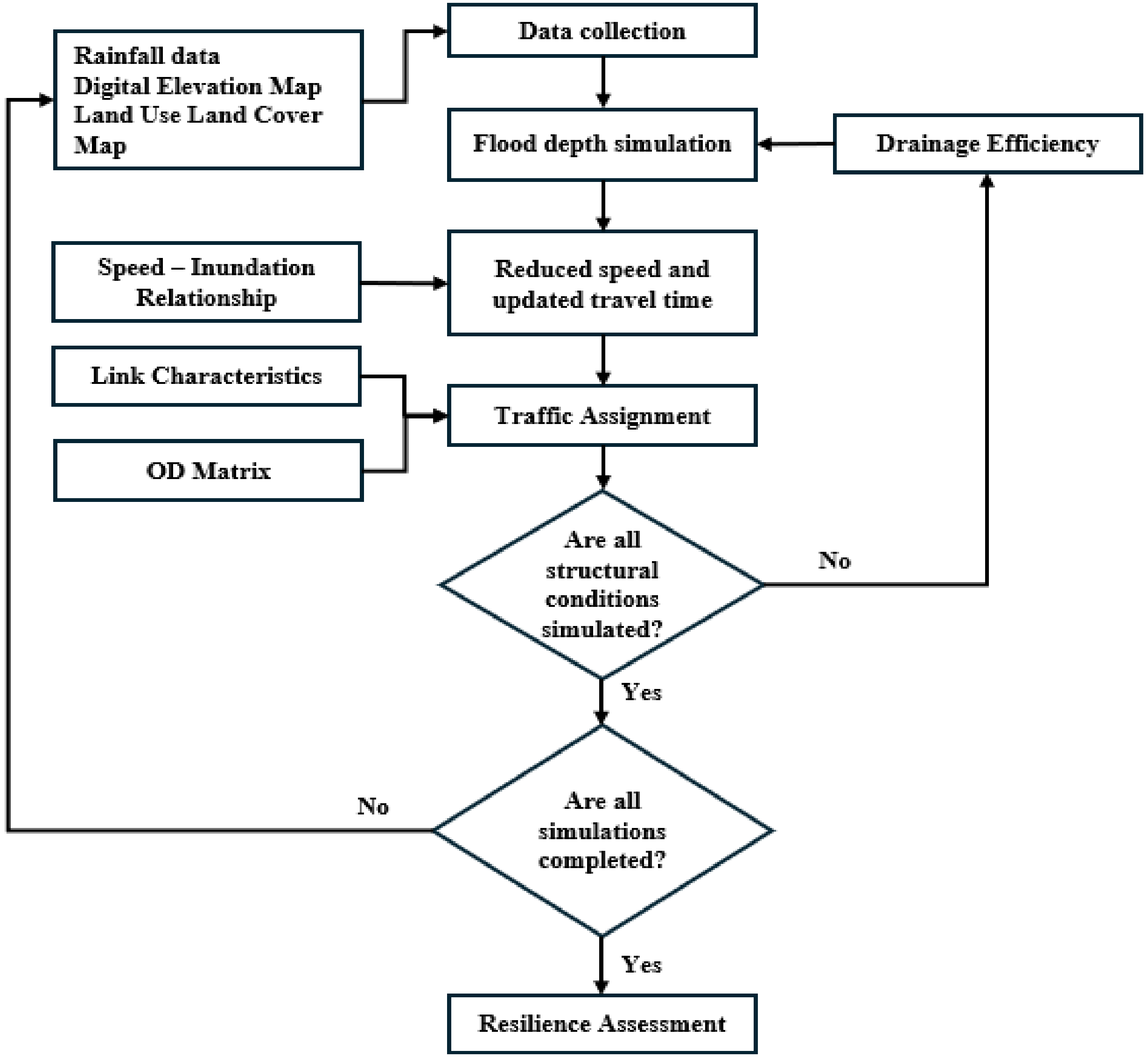
Background

- Simulation models, network theory, and mathematical frameworks (Alabbad et al., 2021; Lin et al., 2024).
- Indicators such as recovery time and performance loss (Bhavathrathan & Patil, 2015; Mukesh & Katpatal, 2021).

What are uncertainties?

- Evaluating resilience is complex due to uncertainties in rainfall variability, drainage performance, and human behaviour during emergencies.
- Ignoring these factors can overestimate network robustness and leave vulnerabilities unaddressed (Chen et al., 2012; Soltani-Sobh et al., 2016).
- Uncertainty theory and probabilistic models (Hosseini & Pishvaee, 2022; Raillani et al., 2023).

Methodology



Rainfall data
Digital Elevation Map
Land Use Land Cover Map

Data collection

Flood depth simulation

Drainage Efficiency

Speed – Inundation Relationship

Reduced speed and updated travel time

Link Characteristics

OD Matrix

Traffic Assignment

Are all structural conditions simulated?

No

Yes

Are all simulations completed?

No

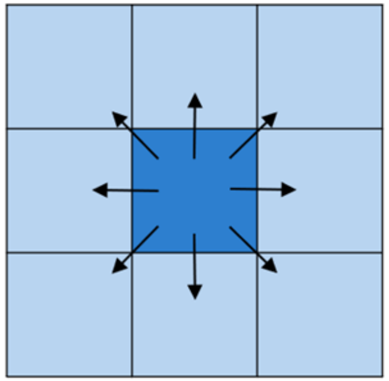
Yes

Resilience Assessment

Methodology

Flood Simulation using Cellular Automata:

- Conducted using a 2D Cellular Automata (CA) model that divides the landscape into grid cells.
- Each cell interacts with its neighbours to simulate runoff generation and runoff.
- Produces flood-depth maps.



Moore Neighbourhood

Network Integration:

- Flood maps are overlaid on the road network to identify areas that are inundated.
- Depending on flood depth, links are assigned reduced speeds or marked impassable (>0.3 m: closed). *(Pregnolato, 2017)*

Methodology

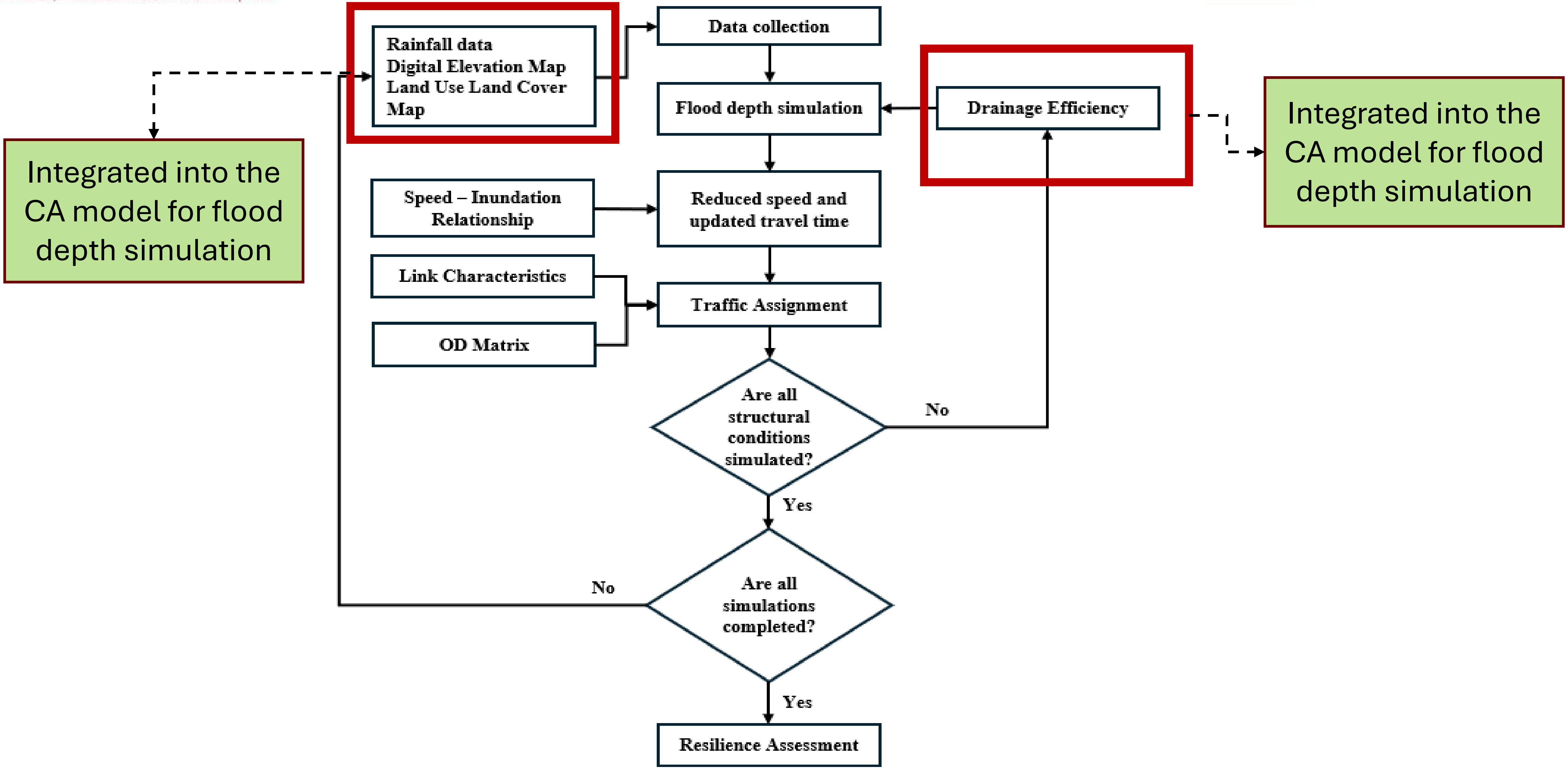
Traffic Assignment:

- Uses a Static User Equilibrium model solved by the Frank-Wolfe algorithm.
- Simulates how travellers reroute to minimise travel time during flood-related disruptions.

Resilience Assessment:

- Based on network performance indicators - Largest Connected Component (LCC) Measuring how much of the system stays connected and functional under each flood scenario.
- Provides an integrated view of how hazard severity, infrastructure conditions, and traffic behaviour influence network resilience.

Sources of Uncertainty



Integrated into the CA model for flood depth simulation

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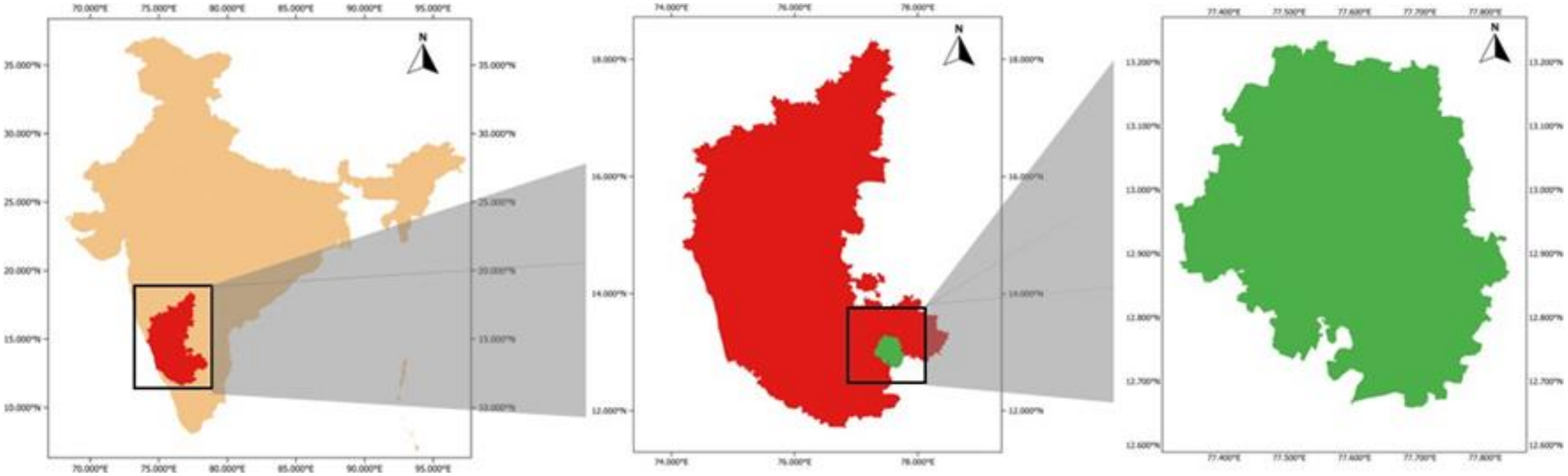
Resilience Assessment

Case Study

Study Area:



Scenarios for Analysis

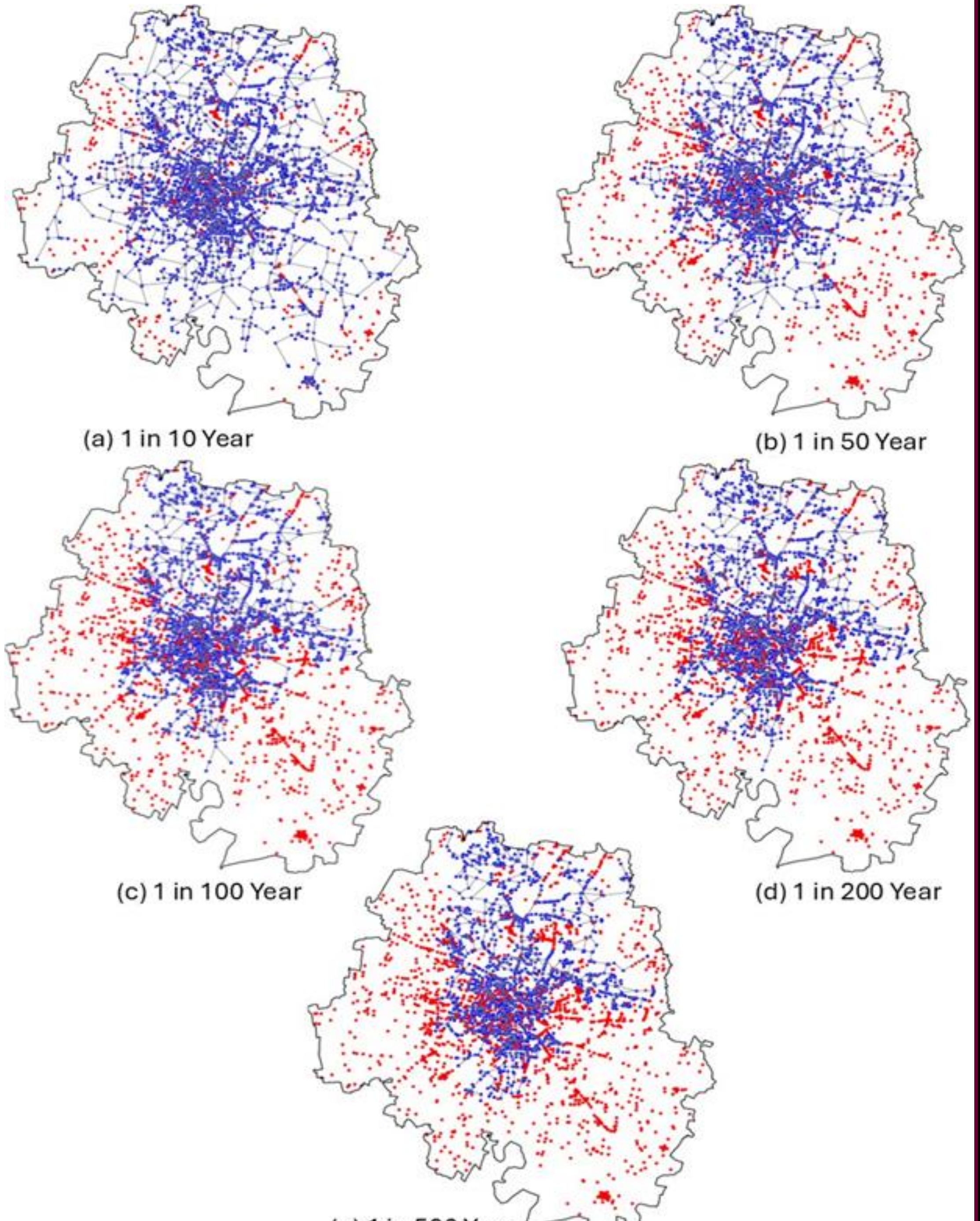
- Rainfall only Scenario
- Rainfall and Drainage Efficiency Scenario

Results

Rainfall Only Scenario:

Rainfall only Scenario	Number of inundated links
1 in 10 years	1002
1 in 50 years	1604
1 in 100 years	1857
1 in 200 years	2130
1 in 500 years	2436

Rainfall only Scenario	Number of nodes in LCC
1 in 10 years	5072
1 in 50 years	4381
1 in 100 years	3965
1 in 200 years	3661
1 in 500 years	3318



(a) 1 in 10 Year

(b) 1 in 50 Year

(c) 1 in 100 Year

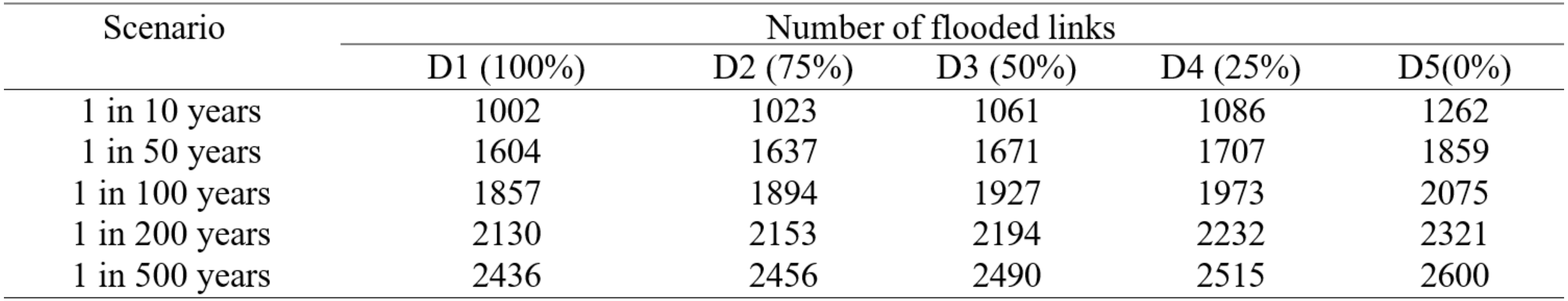
(d) 1 in 200 Year

(e) 1 in 500 Year

Results

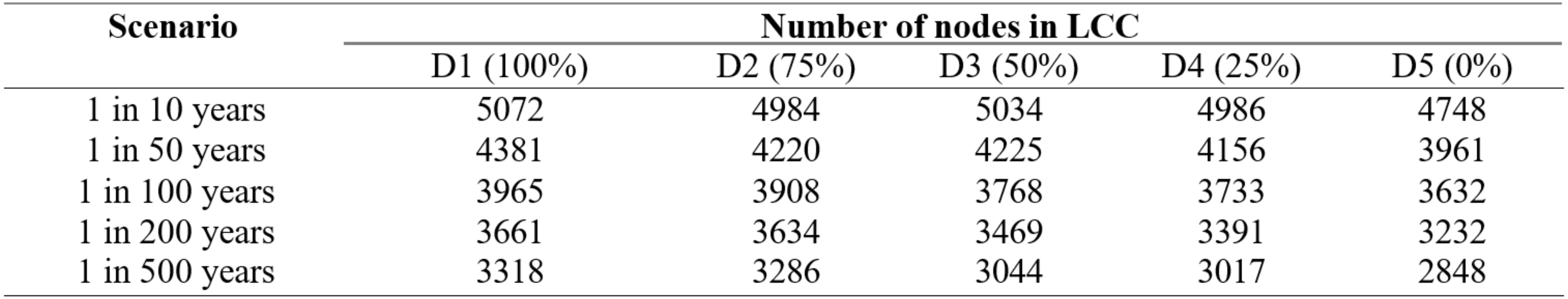
Rainfall and Drainage Efficiency Scenario:

Number of flooded links:



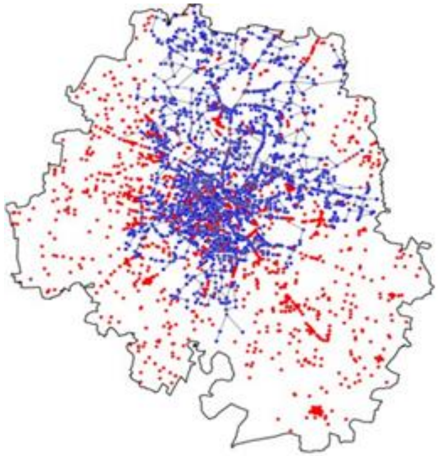
Scenario	Number of flooded links				
	D1 (100%)	D2 (75%)	D3 (50%)	D4 (25%)	D5(0%)
1 in 10 years	1002	1023	1061	1086	1262
1 in 50 years	1604	1637	1671	1707	1859
1 in 100 years	1857	1894	1927	1973	2075
1 in 200 years	2130	2153	2194	2232	2321
1 in 500 years	2436	2456	2490	2515	2600

Size of Largest Connected Component:

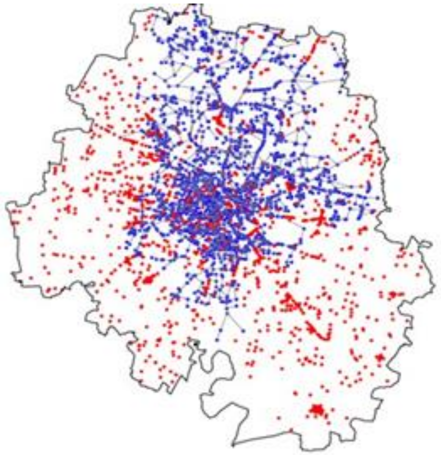


Scenario	**Number of nodes in LCC**				
	D1 (100%)	D2 (75%)	D3 (50%)	D4 (25%)	D5 (0%)
1 in 10 years	5072	4984	5034	4986	4748
1 in 50 years	4381	4220	4225	4156	3961
1 in 100 years	3965	3908	3768	3733	3632
1 in 200 years	3661	3634	3469	3391	3232
1 in 500 years	3318	3286	3044	3017	2848

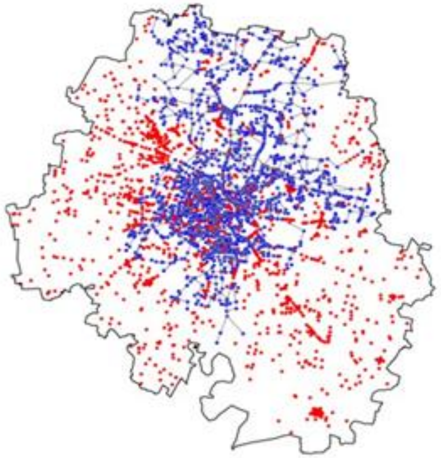
Size of Largest Connected Component for the 1 in 100-year Scenario:



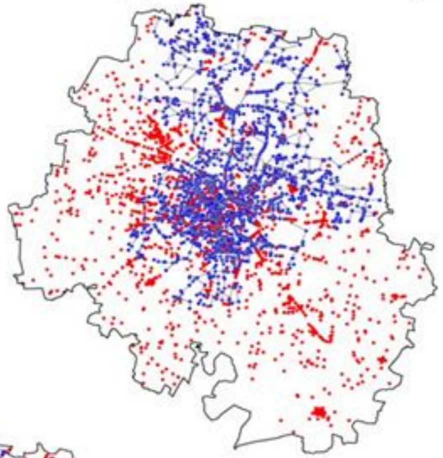
(a) 100% efficient drainage



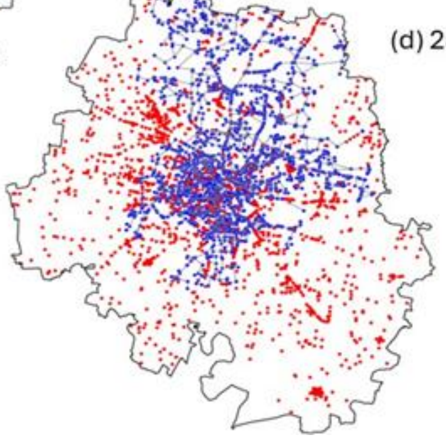
(b) 75% efficient drainage



(c) 50% efficient drainage



(d) 25% efficient drainage



Implications of the Study

- Regular inspection and maintenance are crucial for preventing blockages, reducing flood risk, and enhancing overall network resilience.
- Urban flood management and transportation planning should be coordinated to keep critical transport links operational during floods.
- Upgrades and maintenance should focus on drainage and road segments that are both highly vulnerable and crucial for network connectivity.
- The proposed methodology can be extended to public transport systems to identify alternative routes and promote equitable access during disruptions.

Summary & Conclusions

- Urban transport resilience to flood disruptions
- How uncertainty shapes network performance.
- Developed a framework integrating hydrological modelling, drainage efficiency, and traffic simulation.
- Results show that;
- Network disruptions depend not only on rainfall intensity but are amplified by reduced drainage efficiency.
- Uncertainty factors can significantly alter system performance.
- Ignoring uncertainty leads to overestimation of resilience and missed vulnerabilities in the network.
- Resilience depends significantly on adaptation and proactive planning

Future Directions

- Additional resilience metrics such as economic loss, delay costs, accessibility, and equity.
- Extend analysis from macro-level (OD flows) to micro-level (intersections, signals) for local planning.
- Move beyond static equilibrium to dynamic traffic assignment, capturing evolving patterns and recovery times.
- Model cumulative and cascading uncertainties.
- Extend the framework for analysis of public transport networks.

THANK YOU..☺

QUESTIONS …?

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