QuakeCoRE Infrastructure Resilience Webinar series

Analysis of Transport Network Criticality under Flooding in Ho Chi Minh City, Vietnam

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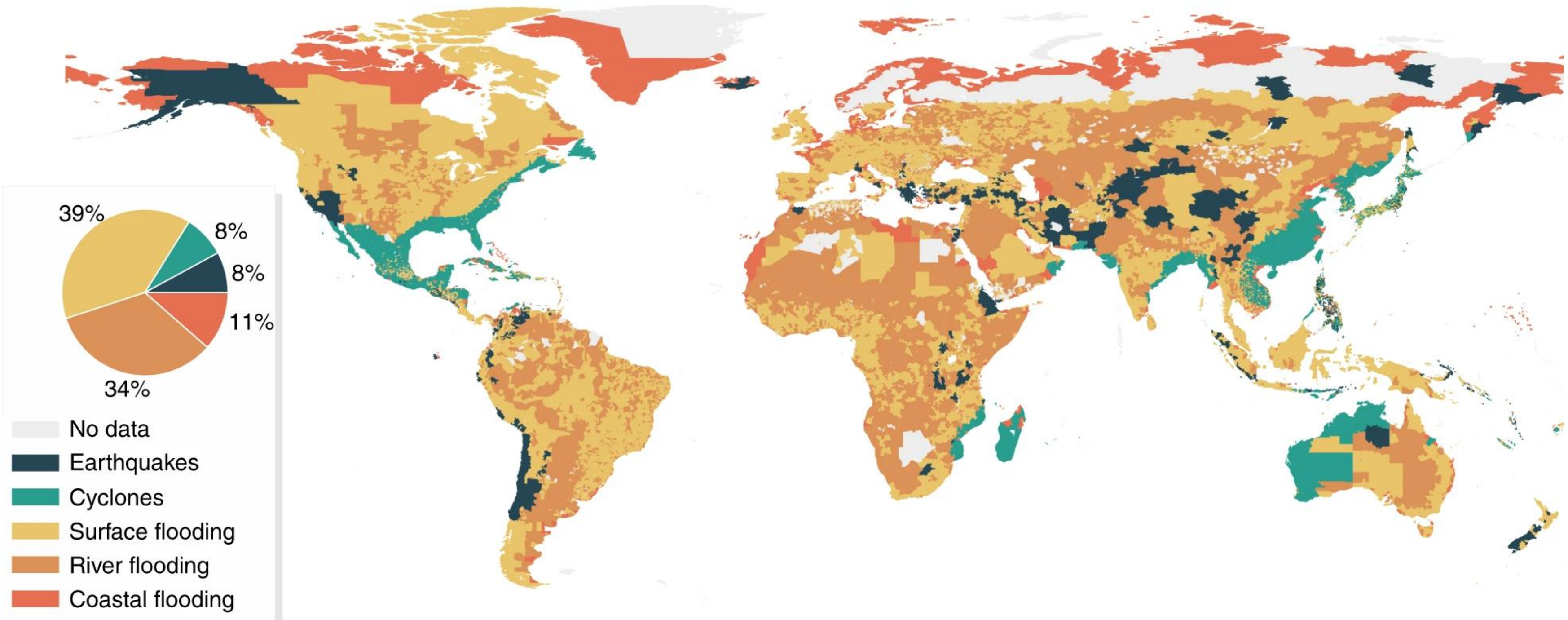
Transport infrastructures and disaster risks

Global dominant hazard exposure per region



Source: Koks, Elco E., et al. "A global multi-hazard risk analysis of road and railway infrastructure assets." *Nature communications* 10.1 (2019): 1-11.

Critical infrastructure services

Direct damages from disasters to the power generation and transport infrastructure are estimated at **US$18 billion** a year in low- and middle income countries globally.

But the estimated cost of the **associated disruption to services** (energy and transport) ranges **from US$391 billion to US$647 billion**, at least 20 times larger.

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Disruptive Technology for Public Assets Governance

A research collaboration with the World Bank Group and Ho Chi Minh City, Vietnam

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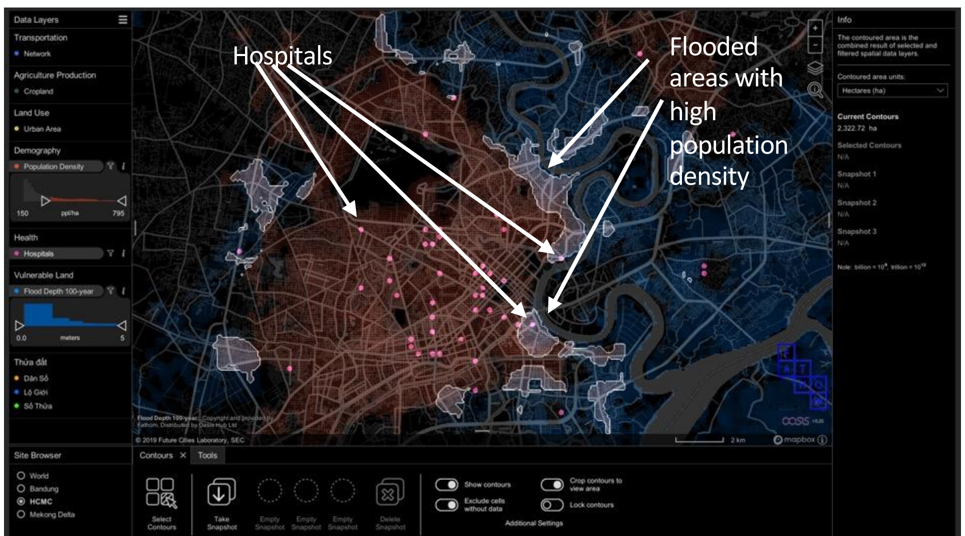
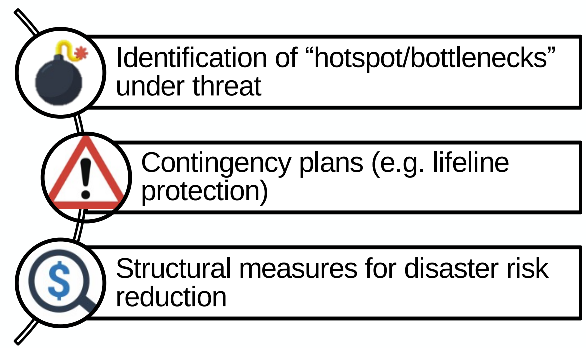
Singapore ETH-Centre

Future Resilience Systems: Dr Jonas Joerin, Dr Peter Lustenberger, Dr. Yi Wang
Future Cities Laboratory: Prof Dr Stephen cairns, Michael Joos,



ur-scape adapted to HCMC for a flooding with 100-year return period



Incorporate resilience thinking into public infrastructure planning

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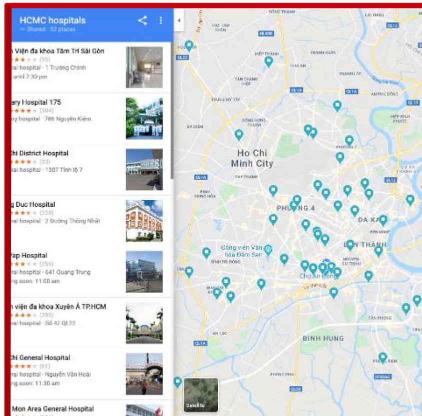
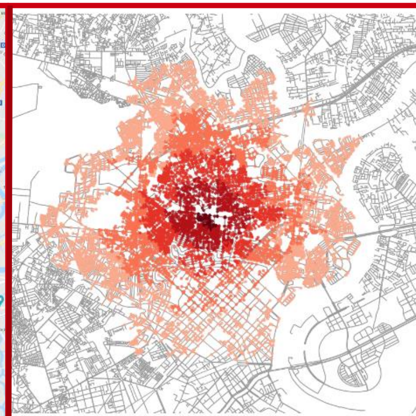
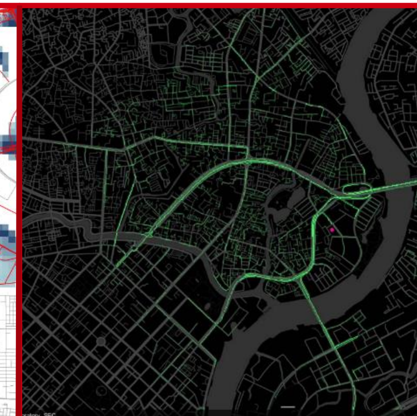


Critical service facilities



Service areas identification

Disruption analysis

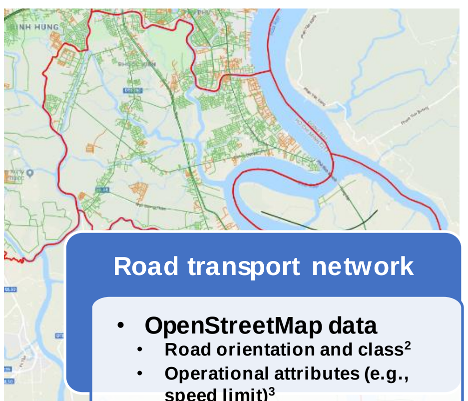


Identification of critical components

Identification of critical infrastructures

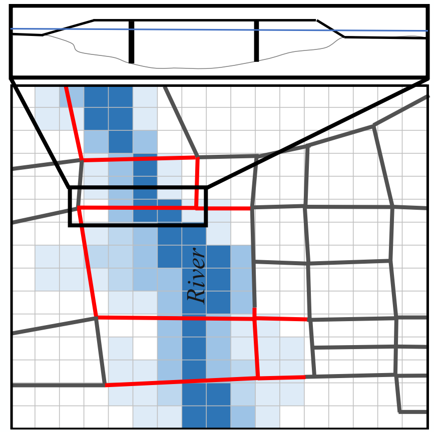
Hazard events

- FATHOM2 flood maps[1]
  - Estimated water level for raster cell (~90m)
  - 10 RP, fluvial and pluvial



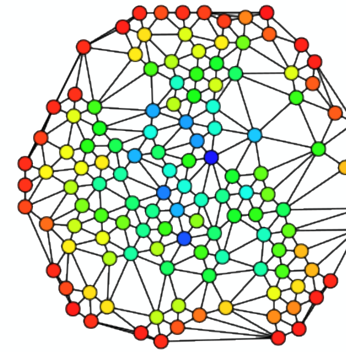
Road transport network

- OpenStreetMap data
  - Road orientation and class[2]
  - Operational attributes (e.g., speed limit)[3]



Exposure and disruption

- Functionality loss
  - Road closure due to "heavy flooding" (inundation depth>0.3 m)
  - Highest cell value (water level)



An undirected graph coloured based on the betweenness centrality of each vertex from least (red) to greatest (blue).

Critical component Analysis

- Topological analysis
  - Network science indicators
  - Before/after a disruptive event

[1] FATHOM. "Fathom-Global." from https://www.fathom.global/fathom-global (2019).
[2] Ramm, Frederik, et al. "OpenStreetMap Data in Layered GIS Format." *Version 0.6 7* (2014).
[3] Zilske, Michael, Andreas Neumann, and Kai Nagel. *OpenStreetMap for traffic simulation*. Technische Universität Berlin, 2015.

Topological analysis

Edge Betweenness Centrality $C_B(e)$[1]

$$C_B(e) = \sum_{s \neq t \in V} \frac{\sigma(s,t|e)}{\sigma(s,t)}$$

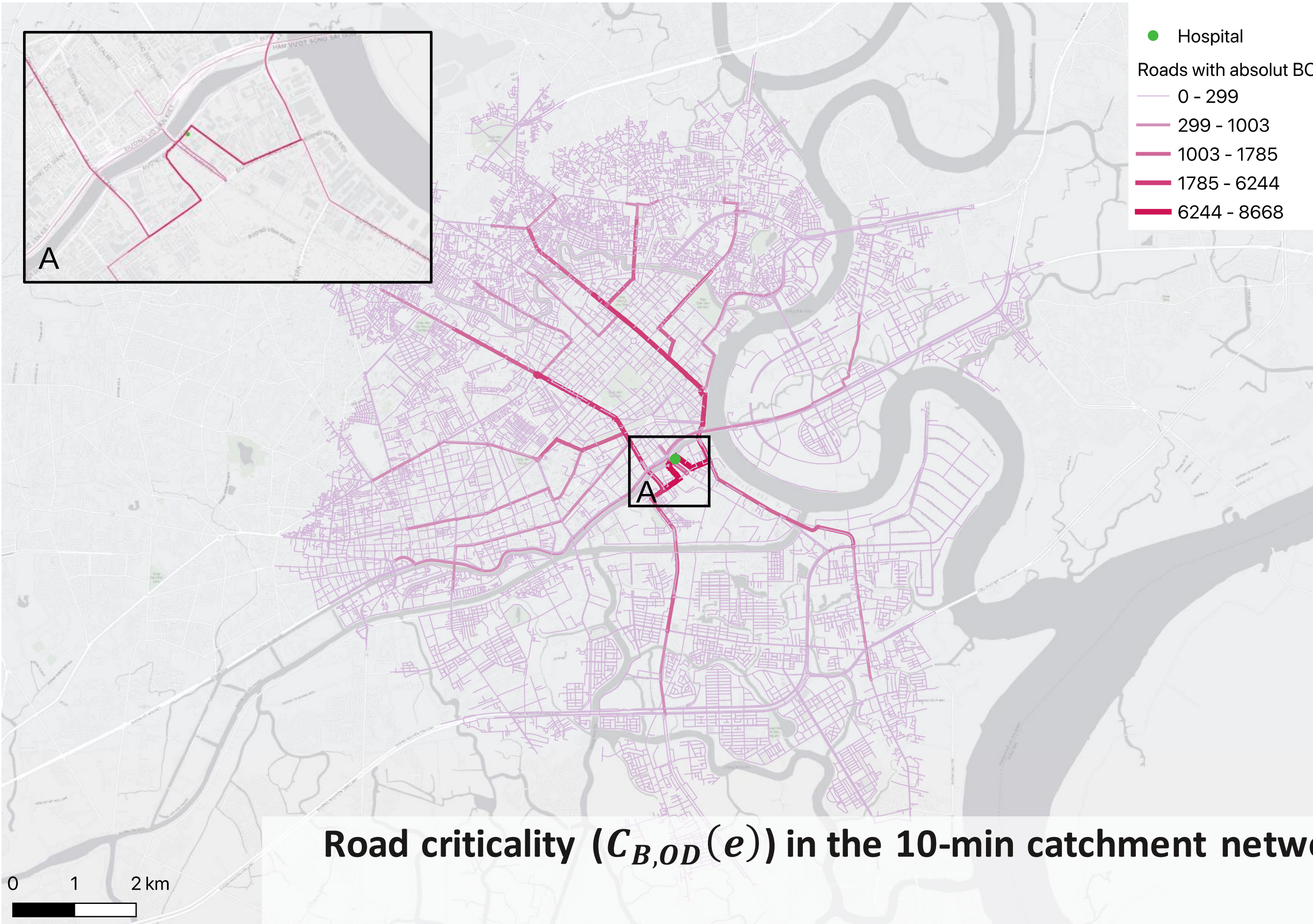
- Measures the extent to which an edge lies on the shortest paths between any pair of nodes.
- A high $C_B(e)$ shows that there are more shortest paths passing through this edge.

OD-based (Subgraph) Betweenness Centrality $C_{B,OD}(e)$[2]

$$C_{B,OD}(e) = \sum_{s \in S} \sum_{t \in T} \frac{\sigma(s,t|e)}{\sigma(s,t)}$$

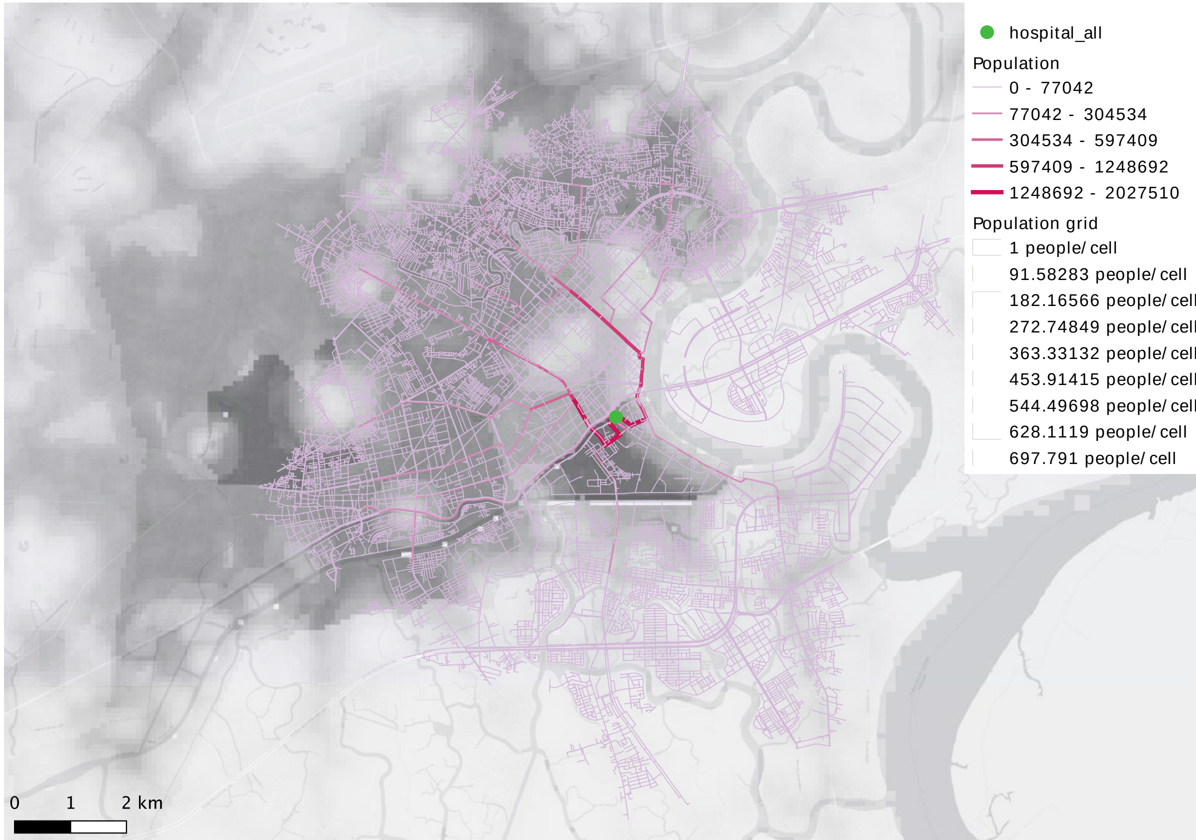
- More realistic from a demand-aware perspective (e.g., critical services by considering their own service area)

[1] Newman, M. (2018). Networks, Oxford university press.
[2] Gauthier, Pauline, Angelo Furno, and Nour-Eddin El Faouzi. "Road network resilience: how to identify critical links subject to day-to-day disruptions." *Transportation research record* 2672.1 (2018): 54-65.



Road criticality ($C_{B,OD}(e)$) in the 10-min catchment network of District 4 Hospital

(No disruption)



OD-based edge betweenness centrality weighted by population density

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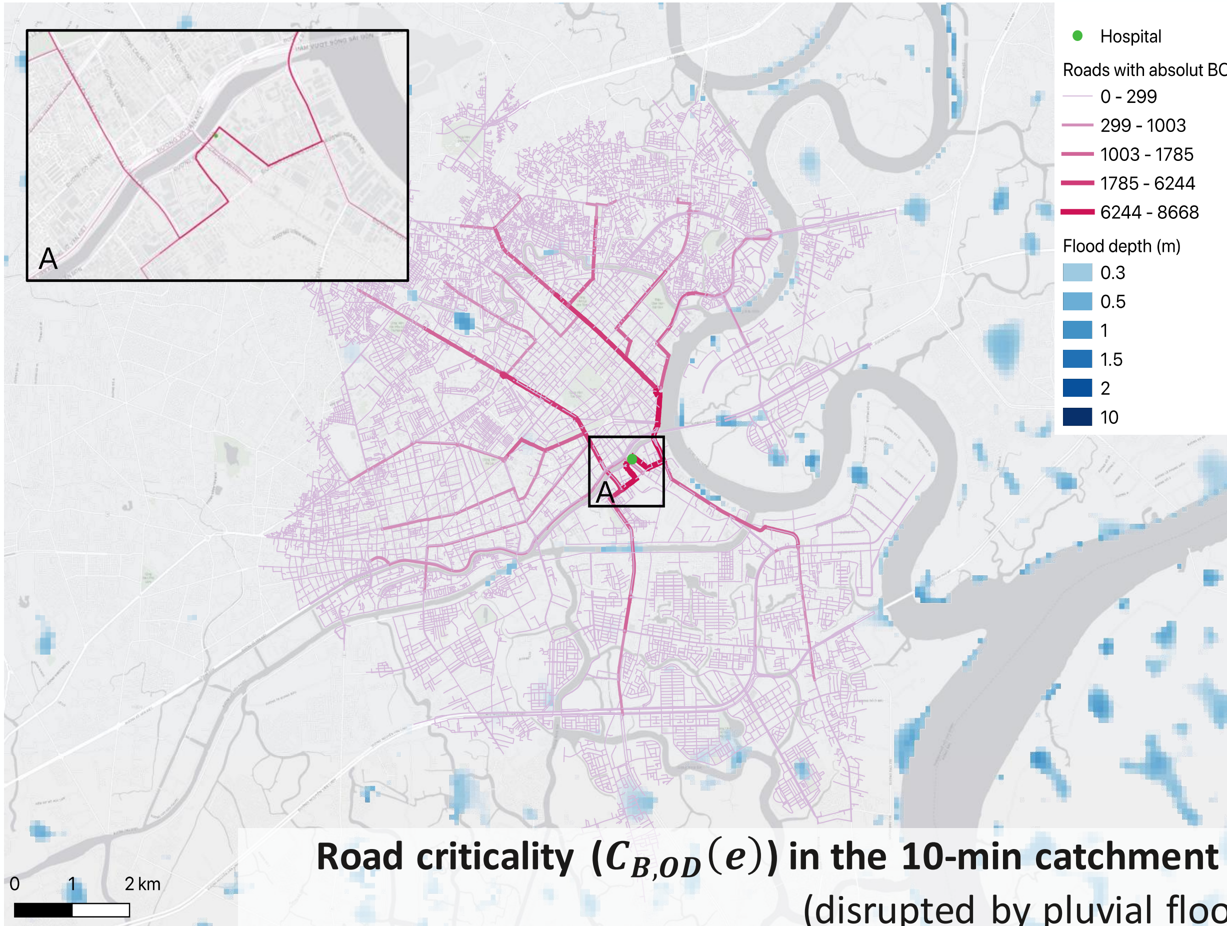
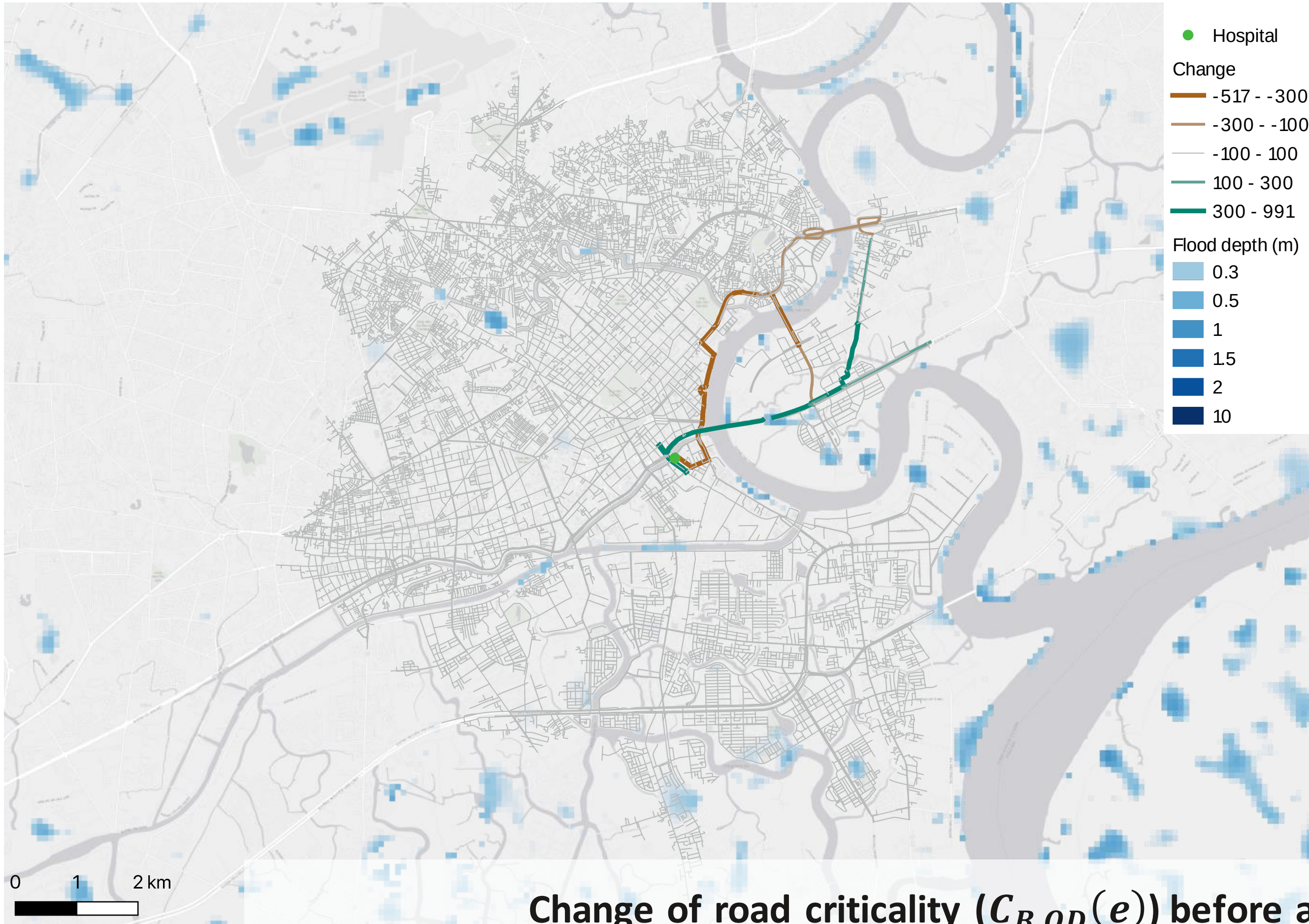


Road criticality ($C_{B,OD}(e)$) in the 10-min catchment network of District 4 Hospital

(disrupted by pluvial flooding with 20-yr return period)



Change of road criticality ($C_{B,OD}(e)$) before and after pluvial flooding

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More things to consider…

Identification of potential critical infrastructures:

- Requires all relevant institutions (e.g., police, fire, medical, and emergency management)
- For ensuring critical services relevant to survival, safety, and security needs of community members.

Implications:

- Optimizing road space allocation (e.g., limit parking)
- Designing permanent flood protection measures
- Improving road drainage (e.g., cleaning roads and draining ducts)

Future research

Resilience quantification and modelling for transport systems

- **Quantitative indices and methods (e.g., efficiency, safety, equity)**

Topological analysis

- Roots in **network/graph theory**
- Captures the **topological properties** of transportation networks
  - Betweenness centrality (C^B): captures importance of a place as a **pass-through connection**
  - Closeness centrality (C^C): captures **accessibility & proximity** of a place

Limited data hungriness, computationally realistic
Do not allow for behavioural responses to a disruption

System-based analysis

- **Demand-supply interactions** as well as **travel behaviour** are considered (via traffic assignment modelling).
- Indices are **system performance (traffic)-based**
  - Traffic volume (throughput)
  - Unified Network Performance Measure[1]
  - Network Robustness Index[2]

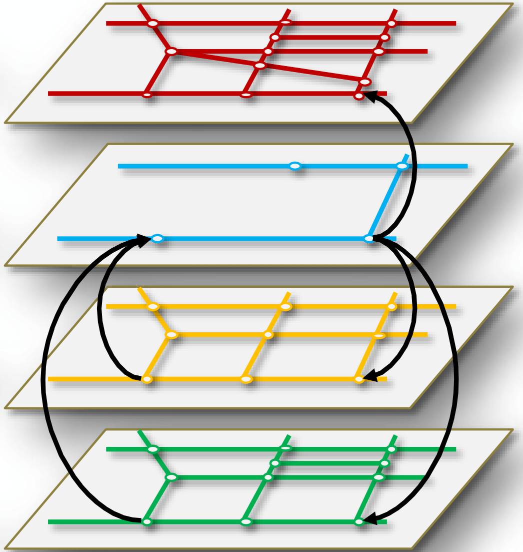
Requires extensive data (e.g., travel demand, road capacity)
More realistic representation of the resulting traffic

[1] Qiang, Qiang, and Anna Nagurney. "A unified network performance measure with importance identification and the ranking of network components." *Optimization Letters* 2.1 (2008): 127-142.
[2] Scott, Darren M., et al. "Network robustness index: A new method for identifying critical links and evaluating the performance of transportation networks." Journal of Transport Geography 14.3 (2006): 215-227.

Future research

Resilience quantification and modelling for transport systems

- **Interdependencies among systems (e.g., power, communication)** E.g., interconnected cars failure[1]



[1] Georgia Institute of Technology and Multiscale Systems, Inc. "Hackers could use connected cars to gridlock whole cities", from https://www.eurekalert.org/pub_releases/2019-07/giot-hcu072819.php

Thank you

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