Infrastructure Resilience for Climate Adaptation

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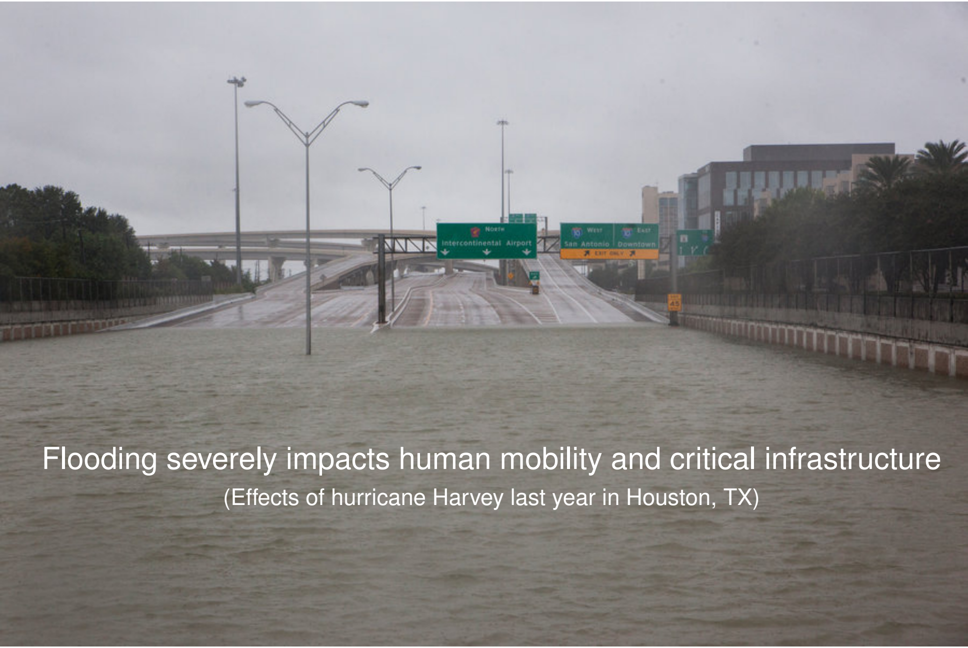
Building Sustainable Societies

- “How can we build sustainable societies that are resilient to climate change?”



Flooding severely impacts human mobility and critical infrastructure

(Effects of hurricane Harvey last year in Houston, TX)

Climate Change and Flooding

- Annual frequencies of high tide flooding are increasing rapidly in coastal areas (NOAA 2018)
- Between the 1995-2005 and the previous 10 years, there was a 90% average increase in nuisance floods on the US East Coast (Jacobs et al. 2018)
- Flood hazards will increase over more than half of the globe, including Africa (IPCC 5th Assessment Report WG2 Ch3)
- Floods are responsible for 52% of deaths and 44% of economic damages from natural disasters in 2017 (CRED CRUNCH Issue No. 48)

Effects of Flooding on Infrastructure

- Flooding can drastically damage critical infrastructure and hamper human mobility.
- Short term
  - Flooding can completely block access to roads for days
- Long term
  - Roads that are inundated by water have weaker structural strength after flooding (Sultana et al. 2014) which can lead to quick deterioration
  - Roads that are inundated by water must go through expensive post flooding maintenance (Ismail et al. 2017)

Role in the SDGs

- Improving the flood resilience of infrastructure can help in alleviating extreme poverty in low-income countries by reducing disaster risk, and providing more reliable access to education, healthcare and financial services

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Road Network Data

- What infrastructure is presently available?

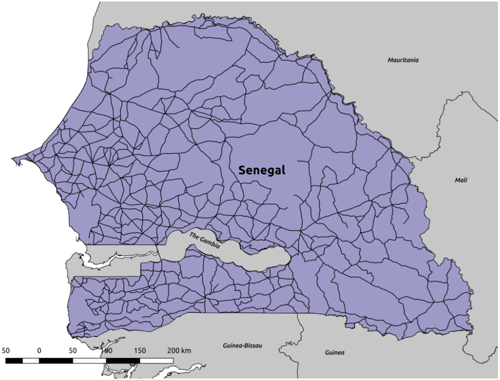

Figure: Senegal national and regional highway system

Flood Data

- How is flood risk distributed?

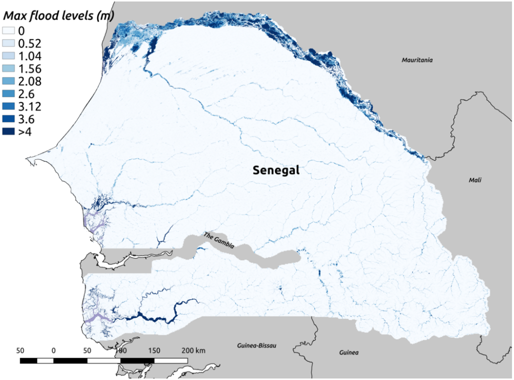

Figure: Estimated flood depth for 100-year flood[1]

[1] We thank Fathom.Global for access to the flooding data.

Mobility Data

- How do people utilize the available infrastructure?

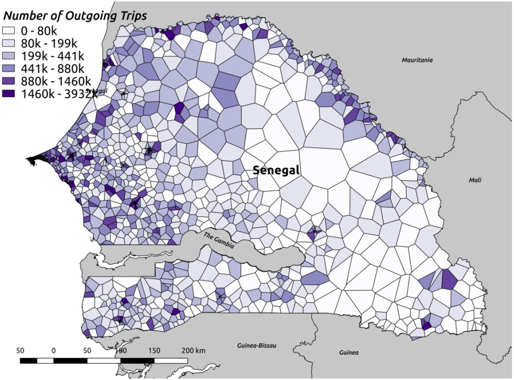

Figure: Number of outgoing trips per cell tower zone[2]

[1] We thank Orange and Sonatel for access to the mobility data.

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Vulnerability Assessment

1. Determine exposure of roads to flooding
   - threshold flood raster (e.g. flooding $\geq$ 1m)
   - compute geometric intersection of roads with flooded raster cells

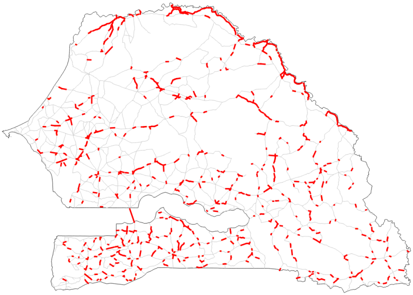

Figure: Roads expected to be impassable during a 100-year flood due to flooding over 1m

Vulnerability Assessment

2. Determine impact of flooded roads on mobility
   - Check if paths between origin and destination locations exist
   - Estimate proportion of travel demand relying on those paths

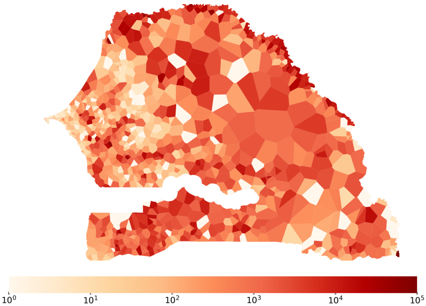

Figure: Estimated number of outgoing trips per cell tower zone that cannot be completed due to the damages in the road network.

Optimizing Accessibility

GOAL (OBJECTIVE): Minimize number of infeasible trips in flooding scenario

ACTIONS (DECISIONS): Upgrade roads (flood barriers, elevation, surfacing)

RESTRICTIONS (CONSTRAINT): Limited budget for upgrades

Baselines:

- *Flooding-driven investment:*

  GOAL: Maximize number of operational roads in flooding scenario

- *Mobility-driven investment:*

  GOAL: Maximize upgrades to roads with highest traffic

Optimizing Accessibility

- **Why is this problem hard?**
  - The added benefit of ‘repairing’ a single edge in the road network depends on all other edges we repair
  - In the worst case we must recompute all pairs shortest paths to evaluate the benefit
- Algorithm
  - Greedily repair the road segment that offers best reduction in number of infeasible trips per unit cost

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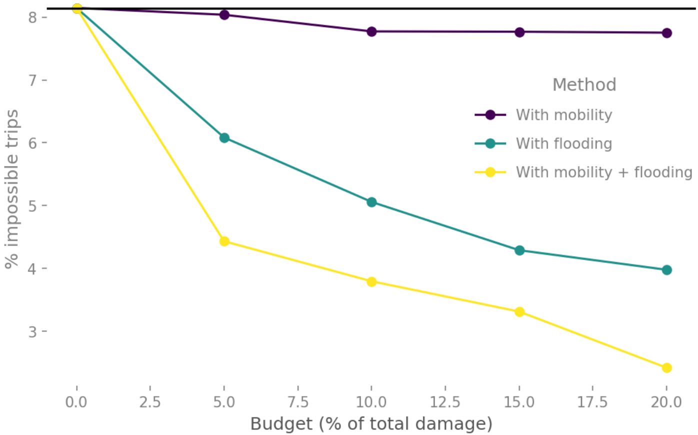
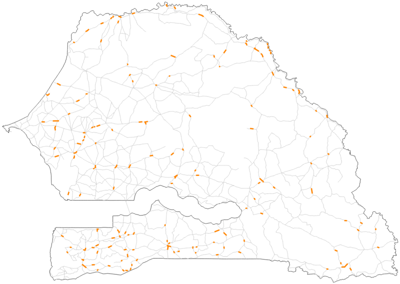
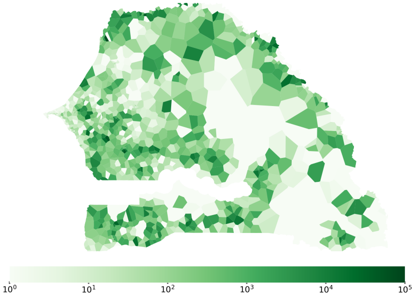
Reduction in number of infeasible trips



Spatial distribution of benefits

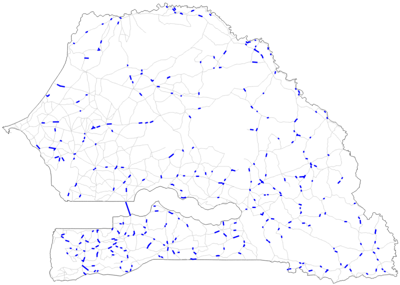
mobility+flooding, 175 roads repaired
1,787,627 trips recovered

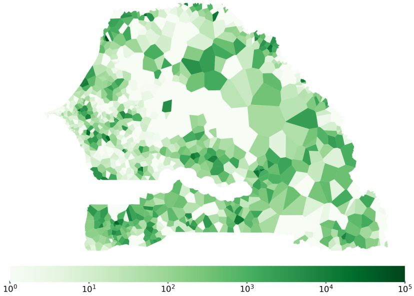




Spatial distribution of benefits

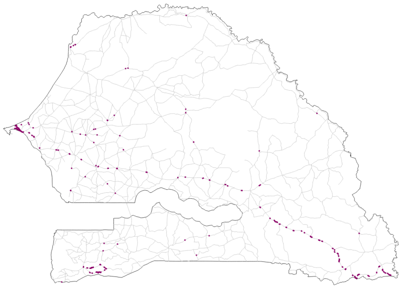
flooding, 359 roads repaired, (126 common with “mobility+flooding”)
992,499 trips recovered

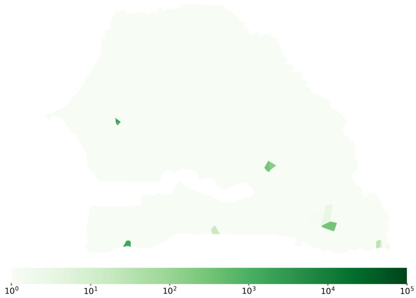




Spatial distribution of benefits

mobility, 179 roads repaired, (5 common with "mobility+flooding")
52,060 trips recovered





Key results

- There is not a large overlap between solutions that depend only on mobility data and solutions that use mobility and flooding data
- The spatial distribution of the solution that only uses mobility data is biased to higher population areas
- The solution that only uses flooding data misses restoring connectivity to populations in the middle of the country
- Half of the infeasible trips in the 100 year flooding scenario can be restored with a modest budget (5% of total flooded distance)

Summary

- We propose a method to quantify the impacts of flooding on human mobility
- We propose a greedy algorithm that maximizes accessibility over a road network and flooding scenario given a budget constraint
- We compare our greedy algorithm to baseline methods that leave out important data dimensions
- We need to combine data from multiple sources to make informed decisions that support climate resilience

Questions?

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