Cholera Data and Modelling in Planning & Targeting WASH Interventions

Lusaka & Harare

Global Task Force for Cholera Control (GFTCC)
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Motivation

- **How to reach the GTFCC target for reducing cholera by 2030**
  - Short term - OCV
  - Medium to long term planning for WASH improvement
- **Proliferation of data and empirical methods**
  - Surveillance databases, Household surveys, institutional and project data, government data,
  - Big data, machine learning and so on
- Question-

How data can be used to determine WASH interventions and target them to reduce cholera cases?

  - **Lusaka, Zambia and Harare, Zimbabwe**

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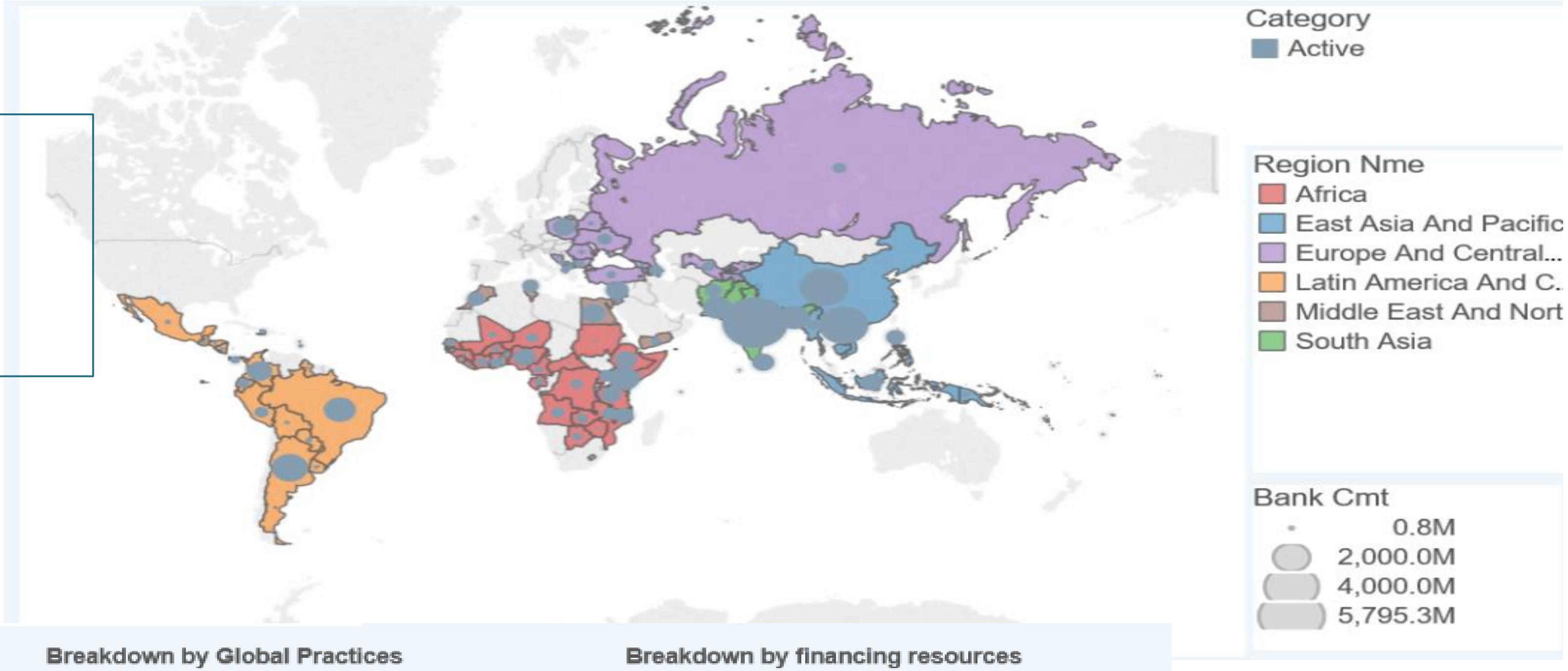
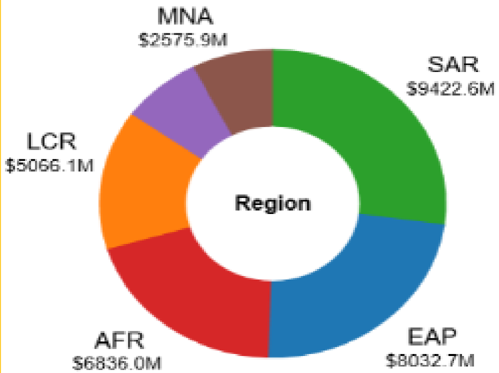
World Bank Water Supply and Sanitation Portfolio

318 Projects

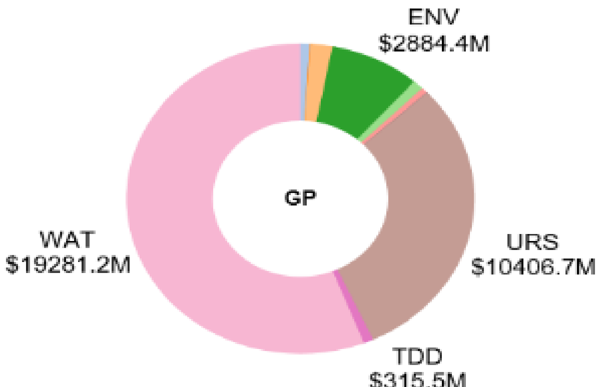
$34.5 Bn in Commitments



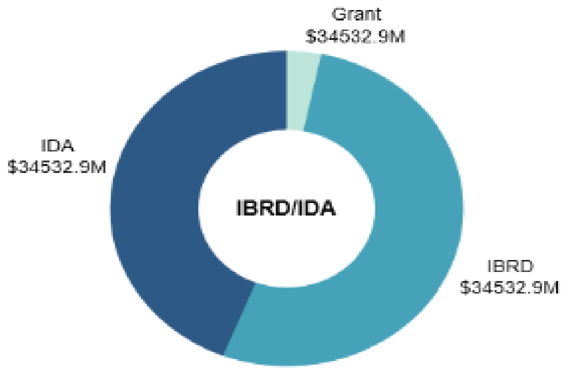
Breakdown by regions



Breakdown by Global Practices



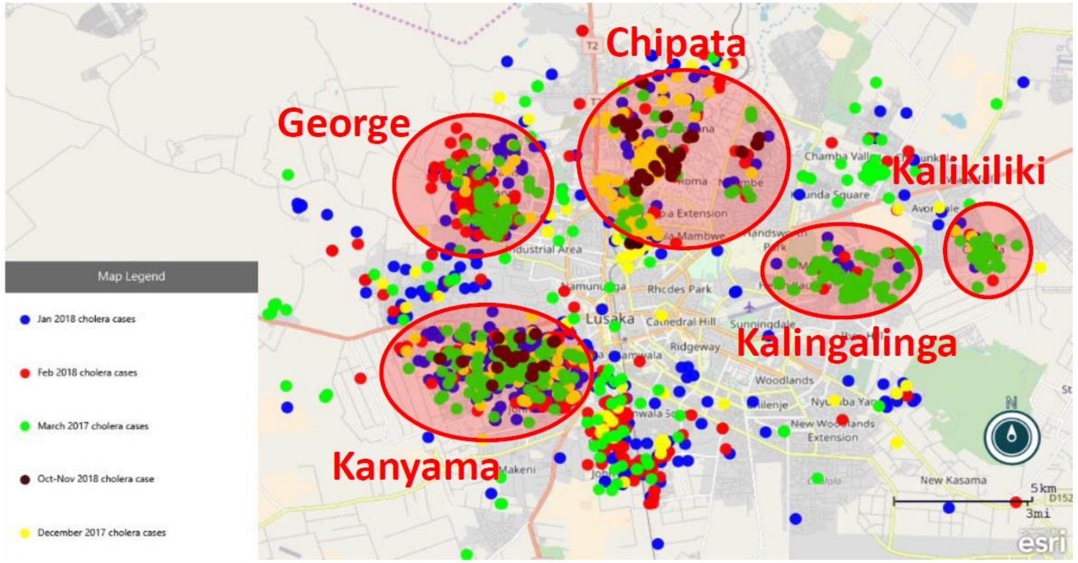
Breakdown by financing resources



Background to Cholera Outbreaks

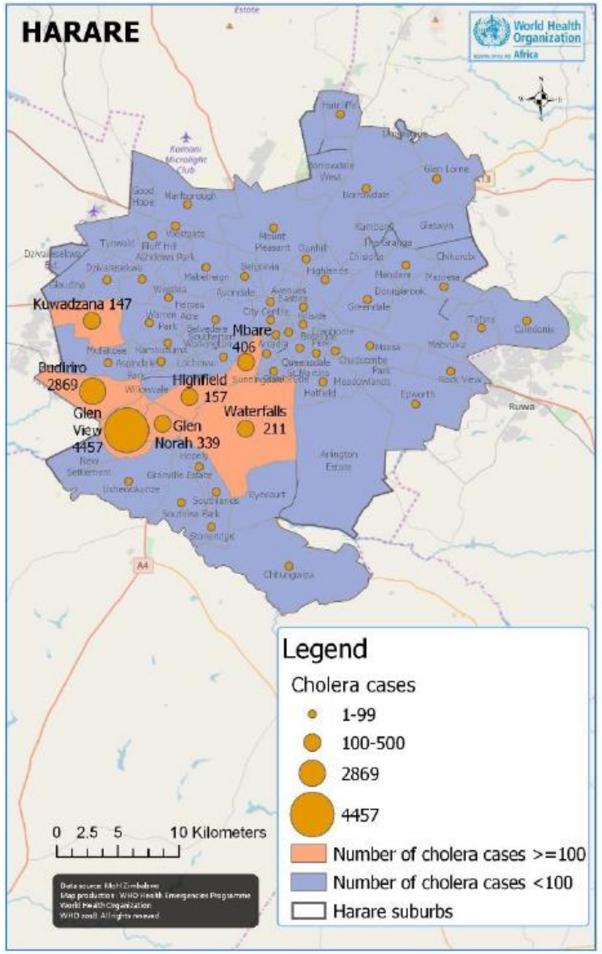
Lusaka; Zambia

- 6th October 2017 a cholera outbreak was declared in Lusaka
- Almost 6,000 cases were reported nationwide, 92% of these (5,444 cases) were in Lusaka
- The peak of the outbreak was between end of Dec 2017 and Jan 2018
- It was prominent in peri-urban settlements of the city but spread widely



Harare; Zimbabwe

- Between Sept and Feb 2019, a cumulative total of 9,971 cases of cholera of which 9,755 were suspected and 217 confirmed were reported in Harare,
- This included 46 deaths.
- Largest number of cases among 20-29 years, followed by 1-4 years and 30-39 years.
- By suburbs: Glenview and Budiriro are the most affected, followed by Mbare (market area). Others identified by WHO include Waterfalls (no network), Glennorah and Hopley



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Risk factors identified from other studies

Studies have revealed a host of different contamination pathways for cholera:

- Contaminated water sources (both drinking and for domestic use) (Conroy et al., 2001; Dunston et al., 2001; Nygren et al., 2014) (Kwesiga et al., 2018)
- Poor sanitation (Koelle et al., 2005; Jutla et al., 2013; Waldman et al., 2013; GTFCC, 2015; Taylor et al., 2015)
- Contaminated food (Sanipath, 2018)
- Poor personal hygiene (Sanipath, 2018)
- Poor solid waste management
- Poor drainage (Sasaki et al., 2009)
- Increase in temperature and rainfall (Luque Fernandez et al., 2009) (Roobthaisong et al., 2017)
- Water service interruptions (Ashraf et al. ,2017); (Brocklehurst et al., 2013)

Lusaka, Zambia

Objectives of Lusaka Sanitation Project (LSP)

Objective: To increase access to improved sanitation services in selected areas of Lusaka and strengthen Lusaka Water and Sanitation Company's (LWSC) capacity to manage sanitation services.

Part of a larger Lusaka Sanitation Program funded by AfDB and EIB. LSP is implemented by LWSC. WB Funding is through an IDA Credit of US$65 million

Project consists of three components:

Component 1: Sewerage improvements US$38 million

Component 2: Onsite sanitation US$13 million

Component 3: Institutional strengthening US$9 million

The MTR offered an opportunity to re-assess the investments being made in order to identify whether and how the project can be re-structured in order to:

Better target areas which were identified as high risk during the cholera outbreak

Enhance public health impact (in terms of cholera risk reduction)

Lusaka - Objectives

Explore how can LSP be better structured to reduce the risk of cholera

Bayesian geostatistical analysis (Taylor, Davies, Rowlingson & Diggle, 2013) was undertaken

The study has done the following:

Stage 1: Construction of geospatial WASH and environmental covariates

- ✓ Used cholera case location data and high-resolution spatial covariates (environmental, WASH access) to map cholera hotspots at high resolution.

Stage 2: Development of a geospatial cholera risk map

- ✓ Sought to explain patterns of risk in relation to putative causal factors.

✓ **Stage 3:** Simulation analysis to explore impact and targeting of improved WASH infrastructure

- ✓ Compared current WASH access and infrastructure gap to the pattern of cholera risk and identify priority areas for improved infrastructure.

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Stage 1:

Construction of geospatial WASH and environmental covariates

Covariates in the Model

Covariate layers were assembled in one of three ways:

1. Pre-existing geospatial grids were obtained from numerous sources:
    - Poverty rates
    - Household size
    - Night-time light brightness
    - Groundwater vulnerability to contaminants

2. Covariate grids were generated based on GIS data describing relevant WASH infrastructure or natural features:
    - Distance from sewer network
    - Distance from water network
    - Distance from stream/river (based on hydrological analysis of Digital Elevation Model data)
    - Distance from cemetery/burial ground

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Covariates in the Model (contd.)

Covariate layers were assembled in one of three ways:

3. WASH covariate grids were generated by implementing a Bayesian geostatistical model applied to household or other survey data describing water and sanitation facilities, water quality, and flood risk
    - % HHs with soap in toilet
    - % HHs not treating water
    - % households with unimproved sanitation
    - Density of population with unimproved sanitation
    - Composite risk index for water source
    - Composite risk index for toilet facility
    - Prevalence of *E. coli* in drinking water sources
    - Risk of flooding (poor drainage)
    - Frequency of complaints regarding sewer network, water supply/quality

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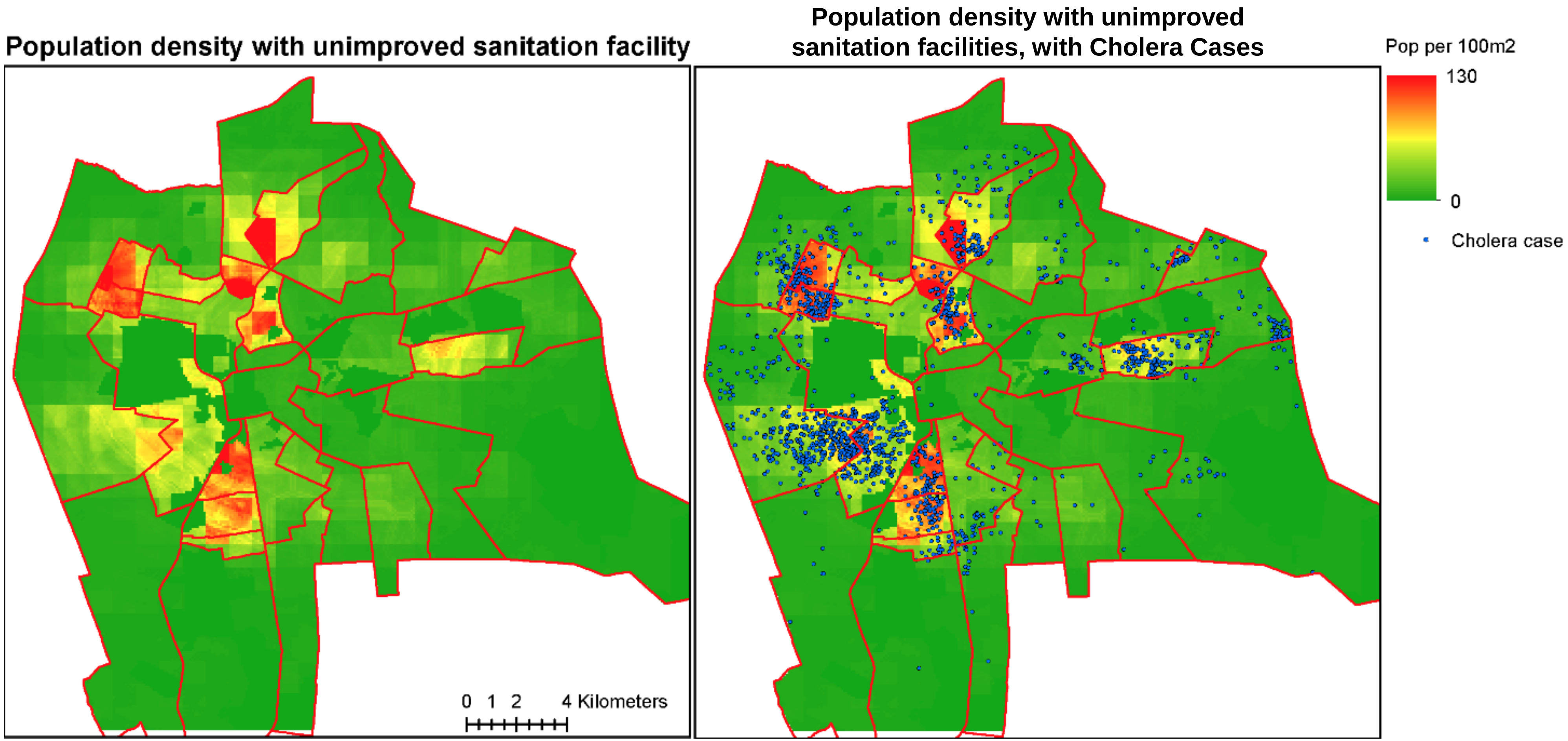
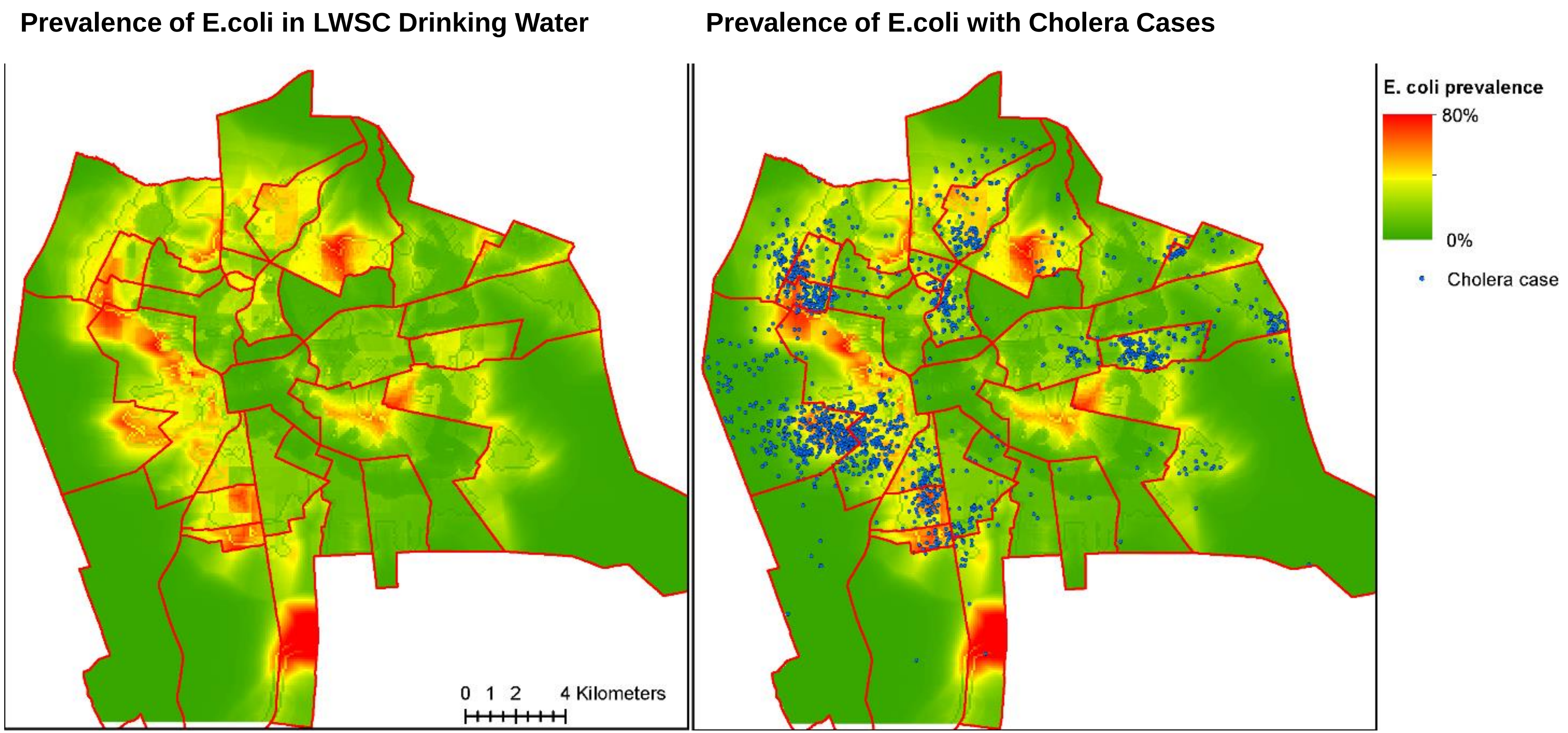
Overlaying Cholera Incidence with a Geospatial Data Surface:
Population Density with Unimproved Sanitation



WASH indicator surface derived from household survey data and geostatistical model. Plot on right shows cholera case locations overlaid for visual comparison.

Overlaying Cholera Incidence with a Geospatial Data Surface: Prevalence of E-Coli in LWSC Drinking Water Sources



Indicator surface derived from CDC water testing data on presence of *E.coli* in water sampled from LWSC sources. Data were then interpolated using a Bayesian geostatistical model to create a continuous surface. Plot on right shows cholera case locations overlaid for visual comparison.

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Stage 2:

Development of a geospatial cholera risk map

Stage 2: Methodology

Response data:

- Spatial locations of reported cholera cases across Lusaka

Covariate data:

- Geospatial WASH and environmental data surfaces described in previous Stage

Model type:

- Cholera cases were treated as a spatiotemporal point pattern
- Geostatistical modelling was performed using a log-Gaussian Cox Process (LGCP) model*, fitted via MCMC
- Output is predicted surface of cholera incidence rate at same resolution as covariates (100m×100m)
- Analysis implemented using R

* Peter J. Diggle, Paula Moraga, Barry Rowlingson and Benjamin M. Taylor (2013) Spatial and Spatio-Temporal Log-Gaussian Cox Processes: Extending the Geostatistical Paradigm, *Statistical Science*, 4, 542-563.

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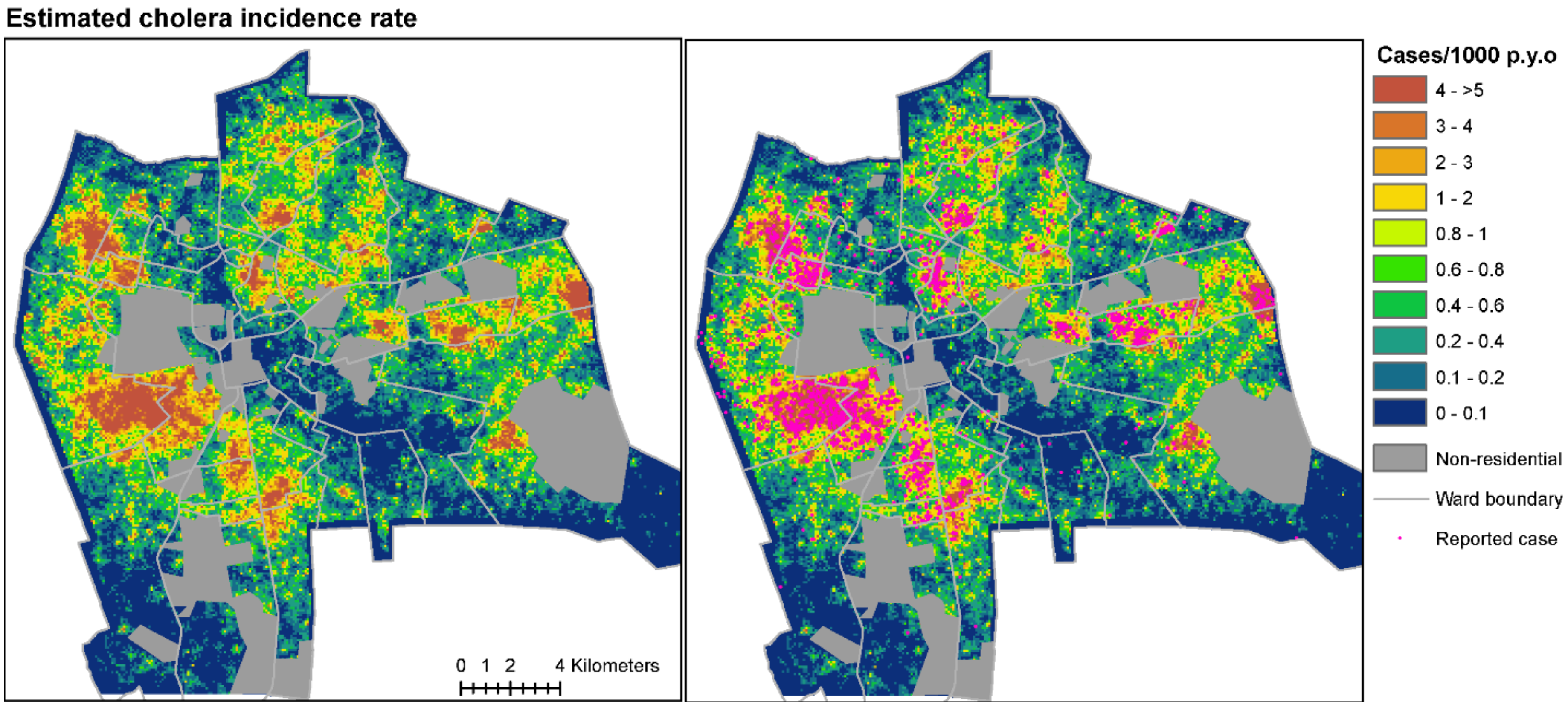
Model Estimated Predicted Incidence (left) vs. Actual Cholera Cases (right)



Output of LGCP model: a predicted surface of cholera risk at 100m resolution. Right-hand map shows raw cholera case data overlaid for visual comparison

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Stage 3:

Counterfactual analysis to explore impact and targeting of improved WASH infrastructure

What reduction in Cholera risk might be achieved by different improvements to WASH infrastructure and environment?

Use modelled relationship between WASH indicators and cholera incidence to generate ‘counterfactual’ incidence maps under different scenarios of improved WASH indicators

Model the effects of having separate water, sanitation or drainage interventions for the whole city, or within 1km or 500m of existing networks using univariate modelling technique. Six scenarios are envisaged with spatial subvariants to cover each of these distinct catchments.

What reduction in Cholera risk might be achieved by different improvements to WASH infrastructure and environment?

Use modelled relationship between WASH indicators and cholera incidence to generate ‘counterfactual’ incidence maps under different scenarios of improved WASH indicators

- **ROUND 1: Six scenarios, each with sub-variants**

	Scenario	Variant
1	Provision of piped water to premises as a drinking water source	• If applied city-wide • If restricted to parts of city within 1km or 500m of existing piped water network
2	Ensuring that households have, as a minimum, access to a pubic tap within 100m	• If applied city-wide • If restricted to parts of city within 1km or 500m of existing piped water network
3	Provision of ‘flush to sewer’ (i.e. connecting households to sewer network)	• If applied city-wide • If restricted to parts of city within 1km or 500m of existing sewer network, or to World Bank project areas
4	Ensuring that households have, as a minimum, access to a shared improved onsite sanitation facility	• If applied city-wide • If restricted to current World Bank project areas
5	Reducing risk of flooding	To zero, to ‘low’, or to ‘medium’ risk (all city-wide)
6	Eliminating *E.coli* contamination in LWSC water sources	If applied city-wide

Round 1 Results

Cholera risk reduction rates by intervention type & location

Action	Location	% reduction in cases city-wide	Population targeted
Provide piped water to premises	Everywhere	-60.89	1,761,855
	<1000m from network	-31.04	770,622
	<500m from network	-25.14	619,937
Ensure at least public tap within 100m	Everywhere	-5.95	532,065
	<1000m from network	-3.24	244,082
	<500m from network	-2.82	210,473
Provide universal flush to sewer	Everywhere	-89.57	1,771,116
	<1000m from network	-28.78	689,562
	<500m from network	-12.71	412,765
	Year 1 WB Sewer Area	-0.83	59,094
	Year 1,CSE14,CSE20	-6.25	89,432
	Year 1,CSE14,CSE20,CSE05,CSE10,CSE25	-9.94	172,723
Ensure at least improved shared onsite facility	Everywhere	-56.35	1,457,934
	WB Onsite Sanitation Areas	-22.83	303,500
Eliminate E.coli risk	Everywhere	-52.00	1,771,116
Eliminate E.coli risk	Existing piped water network	-21.03	738,937
Eliminate flood risk	Everywhere	-29.55	1,771,116
Ensure flood risk does not	Everywhere	-10.57	748,480

Targeting

Given limited resources, investments must be targeted towards areas where the interventions have the greatest effect on reducing cholera risk

Targeting criteria used in this analysis was as follows:

- The number of cases of cholera was calculated for the whole of Lusaka and for each of the 33 wards
- The number of cases that each intervention is estimated to reduce was calculated for the whole of Lusaka and for each ward
- Those wards with the highest percentage of cases reduced of the total cases in Lusaka were ranked as the highest priority wards, those with the lowest were ranked last.

The following graphs and maps illustrate that by targeting the top five or ten wards, you can have a larger reduction in risk before necessarily reaching the whole city.

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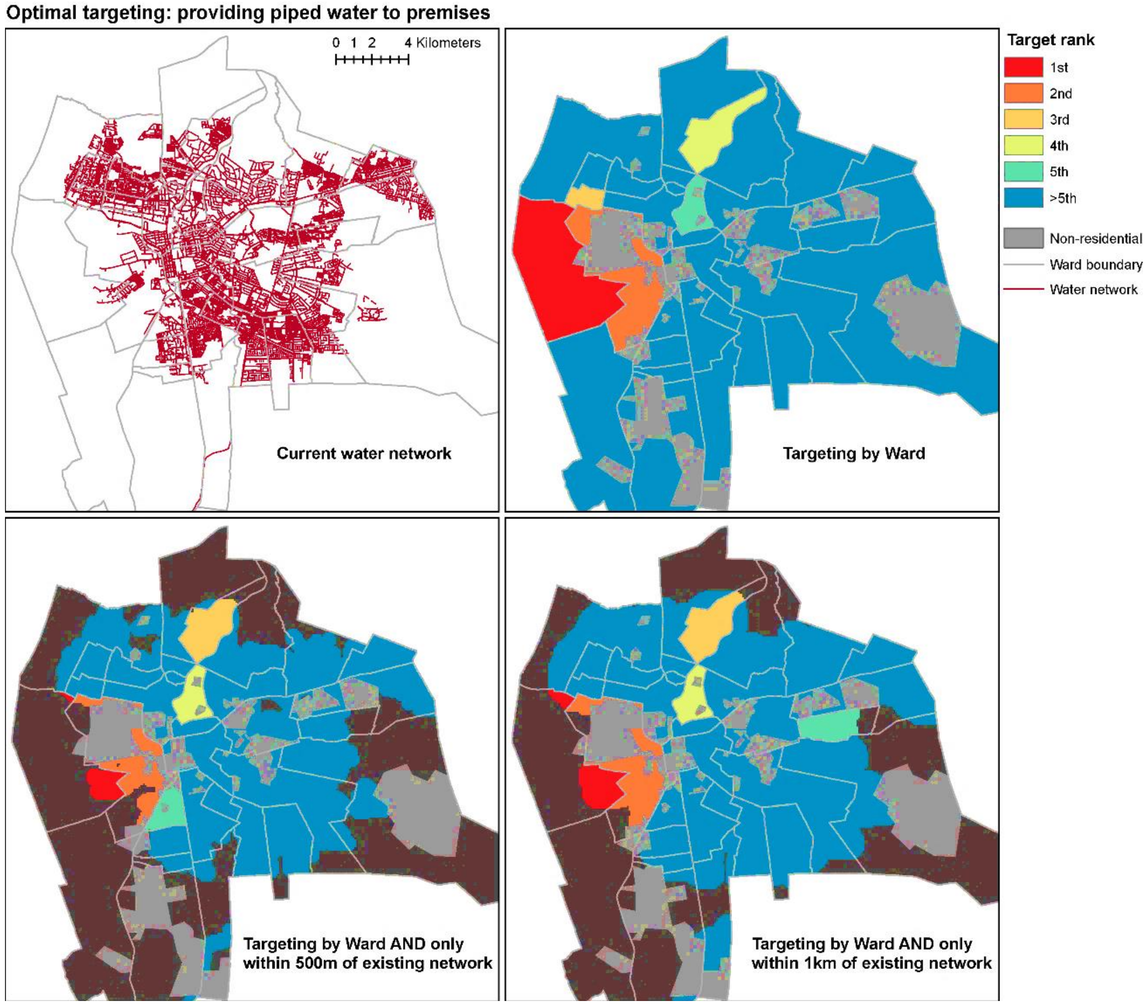
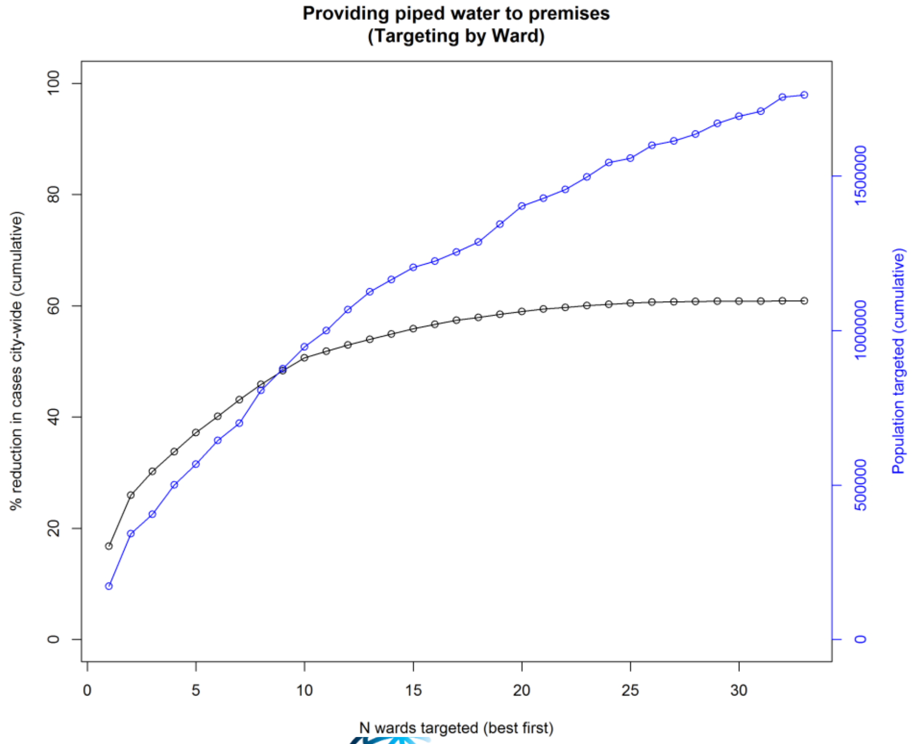
Targeting Results on Ward Prioritization:
Provide Piped Water to Premises

- **Q2: How can each scenario be optimally targeted within the city, ward by ward**



- Provision of piped water to premises



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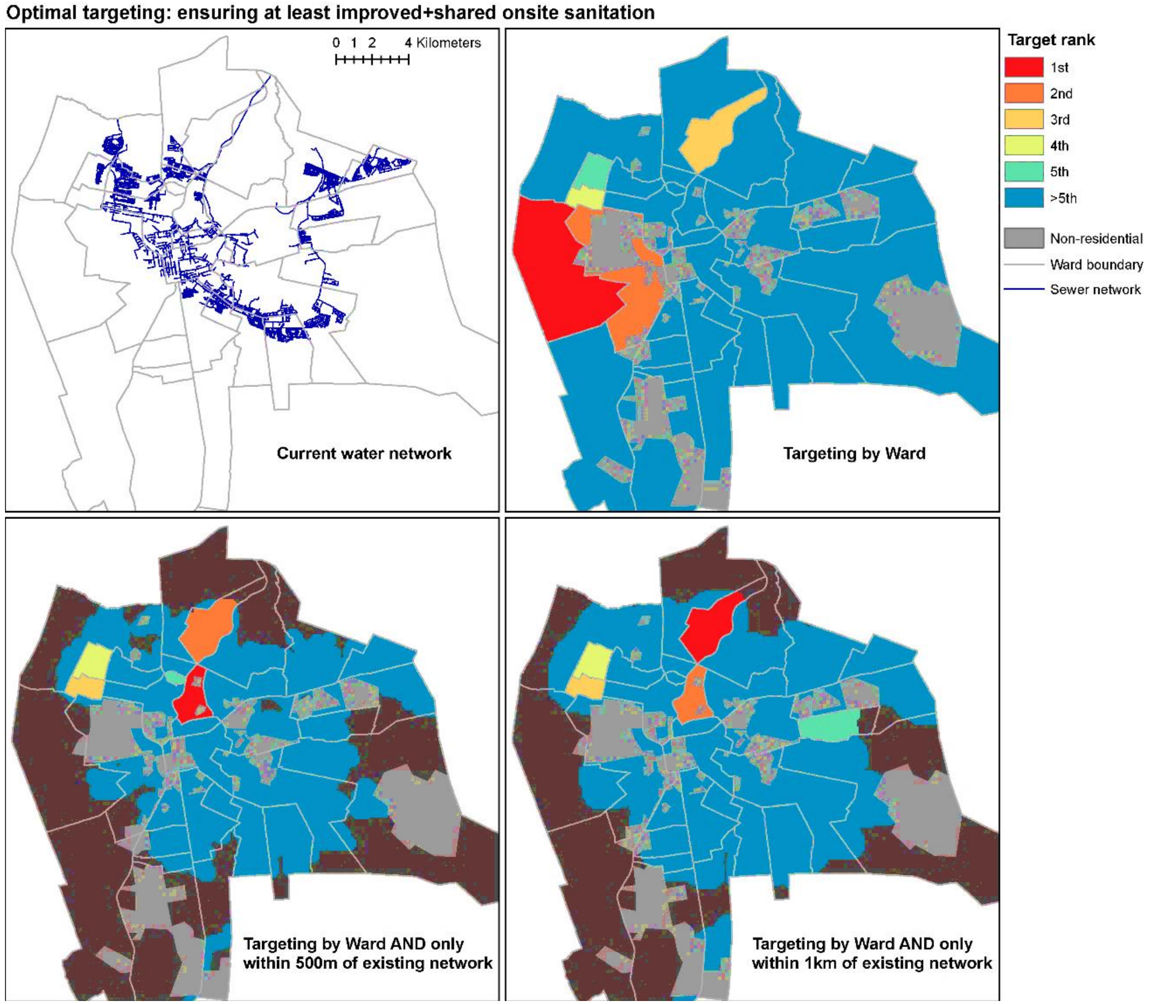
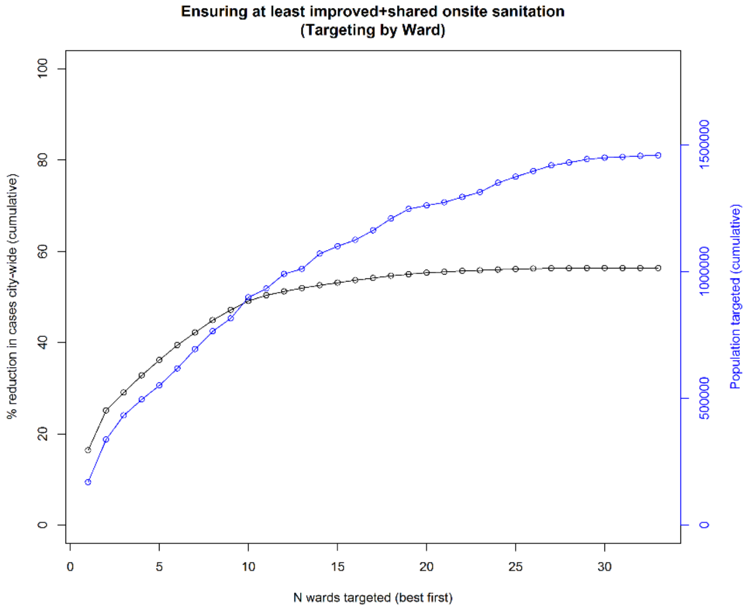
Targeting Results on Ward Prioritization:
Access to Improved & Shared Onsite Sanitation

- **Q2: How can each scenario be optimally targeted within the city, ward by ward**



- Ensuring at least improved+shared onsite facility



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Application:
Lusaka Sanitation Project – Investment Scenarios

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What reduction in Cholera risk might be achieved by different improvements to WASH infrastructure and environment?

Scenario		Description	Additional Cost (USD millions)	Total cost	% reduction in cholera
Reduced scope	1	Reduced Scope	0	65	**-23.7**
	2	Reduced Scope (variant)	0	65	**-28.3**
Partial Scale-up	3A	Original Scope	15	80	**-28.3**
	3B	Original Scope plus water quality by reducing E. Colii in the network	20	85	**-35.2**
	3C	Original Scope plus water quality by reducing E. Coli in the network plus providing on premis piped water access	69	134	**-47.7**
Project expansion	4A	Expanded Scope	36	101	**-31.2**
	4B	Expanded Scope plus water quality by reducing E. Colii in the network	41	106	**-37.6**

Harare, Zimbabwe

Suggested causes in Harare

- Sewer network leakages/breakages
- Poor solid waste management
- Water service interruptions resulting in contamination in the water network
- Contamination of shallow wells, unprotected wells, even unsafely drilled boreholes
- Spread through large markets, public gathering places (district facilities such as schools, hospitals, community halls)
- Onsite sanitation facilities in peri-urban east?
- Exacerbated by poor drainage?

In the context of Harare, questions our analysis would seek to answer include…

- Which infrastructure failures are more strongly correlated with cholera risk in different parts of the city? E.g. sewer blockages vs. boreholes as main water source vs. piped water breakages
- What investments would be the most cost effective in reducing the risk of cholera?
- Which public places are the most at risk when it comes to spreading or diffusing the disease?

Main Innovation- Incorporating the effect of mobility in the spread of cholera Using mobile phone data

- Will help to predict the dynamic pattern of the spread of cholera
- Help the advance effective deployment of OCV and other WASH and behavior change campaigns

Key messages

- Geospatial analysis as presented here has been used to predict the likely risk of cholera; several innovations are possible
- This type of analysis, both in terms of disaggregating investment types, and spatially ranking target areas can be used to inform design of other similar projects in cities in Africa and around the world.

- There is an increasing need to enhance surveillance capacity
- Data sharing is paramount for research as well as quick response
- Need for close interaction between research and control efforts
- Multisectoral coordination is the key to combating cholera

Acknowledgements

This work was made possible by the facilitation and provisioning of data from the following local and national stakeholders:

- Zambia National Public Health Institute (ZNPHI)
- Lusaka Water and Sewerage Company (LWSC)
- Zambia Water Resources Management Authority (WARMA)
- Lusaka City Council (LCC)
- Millennium Challenge Corporation (MCC) & Millennium Challenge Account, Zambia (MCA-Z)
- German Development Cooperation (BGR/GReSP)

Annex

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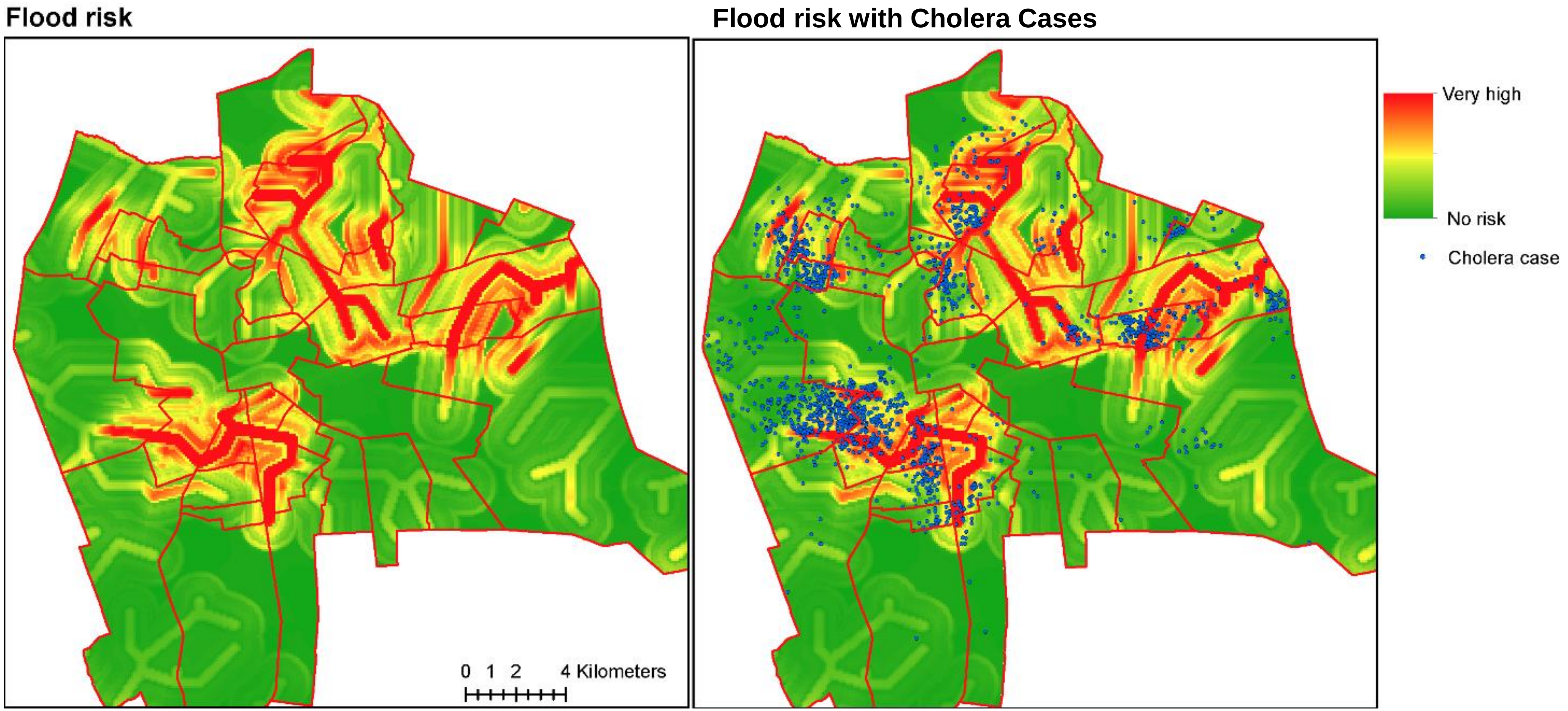
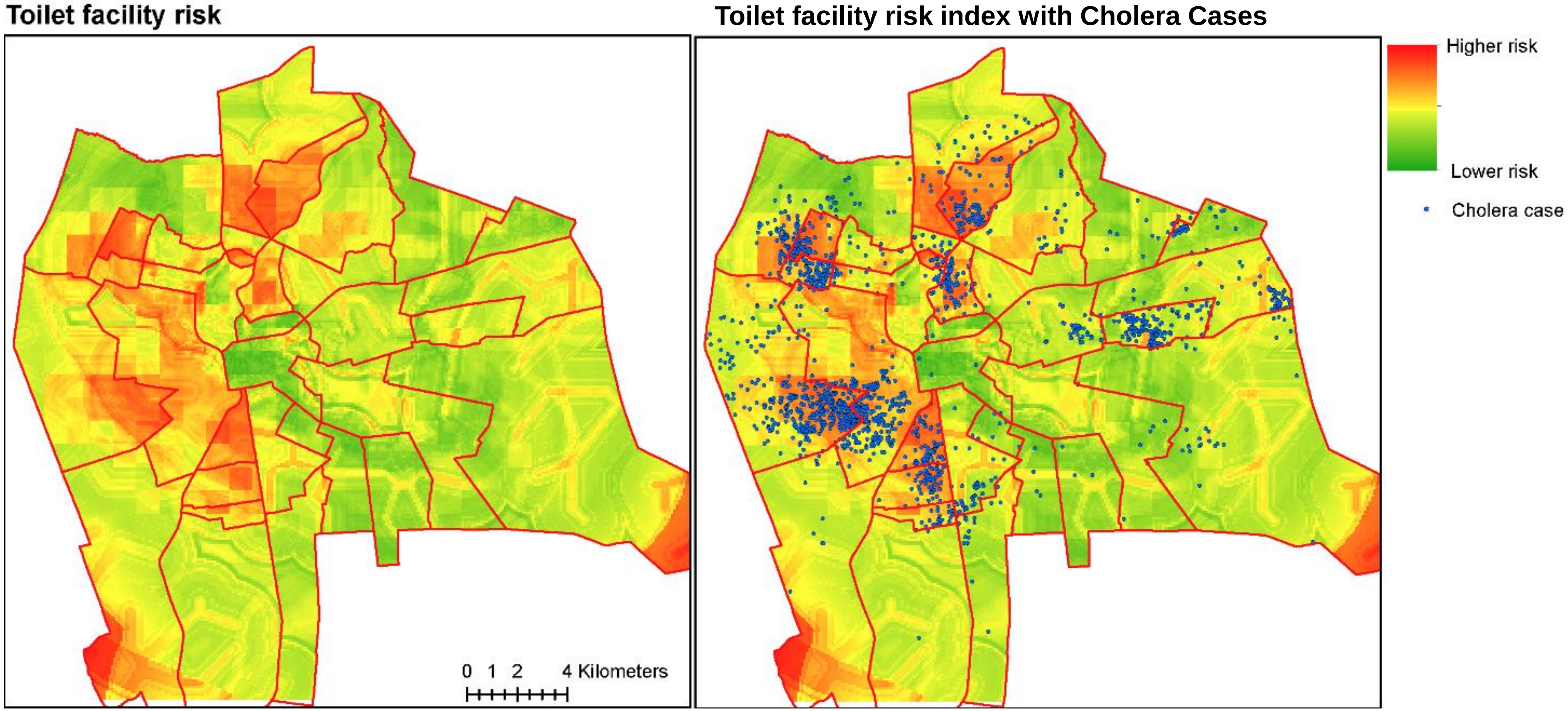
Overlaying Cholera Incidence with Geospatial Data Surface: Flood Risk



Indicator surface derived from data on reported flood risk interpolated using a Bayesian geostatistical model. Plot on right shows cholera case locations overlaid for visual comparison.

Toilet Facility Risk (Constructed Index)



WASH indicator surface derived from household survey data and geostatistical model. Plot on right shows cholera case locations overlaid for visual comparison.

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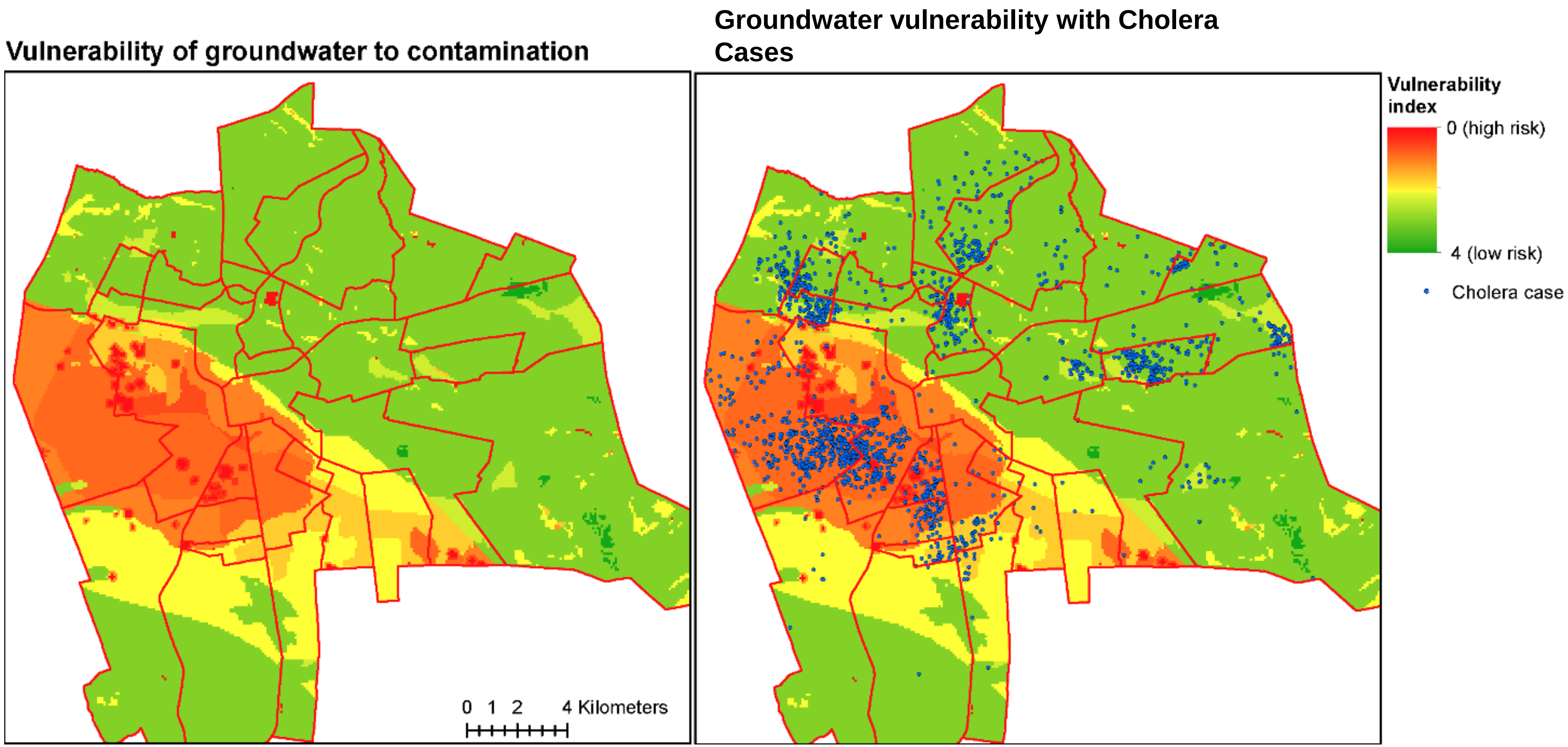
Groundwater Vulnerability Index



Indicator surface derived directly from external data source. Plot on right shows cholera case locations overlaid for visual comparison.

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