How does Infectious Disease Propagate?

Presenter: Matthew Kwok

Why is this important?

- One of the world's deadliest problems

- $8.3 billion (CAD) in total costs (Diener et al., 2016)

  ~ $8.7 billion (CAD) in today's costs

- High mortality rates

H1N1
(H1N1pdm09 virus/Swine Flu)

- Type of deadly lung influenza (bacteria)

- Particular strain discovered in 2009

- Worldwide mortality:
  - 152K – 575K deaths (first year)
  - 80% for ages < 65
  - 80% - 90% for ages ≥ 65

(CDC, 2019)

Classical
Modelling Method

- SIR (Susceptible, Infected & Recovered) - 1927
- Developed by Kermack & Mckendrick

(Zhang, 2016)

Problems with Current & Old Modelling Methods

- Does not account for spatial and microscopic variations
- Long simulation times
- Propagation of disease in
  - Public Transit
  - Workplace
  - Residential Areas
- Environmental Influences
  - Pollution
  - Sanitation
  - Hygiene

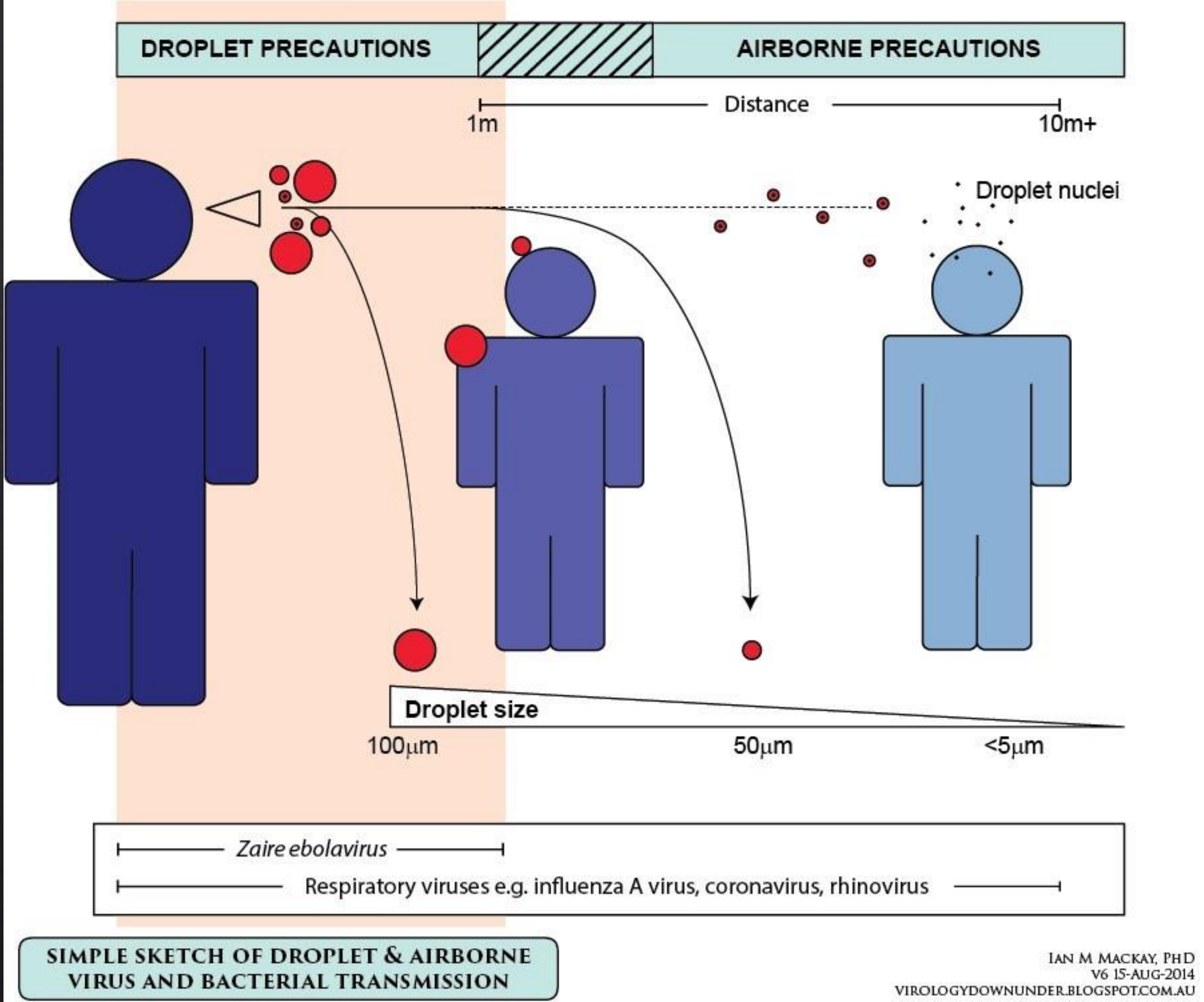
(Zhang, 2016)

Objectives

- Assessing risk of airborne infectious disease propagation in cities
- Treat problem like a mass transport problem
- Modelling based on SIR model
- Considering both static and dynamical factors

Comprehensive Risk Analysis

(Zhang, 2016)


DROPLET PRECAUTIONS
AIRBORNE PRECAUTIONS
Distance
1m
10m+
Droplet nuclei
Droplet size
100µm
50µm
<5µm
Zaire ebolavirus
Respiratory viruses e.g. influenza A virus, coronavirus, rhinovirus
SIMPLE SKETCH OF DROPLET & AIRBORNE VIRUS AND BACTERIAL TRANSMISSION
IAN M MACKAY, PHD
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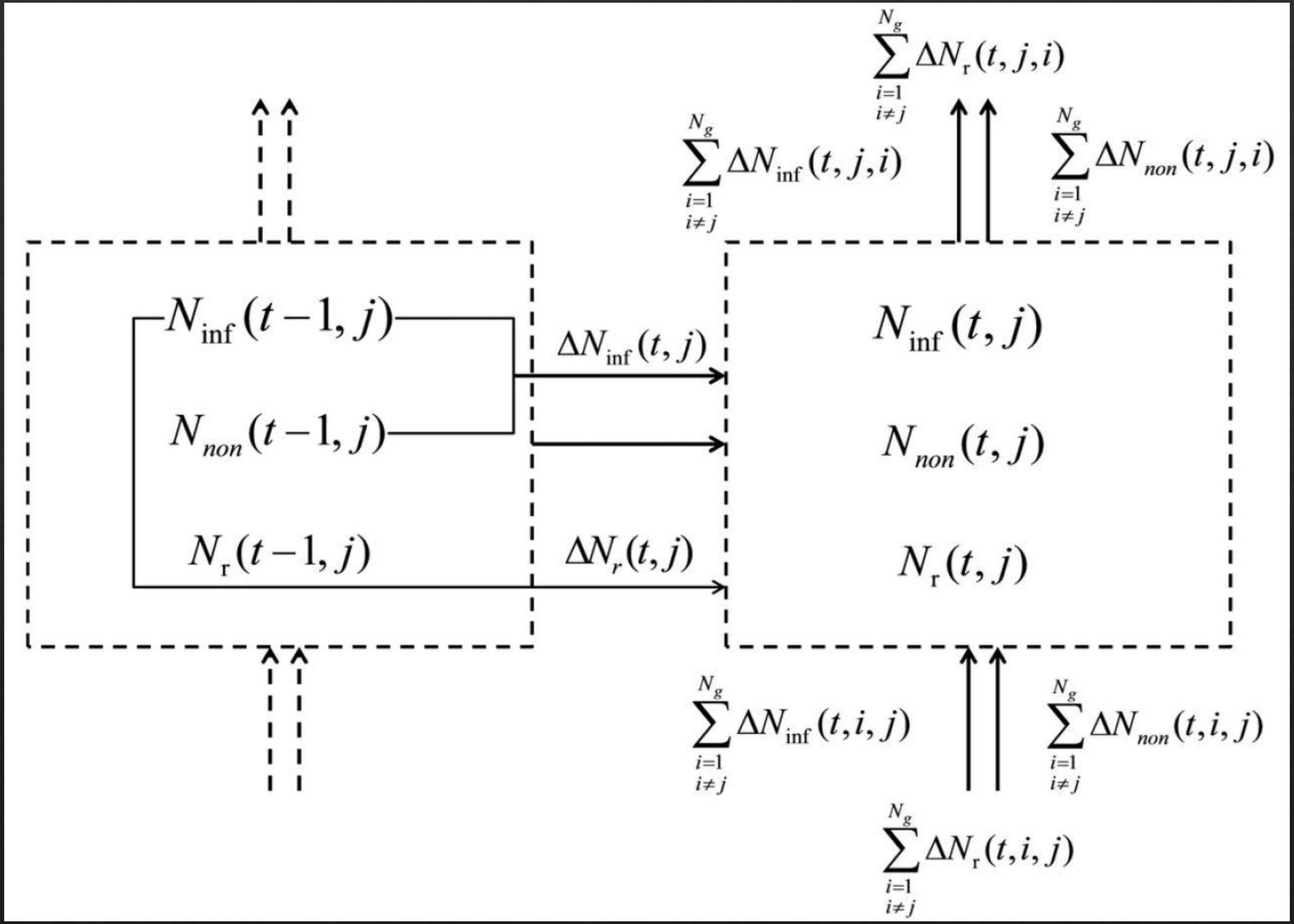
- ΔN_{inf} = Number of Non-Infected becoming Infected
- ΔN_{non} = Number of Infected becoming Non-Infected
- ΔN_{r} = Number of Infected becoming Recovered



(Zhang, 2016)

$$N_{inf}(t,j) = N_{inf}(t-1,j) + \Delta N_{non}(t,j) - \Delta N_r(t,j) + \sum_{\substack{i=1 \\ i \neq j}}^{N_g} \Delta N_{inf}(t,j,i) - \sum_{\substack{i=1 \\ i \neq j}}^{N_g} \Delta N_{inf}(t,i,j)$$

$$N_{non}(t,j) = N_{non}(t-1,j) + \Delta N_{inf}(t,j) + \sum_{\substack{i=1 \\ i \neq j}}^{N_g} \Delta N_{non}(t,i,j) - \sum_{\substack{i=1 \\ i \neq j}}^{N_g} \Delta N_{non}(t,j,i)$$

$$N_r(t,j) = N_r(t-1,j) + \Delta N_r(t,j) + \sum_{\substack{i=1 \\ i \neq j}}^{N_g} \Delta N_r(t,i,j) - \sum_{\substack{i=1 \\ i \neq j}}^{N_g} \Delta N_r(t,j,i)$$

$$[N] = \frac{infected\ person}{\min \cdot\ grid}$$

(Zhang, 2016)

Number of Recoveries from Infection

$$\Delta N_r(t, j) = \alpha \cdot N_{inf}(t-1, j)$$

$$[\alpha] = \frac{person\ from\ infected}{person\ to\ recovery}$$

(Zhang, 2016)

Comprehensive Risk Equation

$$\Delta N_{inf} = \frac{N_{inf}(t-1,j) \cdot N_{non}(t-1,j) \cdot \sigma I \cdot f(T) \cdot f(RH)}{\overline{R_P(t-1,j)}} + N_h(t,j)$$

R(t, j)	Comprehensive risk at time t in grid j
σ	Augment coefficient relating infectivity to sanitation & hygiene
I	Virus Infectivity ~ I = 1 implies 100% chance of infection
$f(T)$	Temperature influence
$f(RH)$	Humidity Influence
R_B	Personal Resistance
N_H	Newly infected caused by hospitals in grid j

(Zhang, 2016)

Number of Infections from getting Hospitalized

$$\Delta N_h(t,j) = \frac{\beta N_{inf}(t) \cdot \; N_{non}(t,j) \cdot \sigma I_{nf}}{\overline{R_P(t,j)}} \cdot \frac{D_h(j)}{\sum_{i=1}^{N_h} D_h(i)}$$

$\Delta N_h(t,j)$	Comprehensive risk at time t in grid j
N_{inf}	Total number of infected individuals in city
β	Probability infected person will be in isolation in a hospital
I_{nf}	Viral Infectivity
σ	Augment coefficient relating infectivity to environmental parameters
$D_h(j)$	Scale of hospitals
N_H	Total number of hospitals in city

(Zhang, 2016)

Study Area

- Beijing, China
- Total Area of 16411 km^2
- Population 20 million
- Urban Population density: 9000 people/km^2
- Suburban population density: 550 people/km^2

(Zhang, 2016)

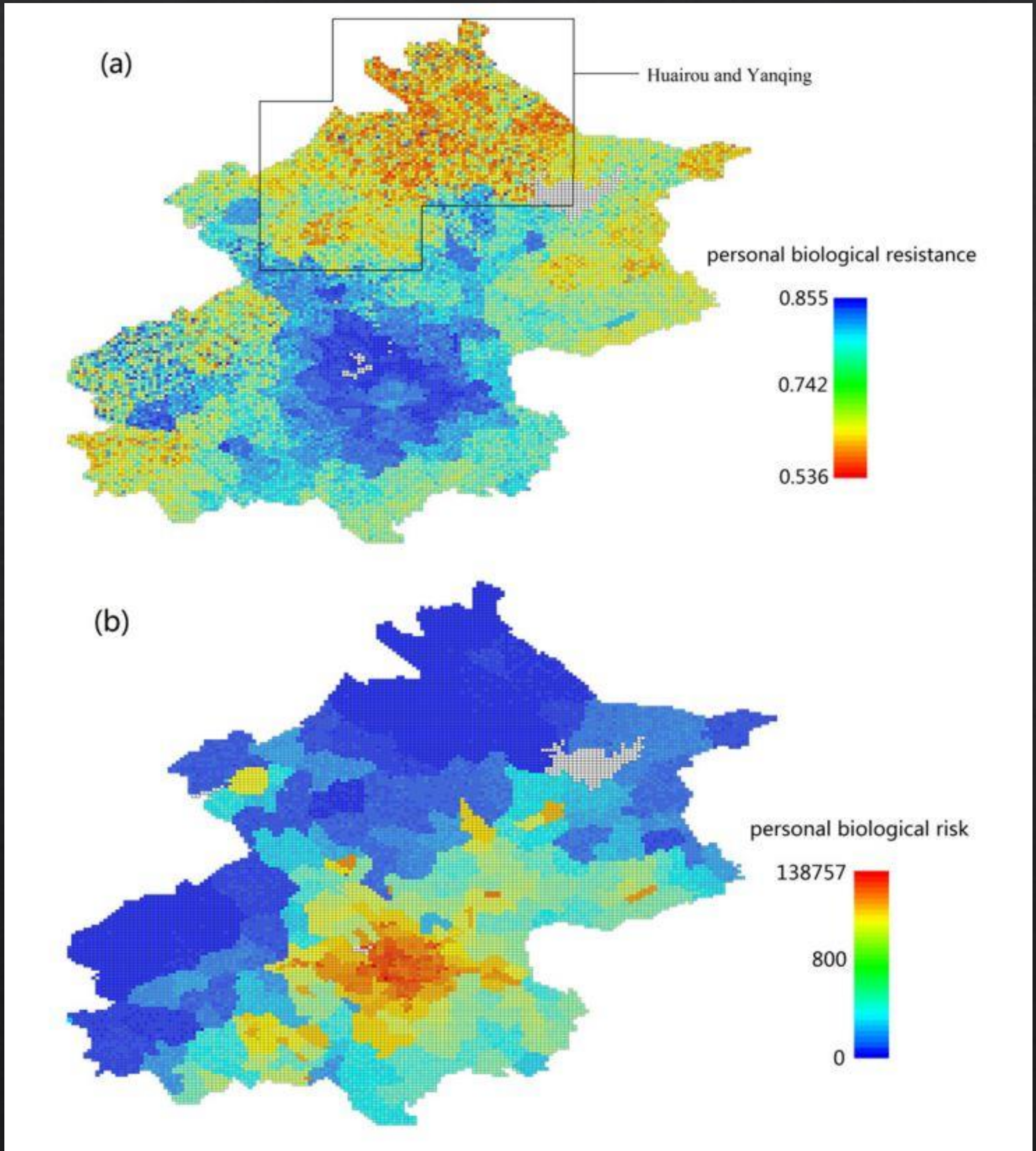
Assumptions

- Viral infectivity (I_{nf} or I) is $\frac{1}{100{,}000}$

$$[I] = \frac{person}{infected \cdot min}$$

- Still some diverse influenza

(Zhang, 2016)

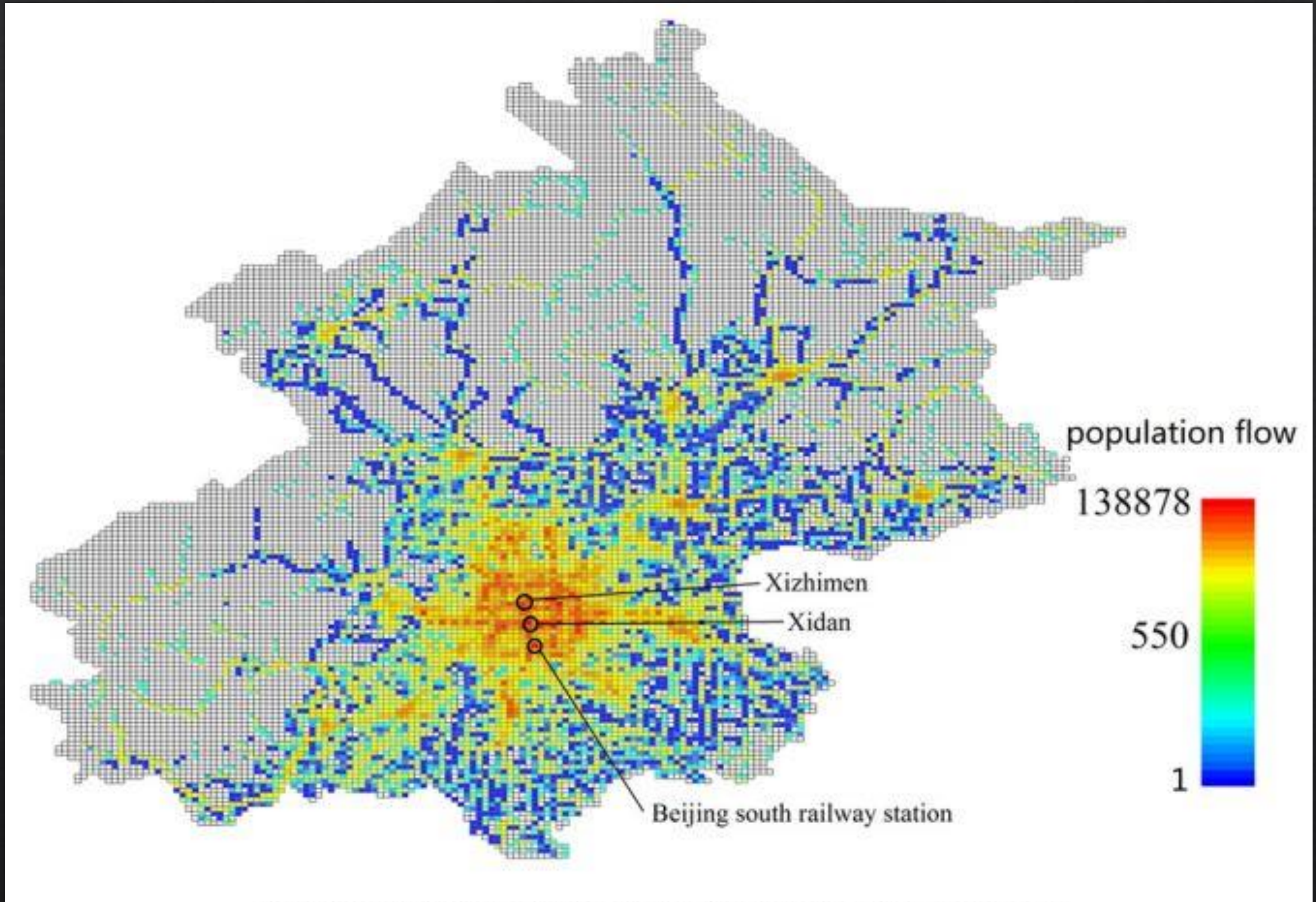


Distribution map of Beijing: (a) personal biological resistance; (b) personal biological risk considering population density.

Distribution of Biological Resistance

$$R_B = G \cdot f(A) \cdot \frac{f(E)}{S \cdot C}$$

(Zhang, 2016)

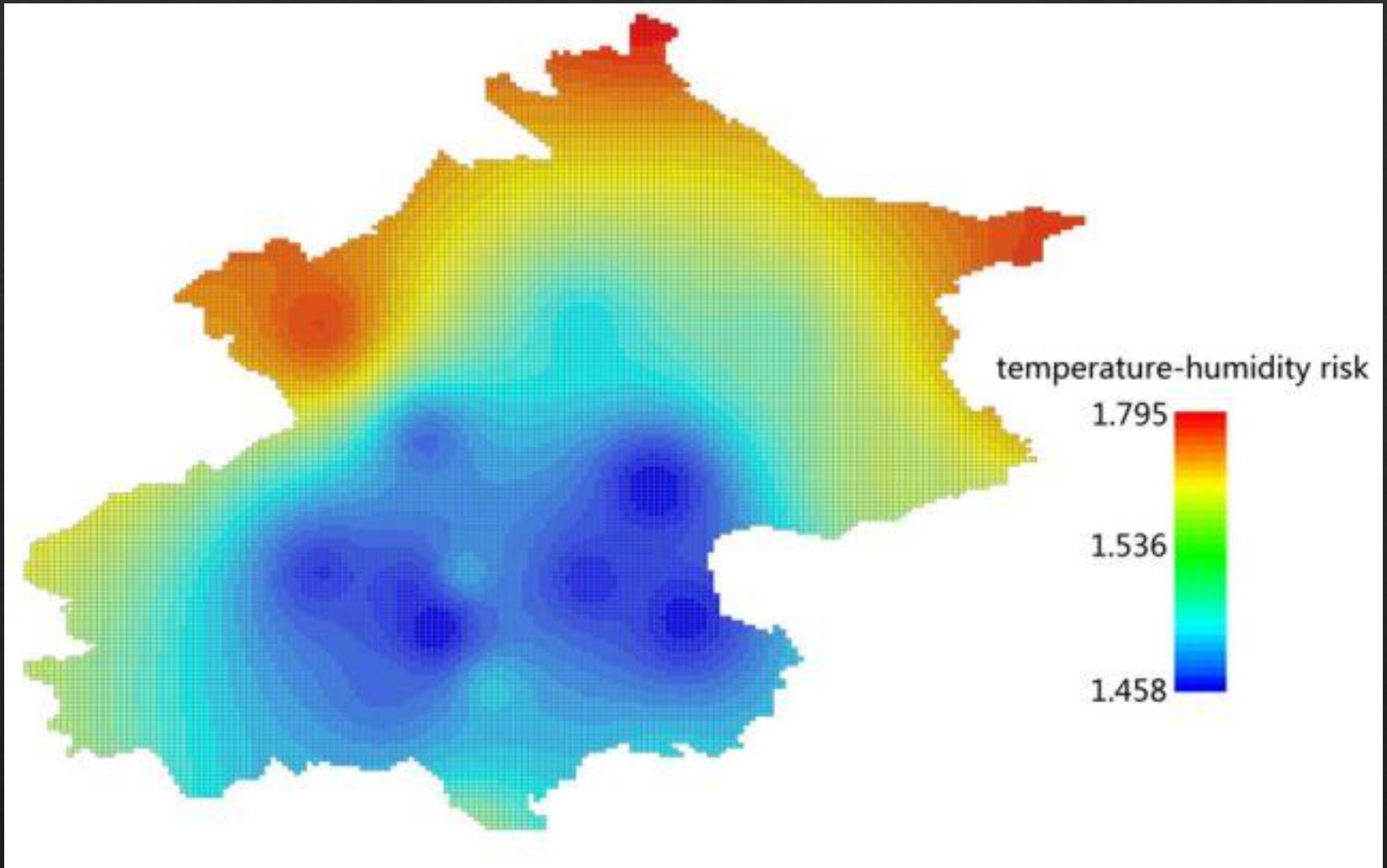


Population flow calculated by the flow rate data of subway and taxi.

Transportation Flow Diagram

(Zhang, 2016)

Distribution of Environmental Risk



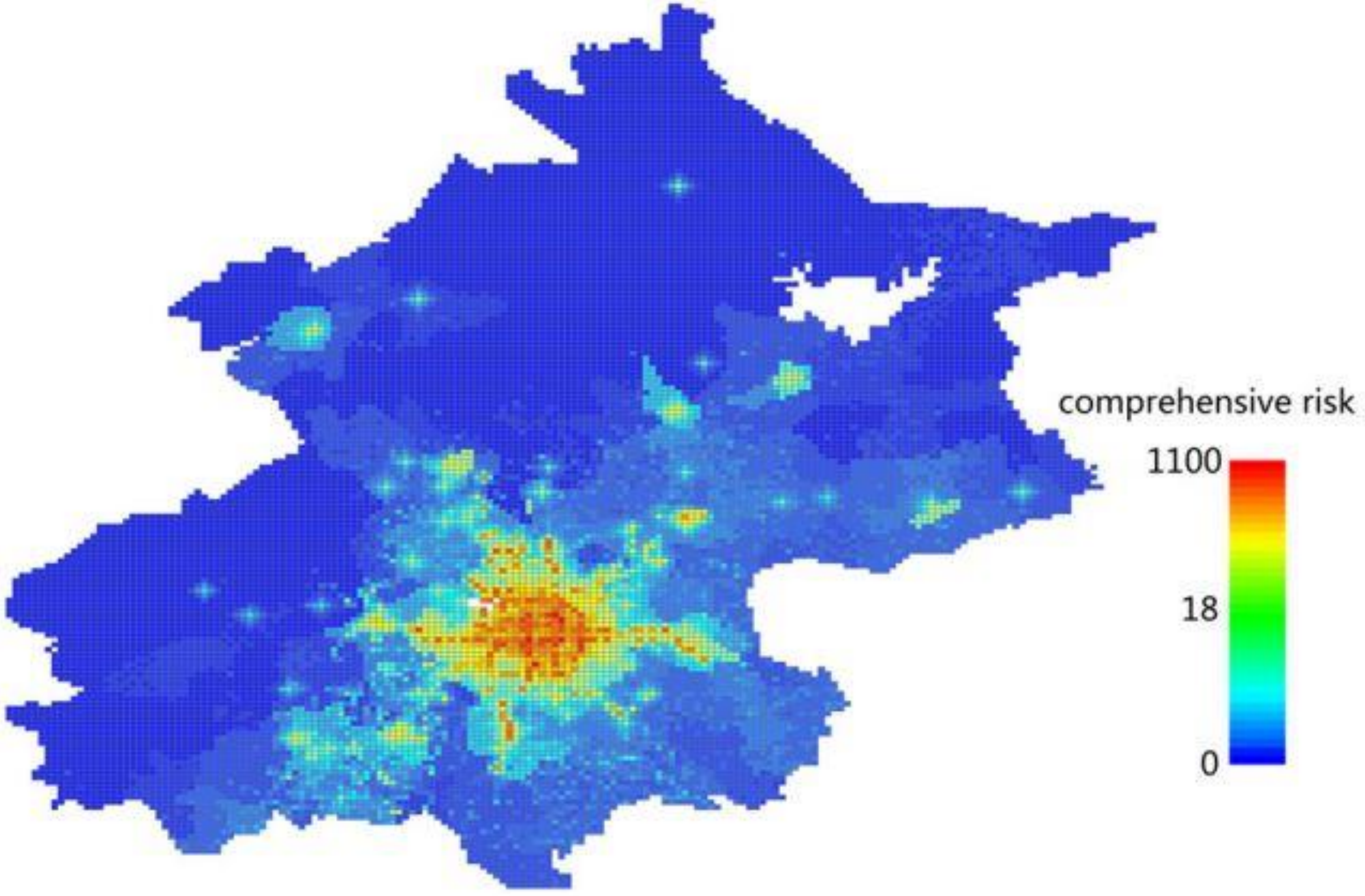
Environmental risk distribution map for temperature-humidity risk.

$$f(T) = 1.34775 + 0.13811\cos(0.1509T) + 0.29952\sin(0.1509T)$$

$$f(RH) = 1 = 0.005 \cdot RH$$

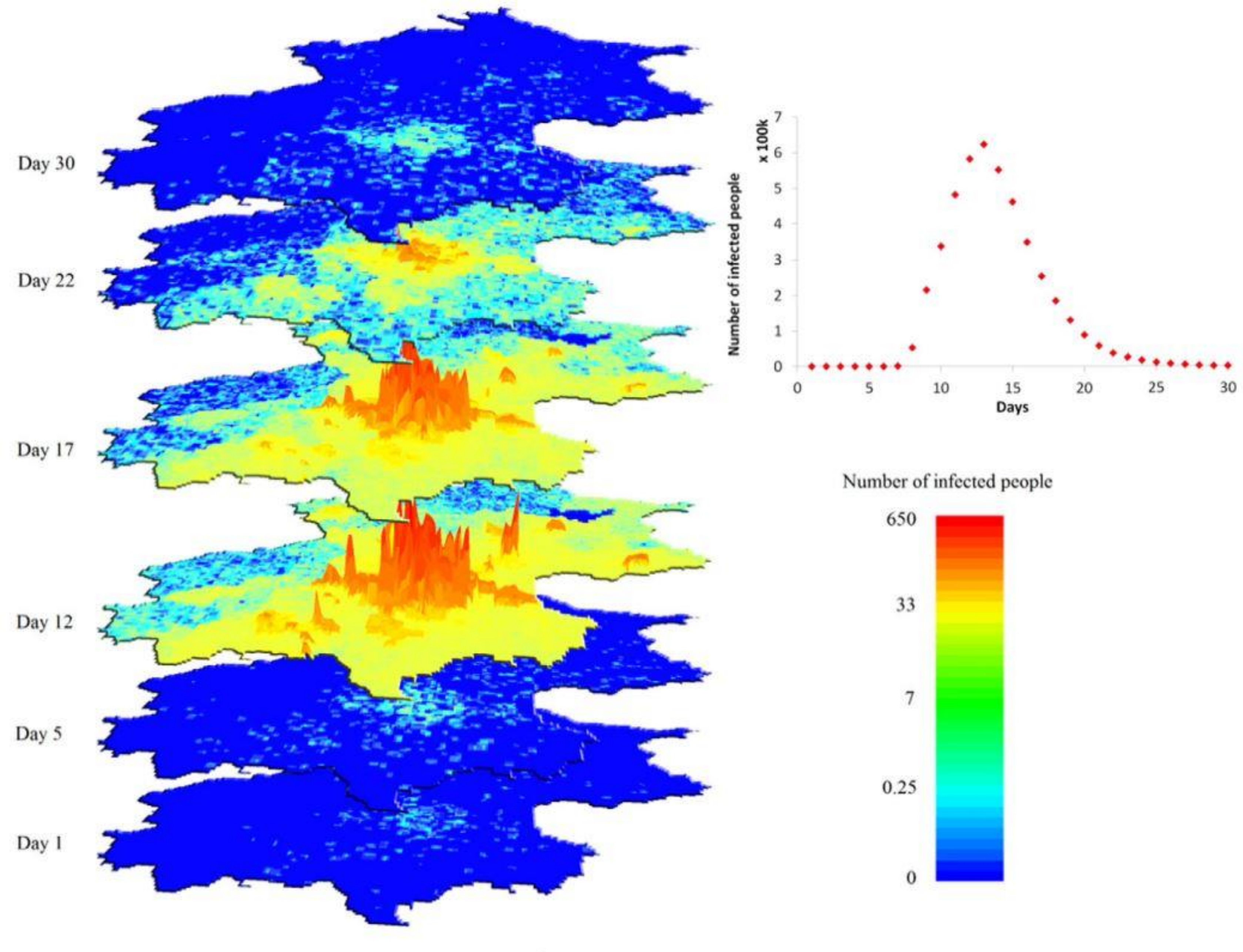
(Zhang, 2016)

Distribution of Comprehensive Risk



Comprehensive risk distribution for airborne infectious disease propagation.

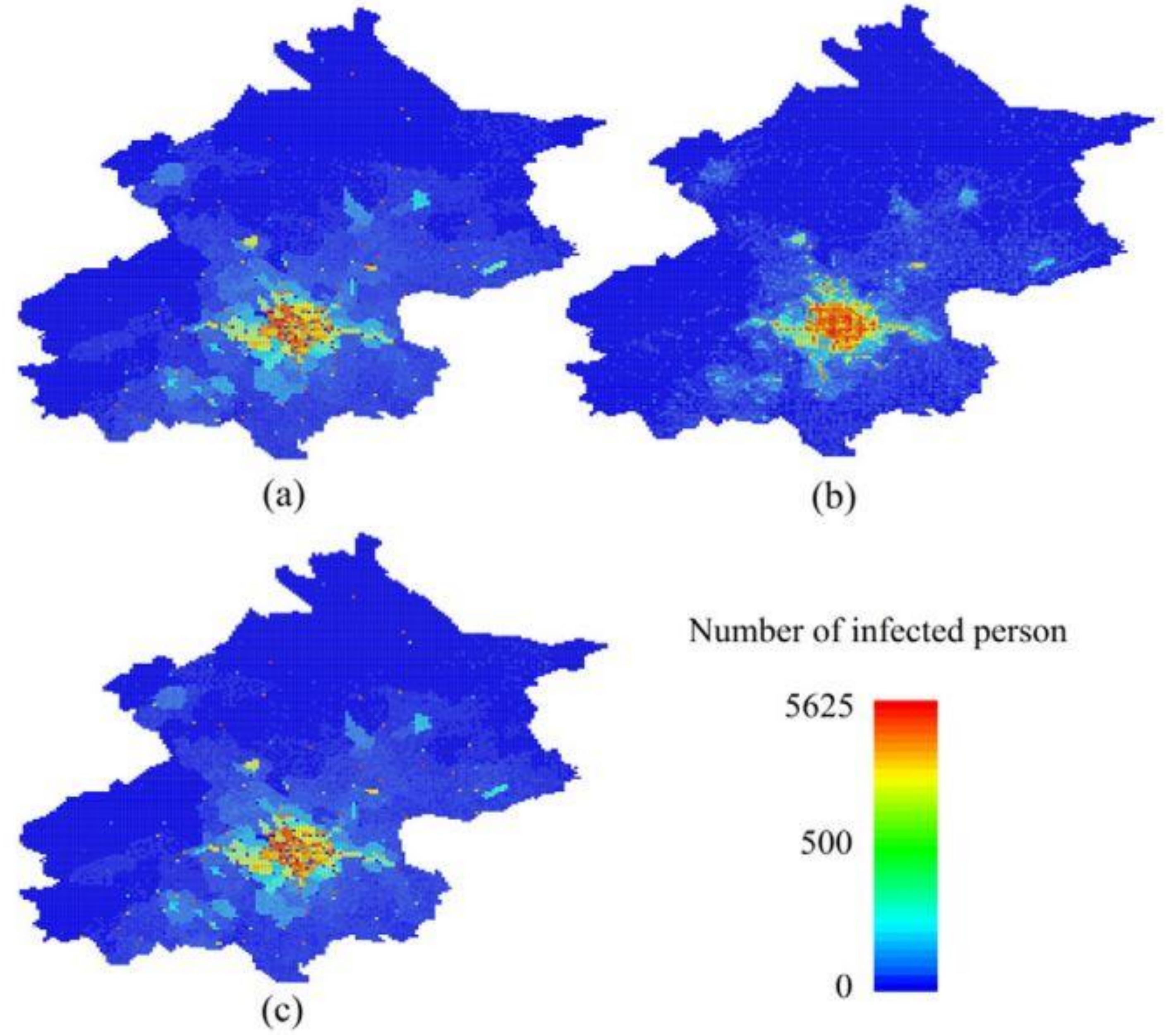
(Zhang, 2016)



Free infectious disease propagation in 30 days.

Distribution of Free Infectious Disease

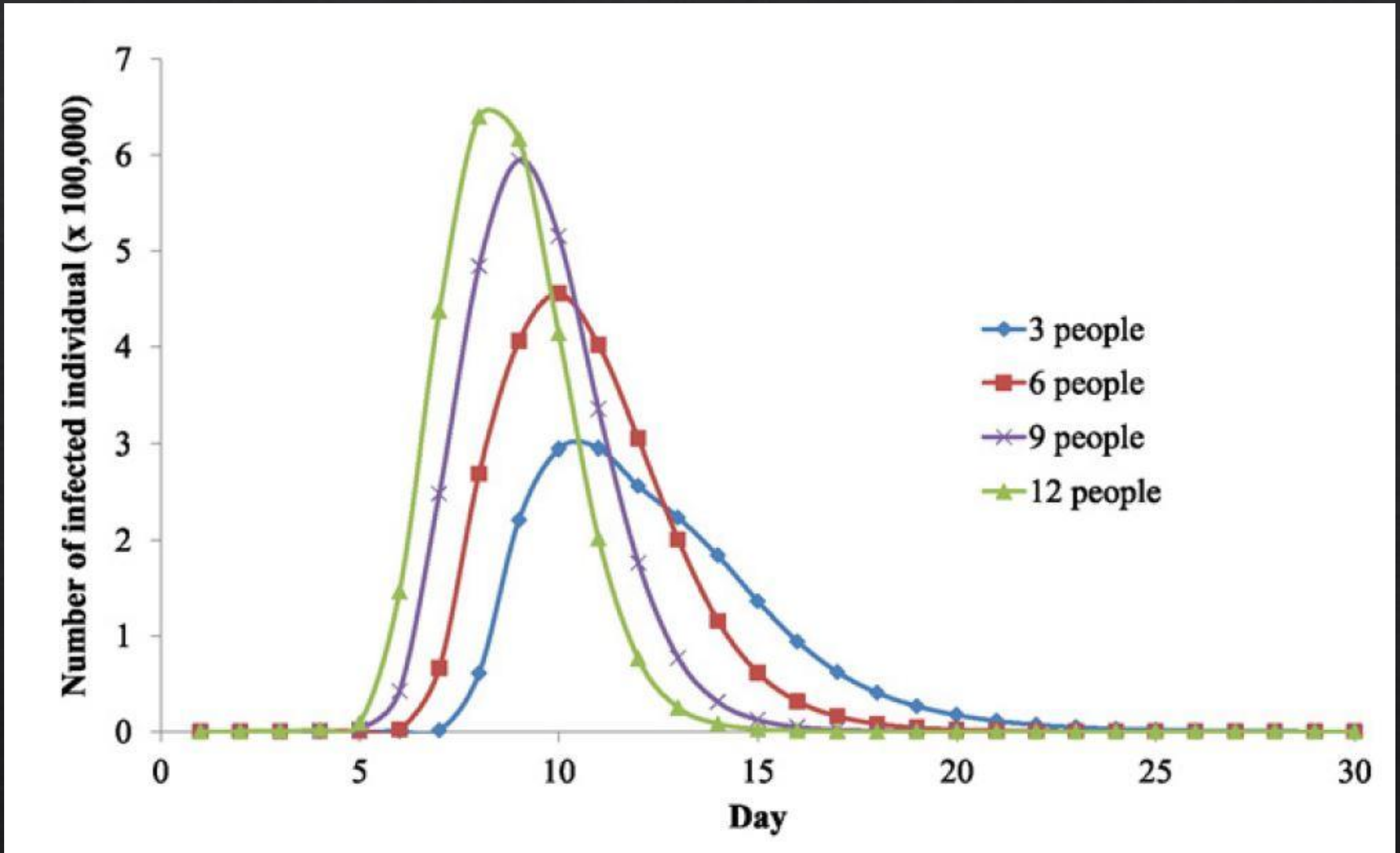
(Zhang, 2016)



Dynamic population distribution in one day (Day 13) at different time points: (a) 0:00; (b): 12:00; (c) 24:00.

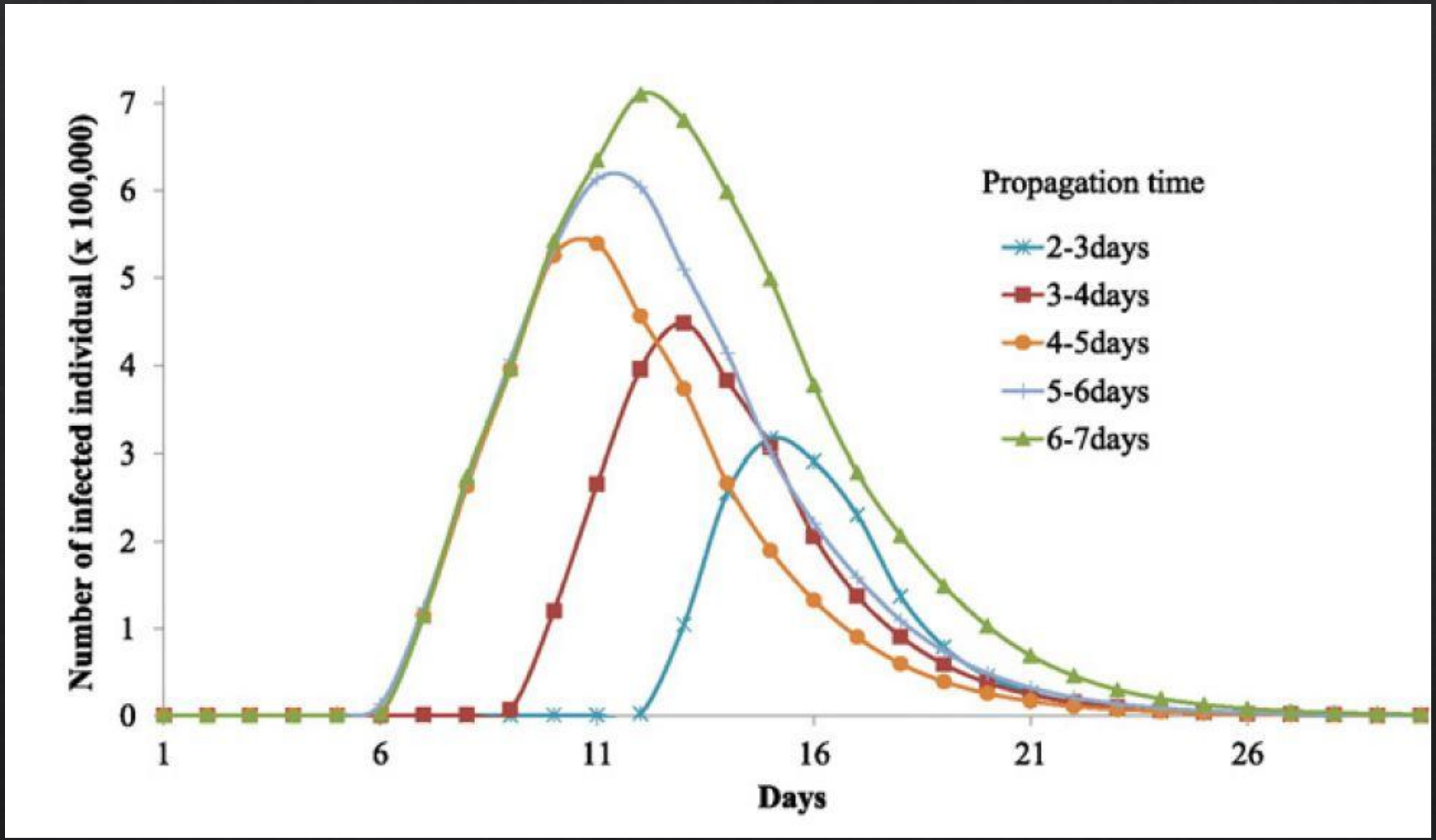
Distribution of Dynamic Population Influence

(Zhang, 2016)



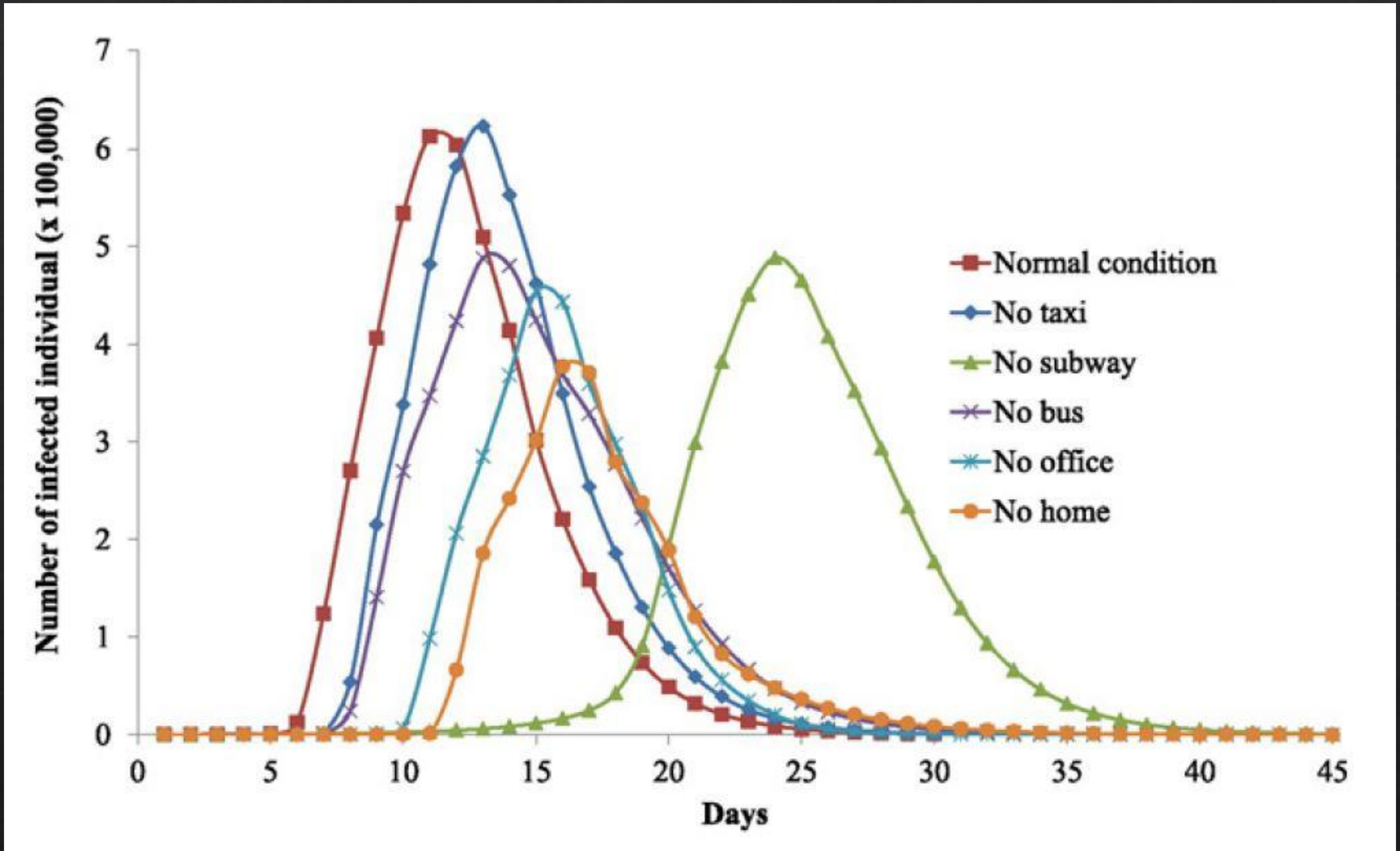
Sensitivity Analysis: Households

(Zhang, 2016)



Sensitivity Analysis: Government Response

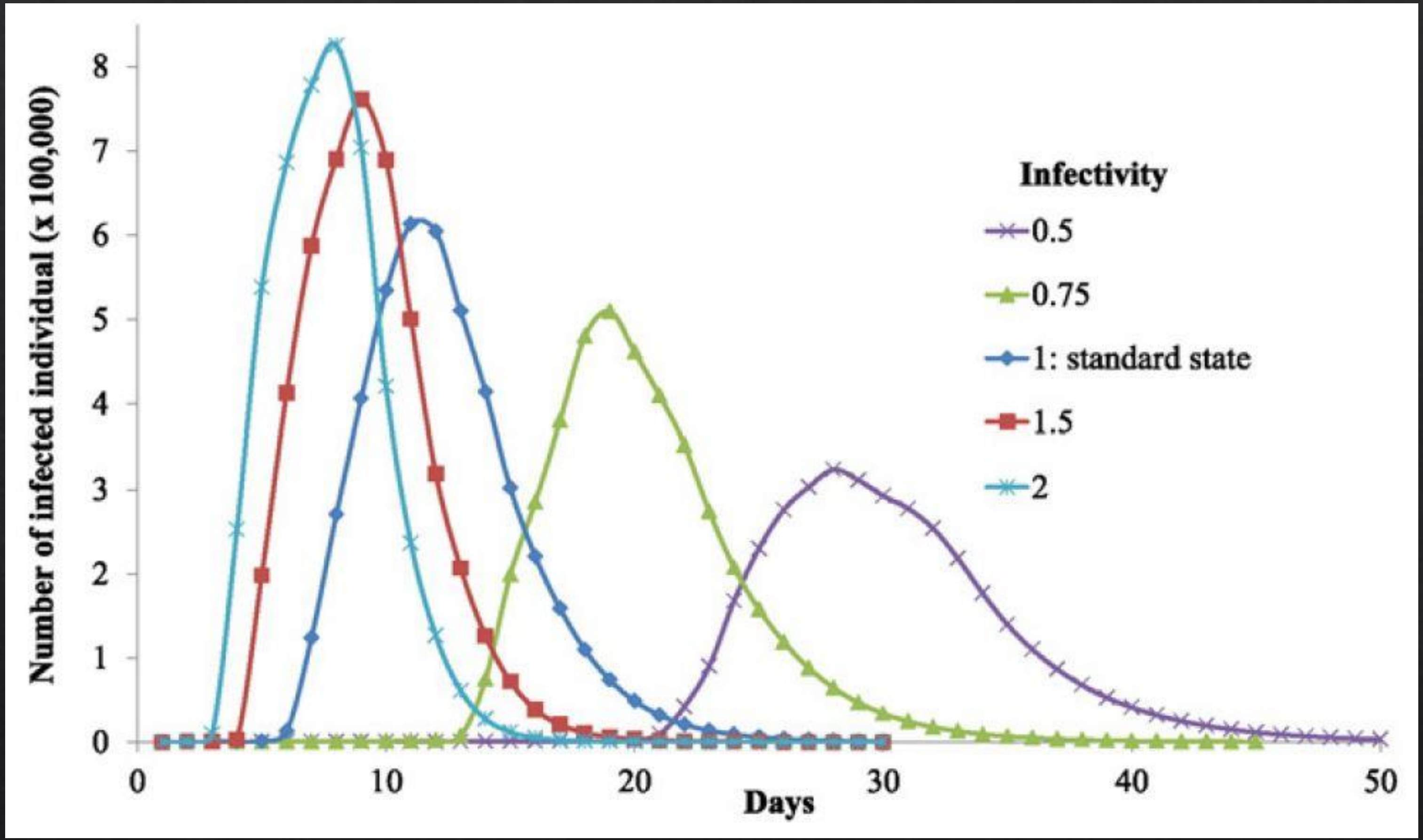
(Zhang, 2016)



Sensitivity Analysis:

Transportation & Workplace

(Zhang, 2016)



Sensitivity Analysis: Different Infectivity Values

(Zhang, 2016)

Summary

- Four Main factors analyzed:
  - Biological Risk
  - Dynamic Population Flow
  - Environmental Risk
  - Risk Source
- Urban Areas are the most at risk of an airborne infectious disease
  - Due to public transportation, close vicinity of individuals
- Mitigation Measures
  - Reduce personal contact
  - Quarantine the sick
  - Immediate intervention
  - Proper population management
  - Improving Air quality

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