Applications of space-based infectious disease detection models and enlightenment for COVID-19 control

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2. Space-based infectious disease detection models

3. Application on typical infections

4. Enlightenment

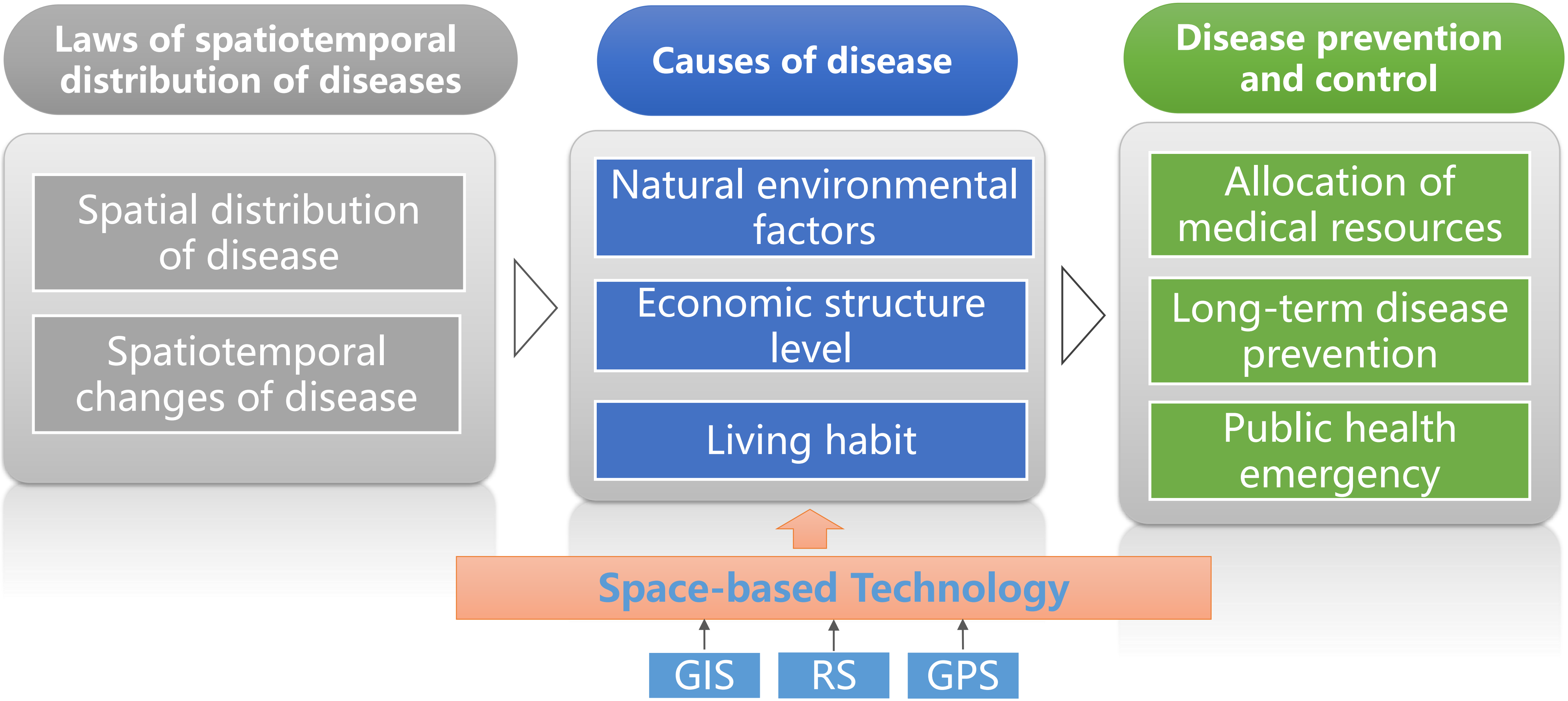
1. Background

1.1 The outbreak and prevalence of infectious diseases

- Great progress: prevention and control
- Severe situation:
  - ✓Old infectious diseases are still spreading
  - ✓New infectious diseases continue to emerge

1. Background

1.2 Application of Space-based Technology



Laws of spatiotemporal distribution of diseases

- Spatial distribution of disease
- Spatiotemporal changes of disease

Causes of disease

- Natural environmental factors
- Economic structure level
- Living habit

Disease prevention and control

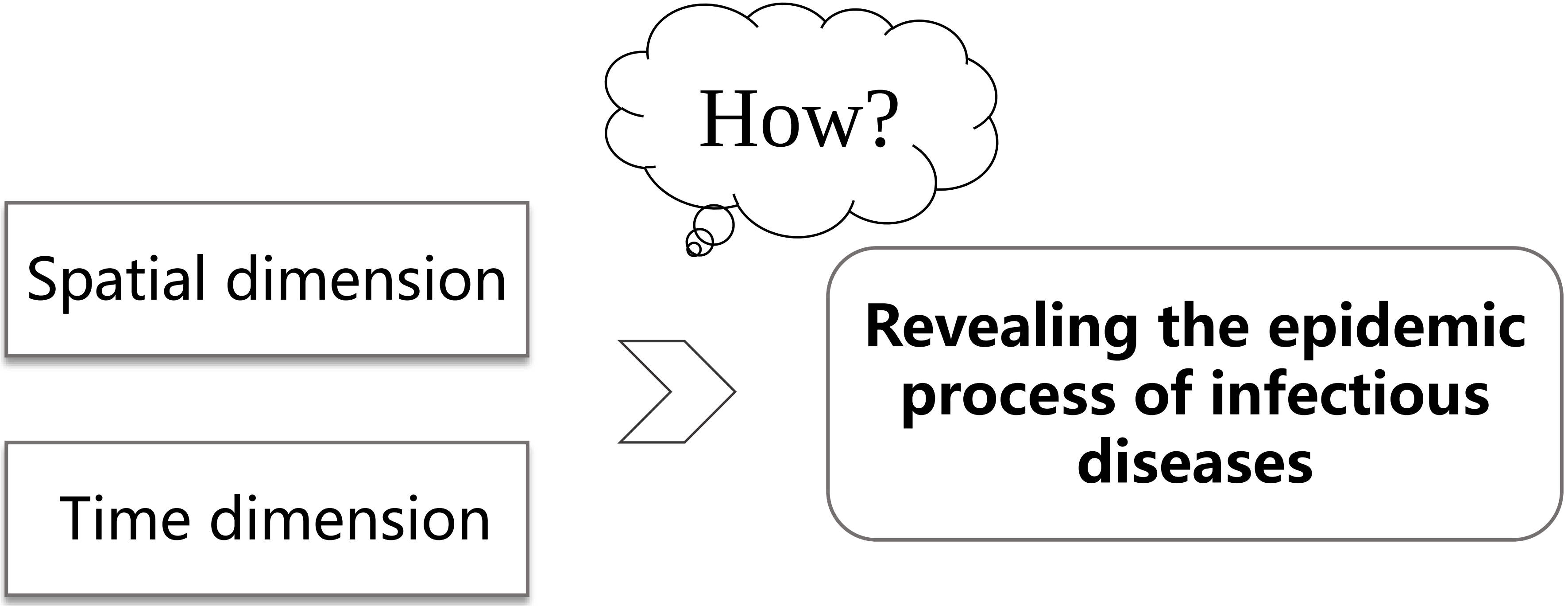
- Allocation of medical resources
- Long-term disease prevention
- Public health emergency

Space-based Technology

GIS RS GPS

2. Space-based infectious disease detection models

2.1 Characteristics of infectious disease data



How?

Spatial dimension

Time dimension

Revealing the epidemic process of infectious diseases

2. Space-based infectious disease detection models

2.2 Space-based detection models

Data → Modelling

y	x
y_1	x_1
y_2	x_2
⋮	⋮
y_n	x_n

$$y = f(x)$$

🟧 CLR	$y_i = a + bx_i + cx_iz_i$
🟧 SLR	$y_i = a + bx_i + W_1y_i + W_2u$
🟧 GWR	$y_i = a_i + b_ix_i$
🟧 MLM	$y_{ij} = a_j + b_jx_{ij}$
🟧 BHM	$y_i = f(x_i\|\theta),\ \theta \sim \mathrm{pdf}(\nu)$
🟦 GAM	$g(y_i) = a + f(x_i)$
🟦 DLNM	$g(y_i, t) = a + f(x_i,\ t\text{-}\tau)$
🟩 DL	⬛ $y_i = a + \Sigma_k f_k(w_kx_i)$
🟩 GP	⬛ $F = [\{+, -, *, /\}; \{x_i, y_i\}]$
🟩 ANOVA	$F(y\|x) = \mathrm{SSB}(y\|x)/\mathrm{SSW}(y)$
🟩 Geodetector q	$q(y\|x) = 1 - \mathrm{SSW}(y\|x)/\mathrm{SST}(y)$

- 🟧 Linear
- 🟦 Fix nonlinear
- 🟩 Any nonlinear
- No interact
- Fix interact
- Any interact

⬛ Black box ⬜ Interpretable

2. Space-based infectious disease detection models

2.2.1 Ordinary Least Squares Regression (OLS)

Suitable for all observation objects that do not change with geographic location

$$y = x\beta + \varepsilon$$

where

$$y = \left\{\begin{matrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{matrix}\right\}, x = \left\{\begin{matrix} 1x_{11} \cdots x_{1p} \\ 1x_{12} \cdots x_{2p} \\ \vdots\vdots \quad \vdots \\ 1x_{n1} \cdots x_{np} \end{matrix}\right\}, \beta = \left\{\begin{matrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_n \end{matrix}\right\}, \varepsilon = \left\{\begin{matrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{matrix}\right\}$$

Y : dependent variable

x : n*(p+1) -order regression matrix

β : parameter vector

ε : random error vector

2. Space-based infectious disease detection models

2.2.2 Geographically Weighted Regression Model (GWR)

- ✓ Spatial extension of the OLS model
- ✓ Changes with the geographic location of the regression parameters.

$$y_i = \beta_{i0}(u_i, v_i) + \sum_{k=1}^{p} \beta_{ik}(u_i, v_i) x_{ik} + \varepsilon_i$$

(u_i, v_i) : the spatial position of the i-th sample point

$\beta_{i0}(u_i, v_i)$: the constant estimated value

$\beta_{ik}(u_i, v_i)x_{ik}$: parameter estimated value of the i-th sample point

ε_i : the random error term of the i-th sample point

2. Space-based infectious disease detection models

2.2.2 Geographically Weighted Regression Model (GWR)

- ✓ The distance weighted OLS method to estimate the parameters

$$\widehat{\boldsymbol{\beta}}(u_i, v_i) = \left(\boldsymbol{X}^{\mathrm{T}} \boldsymbol{W}(u_i, v_i) X\right)^{-1} \boldsymbol{X}^{\mathrm{T}} \boldsymbol{W}(u_i, v_i) \boldsymbol{Y}$$

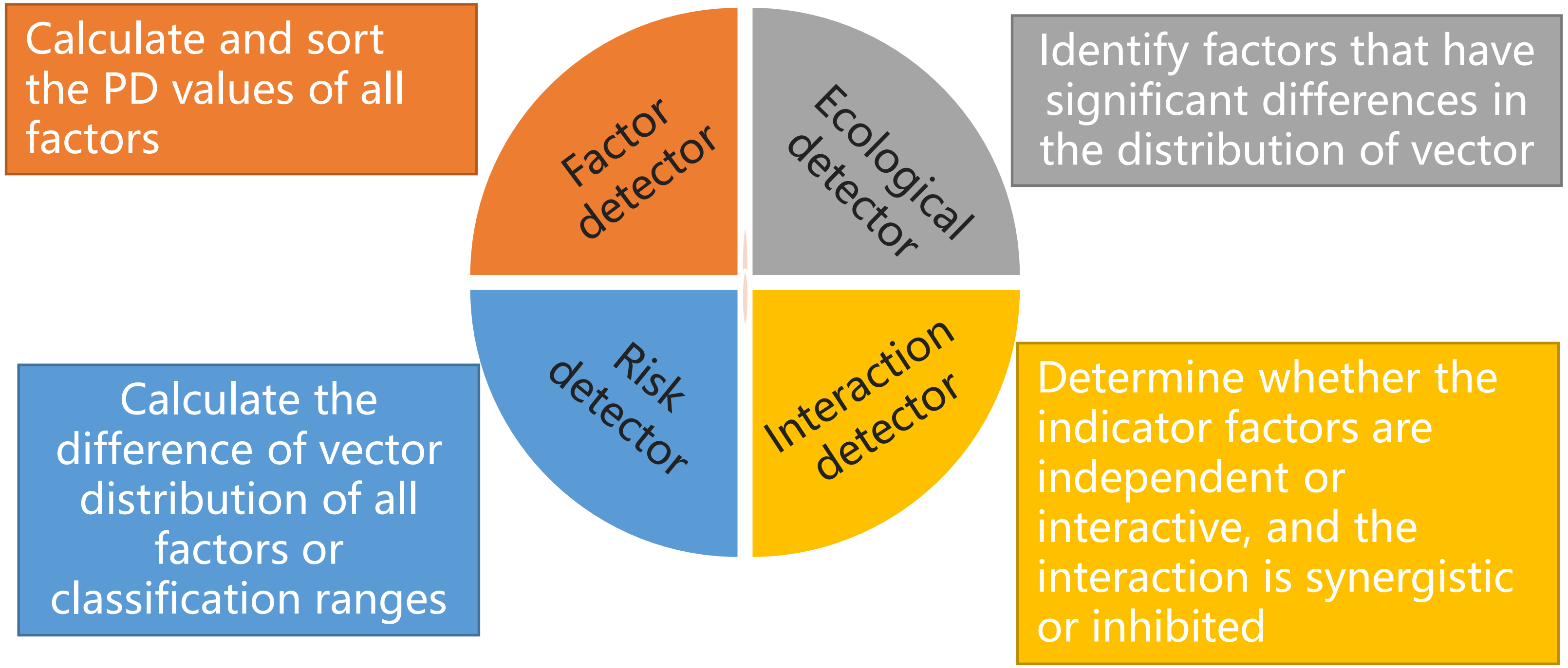
$\widehat{\boldsymbol{\beta}}$: the estimated value of parameter β

Y : a variable composed of observations of independent variables

W : a matrix of spatial weights, which guarantees each distance Observations with closer sample points have greater weight.

2. Space-based infectious disease detection models

2.2.3 Geodetector



Factor detector: Calculate and sort the PD values of all factors

Ecological detector: Identify factors that have significant differences in the distribution of vector

Risk detector: Calculate the difference of vector distribution of all factors or classification ranges

Interaction detector: Determine whether the indicator factors are independent or interactive, and the interaction is synergistic or inhibited

PD value: Measure the degree of impact of all factors on the occurrence of diseases, the range is [0,1], the larger the value, the greater the correlation between the two, and vice versa

3. Application on typical infections

Typical infections

Dengue Fever : Natural and social factors influencing the incidence of dengue

The spatial heterogeneity of dengue fever → The contribution of influencing factors → Advice on prevention and control

Schistosomiasis : Spatiotemporal distribution and risk assessment

Spatiotemporal distribution of snail density → Analysis of the leading factors → Rapid Monitoring and Evaluation

Plague： Spatiotemporal distribution characteristics

The nest flea indexes cluster \hotspot analysis → Influencing factors of nest indexes contribution → Advice on prevention and control

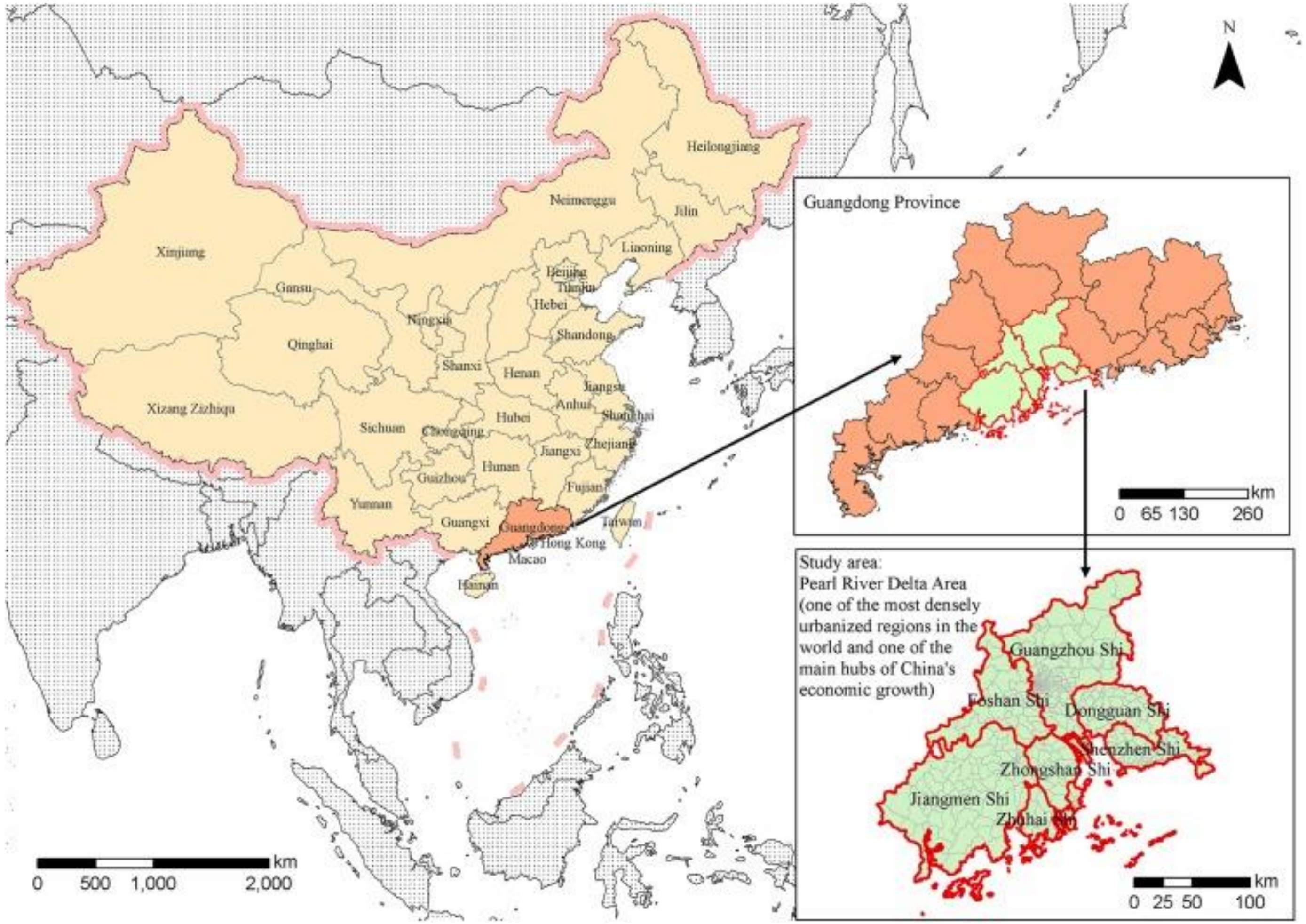
COVID-19 ： Epidemic situation、prevention and control measures

Meteorological factors ; Location; Atmospheric factors & Disease prevention and control

Law of diseased spatiotemporal distribution → Causes of disease → Disease prevention and control

3. Typical infections——Dengue Fever

3.1.1 The Effects of Socioeconomic and Environmental Factors on the Incidence of Dengue



Dengue fever is an acute infectious disease, which is mainly transmitted through the bites of Aedes albopictus and Aedes aegypti in China .

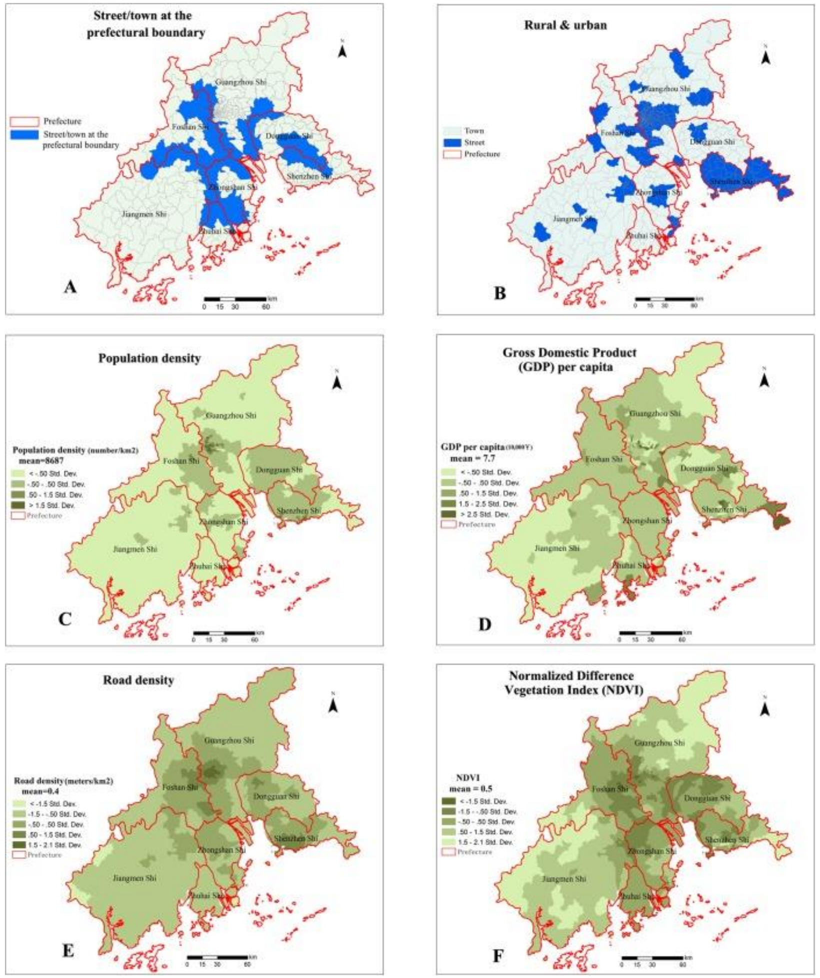
Study area：
Pearl River Delta

3. Typical infections——Dengue Fever

3.1.1 The Effects of Socioeconomic and Environmental Factors on the Incidence of Dengue

The accuracy of previous studies is not enough to accurately describe the influence law of specific features.

At the village level, the impact of natural factors and socio-economic factors on the incidence of dengue fever is analyzed.



Spatial distribution of socioeconomic and environmental data at the township level in the PRD, China

Qi X, Wang Y, Li Y, Meng Y, Chen Q, Ma J,et al. (2015) The Effects of Socioeconomic and Environmental Factors on the Incidence of Dengue Fever in the Pearl River Delta, China, 2013. PLoS Negl Trop Dis 9(10): e0004159. doi:10.1371/journal.pntd.0004159

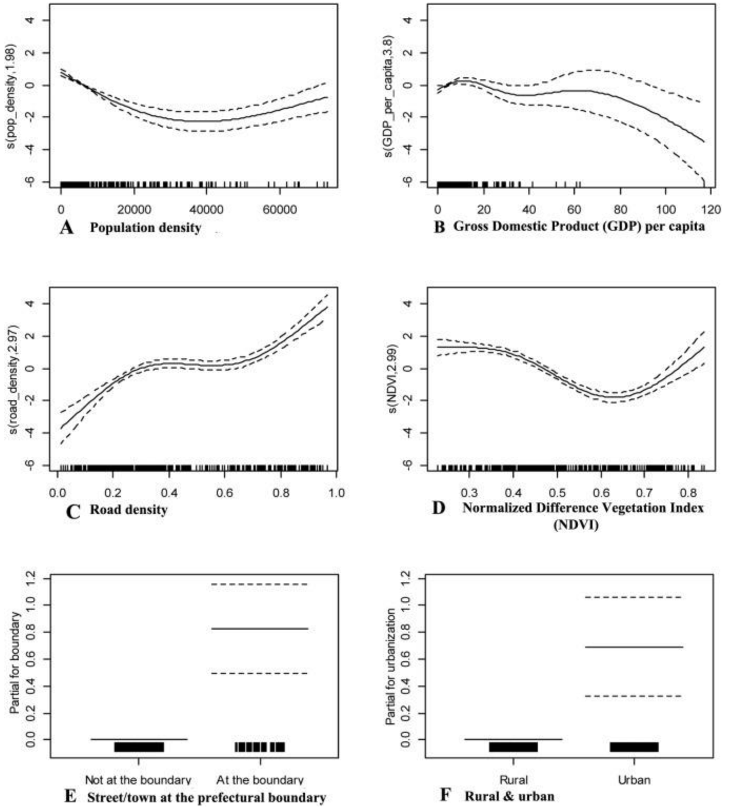
3. Typical infections——Dengue Fever

3.1.1 The Effects of Socioeconomic and Environmental Factors on the Incidence of Dengue

- ✓ **Generalized Additive Models (GAM)**

$$\begin{aligned}&\log(\text{case})\\&= \beta_0 + \beta_1(\text{boundary}) + \beta_2(\text{urban \& rural})\\&+ s(\text{ pop\_density }) + s(\text{ GDP\_per\_capita })\\&+ s(\text{ road\_density }) + s(\text{ NDVI })\end{aligned}$$

s() is the spline smooth, non-parametric function

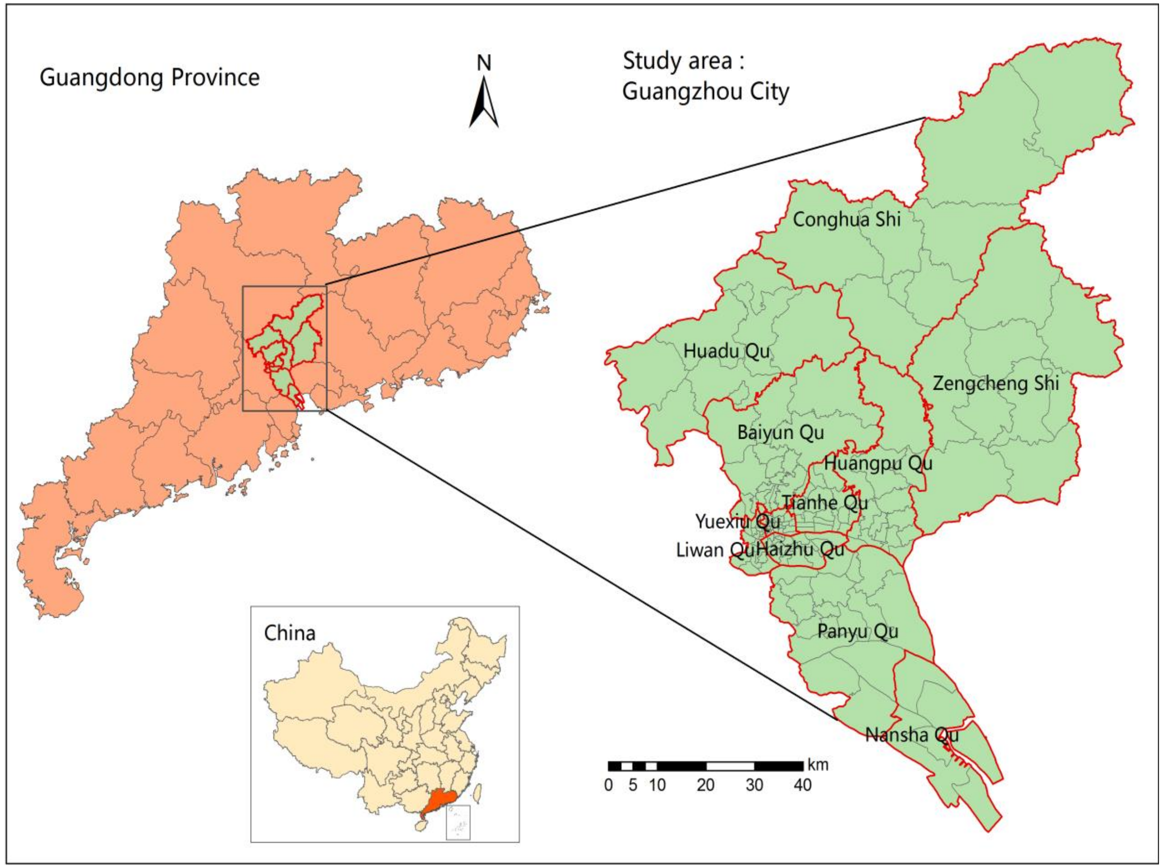


Partial contributions of six exploratory variables with confidence bands

Qi X, Wang Y, Li Y, Meng Y, Chen Q, Ma J,et al. (2015) The Effects of Socioeconomic and Environmental Factors on the Incidence of Dengue Fever in the Pearl River Delta, China, 2013. PLoS Negl Trop Dis 9(10): e0004159. doi:10.1371/journal.pntd.0004159

3. Typical infections——Dengue Fever

3.1.2 Effects of socio-economic and environmental factors on the spatial heterogeneity of dengue fever



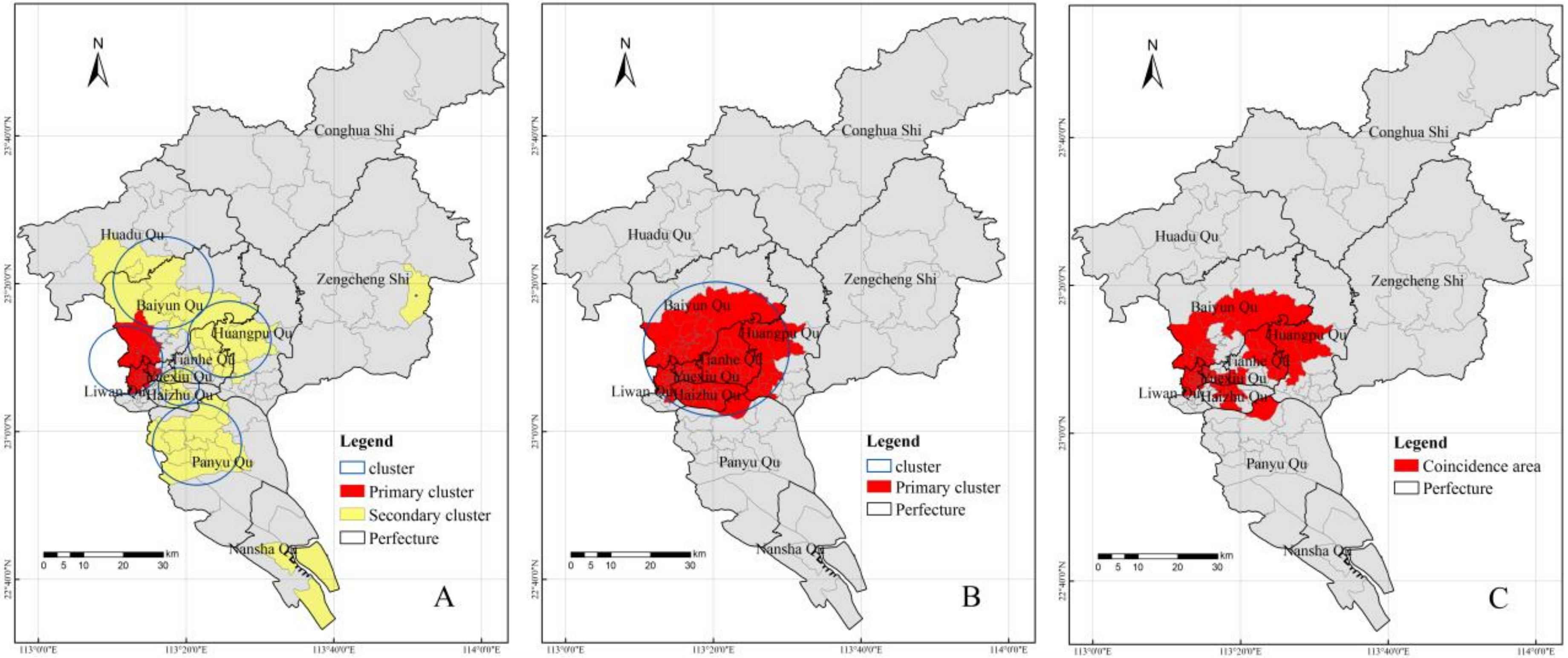
Study area:
Guangzhou city

Qu Y, Shi X, Wang Y, et al. Effects of socio-economic and environmental factors on the spatial heterogeneity of dengue fever investigated at a fine scale[J]. Geospatial health, 2018, 13(2).

3. Typical infections——Dengue Fever

3.1.2 Effects of socio-economic and environmental factors on the spatial heterogeneity of dengue fever

- ✓ **Spatiotemporal scanning statistics**



(A) 14 days and 10% risk population
(B) 14 days and 40% risk population
(C) The area of agreement in analysis results.

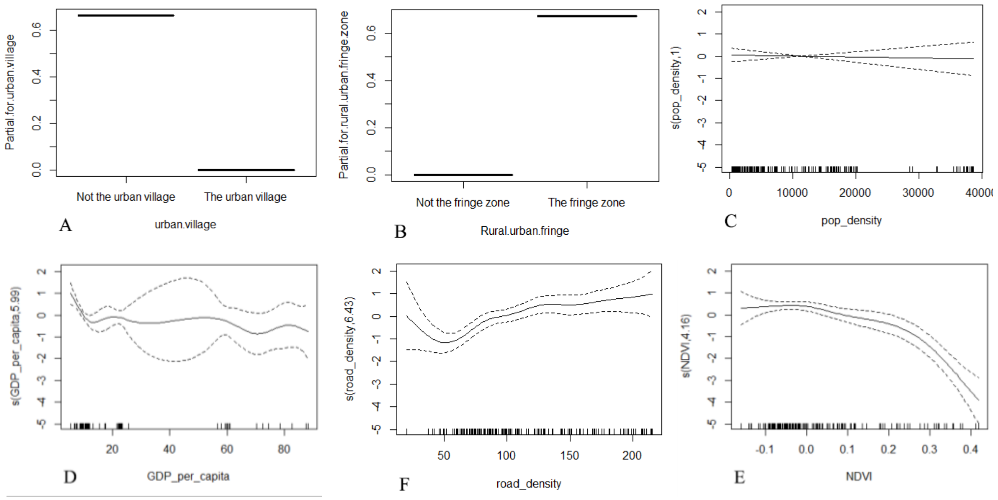
Qu Y, Shi X, Wang Y, et al. Effects of socio-economic and environmental factors on the spatial heterogeneity of dengue fever investigated at a fine scale[J]. Geospatial health, 2018, 13(2).

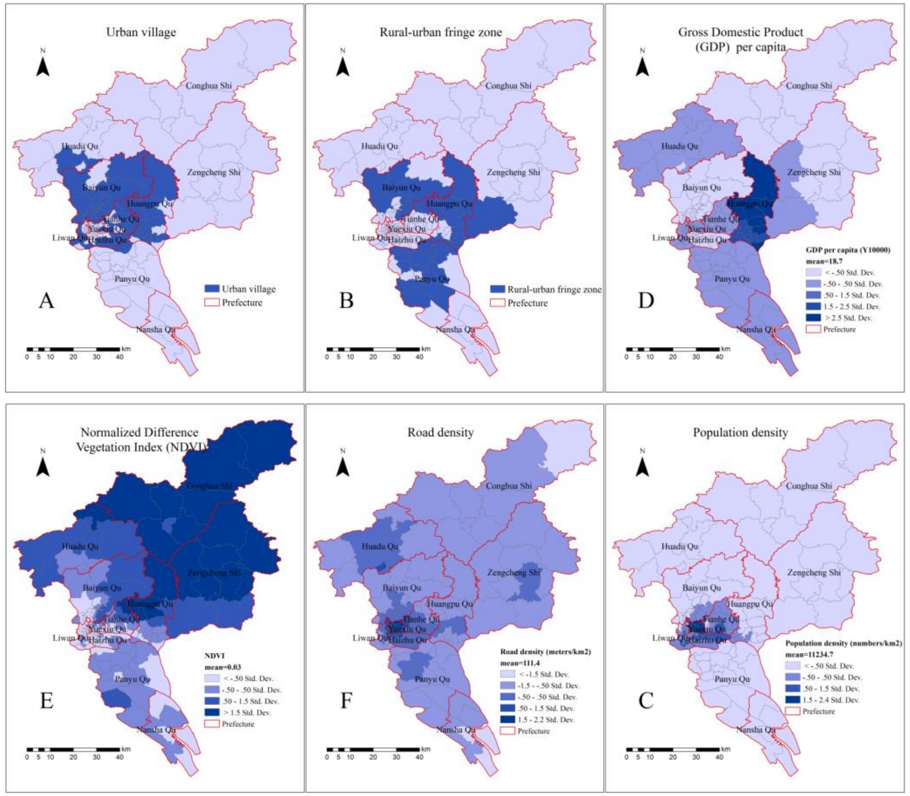
3. Typical infections——Dengue Fever

3.1.2 Effects of socio-economic and environmental factors on the spatial heterogeneity of dengue fever

- ✓ **Generalized Additive Models (GAM)**

$$\log(\text{case}) = \beta_0 + \beta_1\left(urban_{village}\right) + \beta_2\left(urban_{village_{fringe_{zone}}}\right)$$
$$+ s(pop\_density) + s(GDP\_per\_capita) + s(NDVI)$$
$$+ s(road\_density).$$





Qu Y, Shi X, Wang Y, et al. Effects of socio-economic and environmental factors on the spatial heterogeneity of dengue fever investigated at a fine scale[J]. Geospatial health, 2018, 13(2).

3. Typical infections——Dengue Fever

Summary

Theme	**The relationship between natural and socio-economic factors and the incidence of dengue fever**	
Study Area	Pearl River Delta	Guangzhou City
Scale	Township/street	Township/street
Time	2013	2014
Model	GAM	Space-time scan statistics; GAM
Independent variable	DF incidence in PRD,2013	DF incidence in Guangzhou,2014
Exploratory variable	Street/town at the prefectural boundary; Rural and urban; Population density; GDP per capita; Road density; NDVI.	Urban villages; Urban-rural fringes zones; Population density; GDP per capita; NDVI; Road density.
Conclusion	The relative risk of living at the **prefectural boundary** was higher than that of living in the urban areas. **Higher “road density” or lower “GDP per capita”** were considered to be consistent risk factors. Moreover**, higher or lower values of “population density” and “NDVI”** could result in an increase in DF cases.	The junction of the central districts of Guangzhou is a high-risk area with the urban village and urban-rural fringe zone formed by urbanization as important regional factors. The **low GDP per capita, the high population density, the low NDVI and the high road density** were perceived as risk factors.

3. Typical infections——Dengue Fever

Enligtenment

- ✓ Space-based research results are helpful for the prevention and control of dengue fever.
- ✓ Other countries can learn from China‘s experience.

3. Typical infections——COVID-19

3.2 China's response to COVID-19

In China, space-based technology is used to provide important scientific and technical support to allow the government to judge the epidemic situation and formulate prevention and control measures.

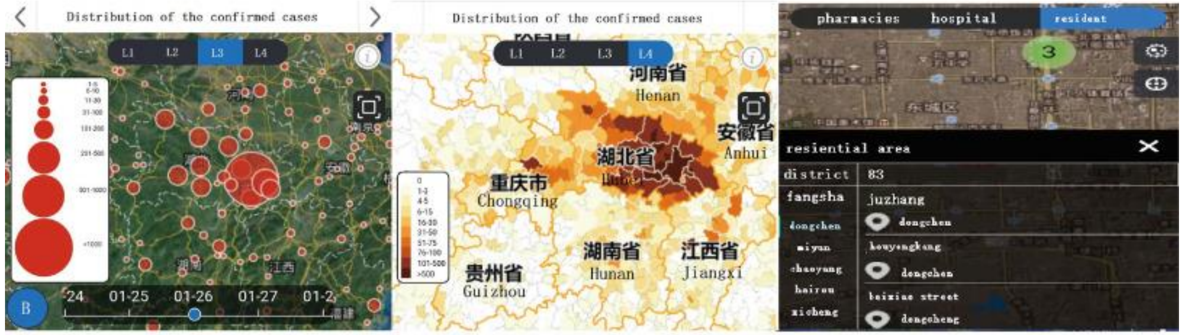
Space-based Technology

- Information system
- Information Display
- Multisource data
- Spatial tracking
- Epidemic transmission
- Risk segmentation
- Medical balancing
- Material supply
- Population flow
- Social sentiment

Zhou C, Su F, Pei T, et al. COVID-19: Challenges to GIS with big data[J]. Geography and Sustainability, 2020.

3. Typical infections——COVID-19

- Rapid construction of a big data information system for epidemics



(a) (b) (c)

Dynamic information query system for different scales:
(a)City level; (b) County level; (c) Community level

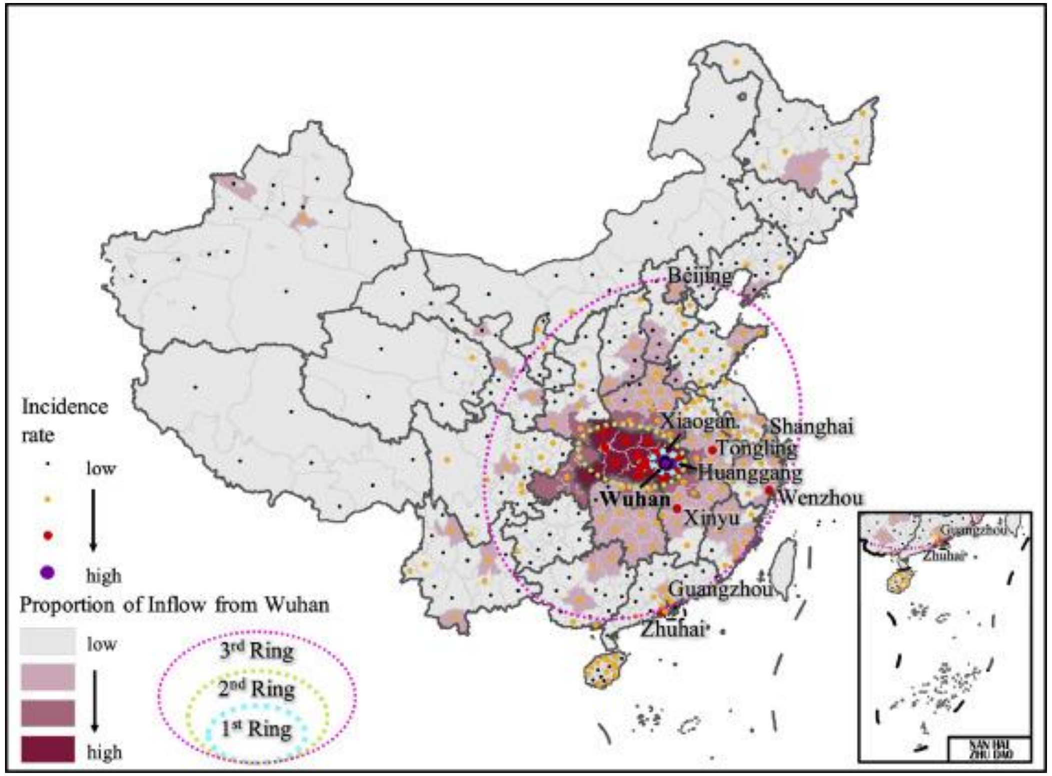
- Spatial tracking and spatiotemporal trajectory

Exposure analysis of a patient's spatial trajectory

Zhou C, Su F, Pei T, et al. COVID-19: Challenges to GIS with big data[J]. Geography and Sustainability, 2020.

3. Typical infections——COVID-19

- Spatial segmentation of the epidemic risk and prevention level



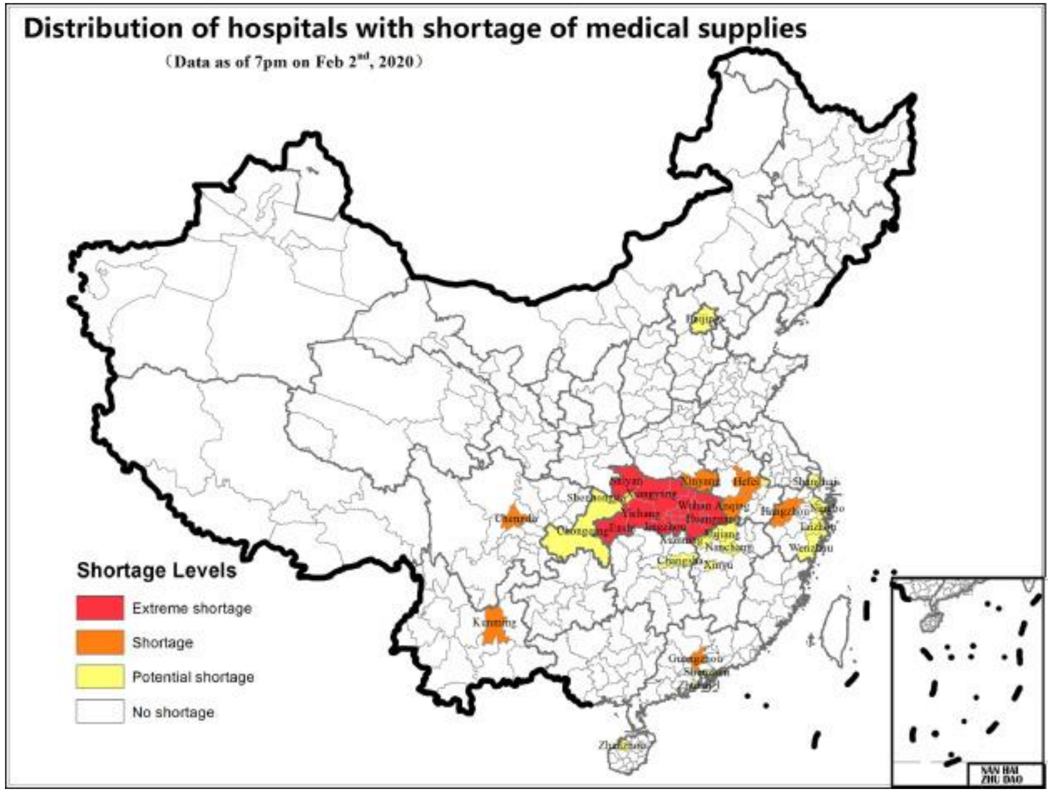
National spatial segmentation of the COVID-19 epidemic risk

A risk assessment model was constructed with the spatial distribution of the number of confirmed cases and the population migration, and three risk level areas were outlined on the regional scale and on the urban scale for the cities with high risks of epidemics.

Zhou C, Su F, Pei T, et al. COVID-19: Challenges to GIS with big data[J]. Geography and Sustainability, 2020.

3. Typical infections——COVID-19

- Spatial dynamic balancing of supply and demand for medical resources



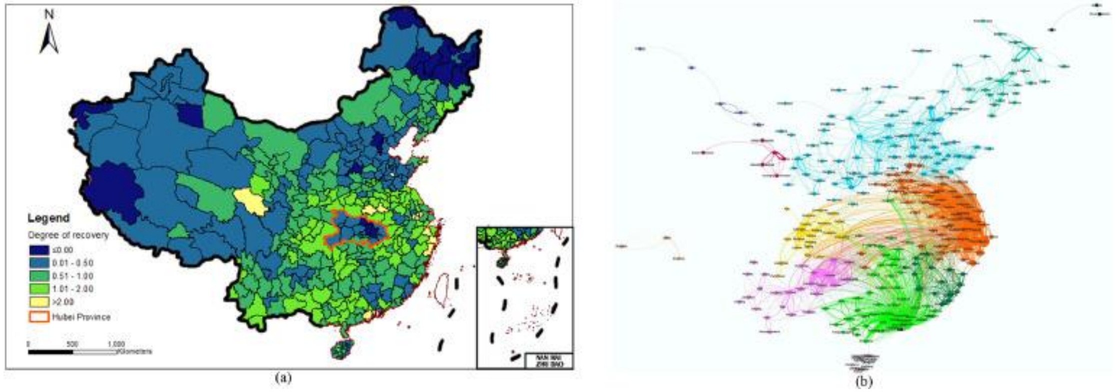
Based on the factors of online hospital help information, local cases and forecasts, and existing resource data, the current dynamic situation of medical protective equipment across the country were analyzed.

National distribution of hospitals in shortage of medical protective materials

Zhou C, Su F, Pei T, et al. COVID-19: Challenges to GIS with big data[J]. Geography and Sustainability, 2020.

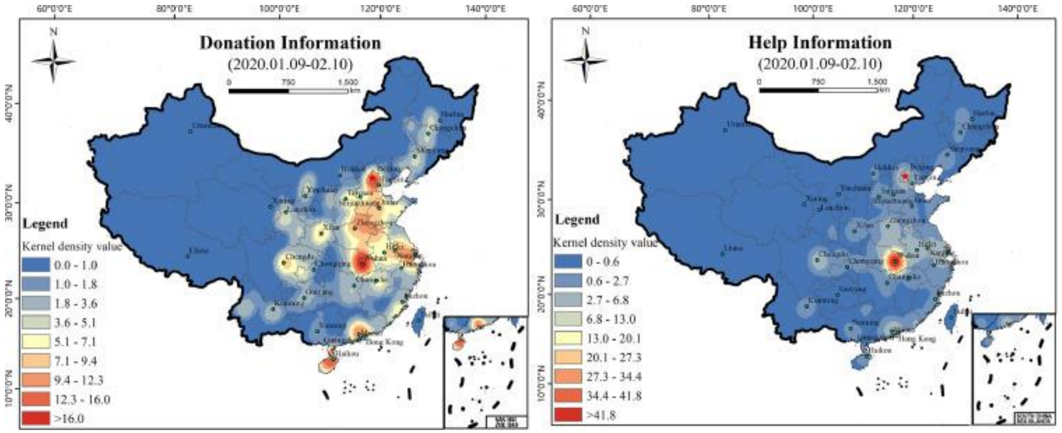
3. Typical infections——COVID-19

- Estimation of population flow and distribution



(a) Recovery of urban population flow;
(b) Rework population flow network and community Division.

- Spatial spread and detection of social sentiment



Spatial distribution of help and donation information of COVID-19 during the epidemic period (2020/01/09 - 2020/02/10)

Zhou C, Su F, Pei T, et al. COVID-19: Challenges to GIS with big data[J]. Geography and Sustainability, 2020.

4. Enlightenment

Laws of spatiotemporal distribution of diseases

- ✓ Sufficient data support: natural environment data、socio-economic data、demographic data with multiple types and multiple years
- ✓ Spatial feature extraction: extract natural and social factors closely related to infectious diseases and construct spatiotemporal data sets of related indicators

4. Enlightenment

Causes of disease

- ✓ Impact factor exploration： select impact factors and build appropriate models
- ✓ Disease transmission mechanism: establish the relationship between various natural and social indicators and the epidemic, analyze the distribution and spread of the dangerous environmental factors of the disease

4. Enlightenment

Disease prevention and control

- ✓ Risk prediction: according to the space-based detection model, reveal disease distribution and transmission risk indicators, and evaluate the risk of disease distribution in time and space
- ✓ Precise prevention and control: based on the comprehensive risk value and the similarity and difference of the spatial distribution of the scores of each risk factor, a zoning plan for comprehensive prevention and control measures focusing on controlling the source of infection and cutting off the transmission route

4. Enlightenment

China’ s Experience

- ✓ Large-scale testing：making nucleic acid testing compulsory among all key groups
- ✓ Traceability：locating patients and contacts
- ✓ Isolate the diagnosed： people's cooperation

Thanks！

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