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

Wang Yong

State key laboratory of resource and environmental information systems (LREIS), Institute of Geographic Sciences and Natural Resources Research (IGSNRR), Chinese Academy of Sciences (CAS)

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1. Background
2. Space-based infectious disease detection models
3. Application on typical infections
4. Enlightenment
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

- Spatial dimension
- Time dimension

How?

Revealing the epidemic process of infectious diseases
2. Space-based infectious disease detection models

2.2 Space-based detection models

Data → Modelling

<table>
<thead>
<tr>
<th>Model</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLR</td>
<td>$y_i = a + bx_i + cx_i$</td>
</tr>
<tr>
<td>SLR</td>
<td>$y_i = a + bx_i + W_1 y_i + W_2 u$</td>
</tr>
<tr>
<td>GWR</td>
<td>$y_i = a_i + b_i x_i$</td>
</tr>
<tr>
<td>MLM</td>
<td>$y_{ij} = a_i + b_j x_{ij}$</td>
</tr>
<tr>
<td>BHM</td>
<td>$y_i = f(x_i</td>
</tr>
<tr>
<td>GAM</td>
<td>$g(y_i) = a + f(x_i)$</td>
</tr>
<tr>
<td>DLNM</td>
<td>$g(y_{ip}, t) = a + f(x_{ip}, t-\tau)$</td>
</tr>
<tr>
<td>DL</td>
<td>$y_i = a + \sum_k w_k x_i$</td>
</tr>
<tr>
<td>GP</td>
<td>$F = {{+, -, \times, \div}; {x_i, y_i}}$</td>
</tr>
<tr>
<td>ANOVA</td>
<td>$F(y</td>
</tr>
<tr>
<td>Geodetector $q$</td>
<td>$q(y</td>
</tr>
</tbody>
</table>

- **Black box**
- **Interpretable**

- Linear
- Fix nonlinear
- Any nonlinear
- No interact
- Fix interact
- Any interact
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

\[ y = x\beta + \epsilon \]

where

\[ y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}, \quad x = \begin{bmatrix} 1x_{11} \cdots x_{1p} \\ 1x_{12} \cdots x_{2p} \\ \vdots \\ 1x_{n1} \cdots x_{np} \end{bmatrix}, \quad \beta = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_n \end{bmatrix}, \quad \epsilon = \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ \epsilon_n \end{bmatrix} \]

Y: dependent variable
x: n*(p+1)-order regression matrix
\( \beta \): parameter vector
\( \epsilon \): 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
- \(\varepsilon_i\) : 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

\[
\hat{\beta}(u_i, v_i) = \left( X^T W(u_i, v_i) X \right)^{-1} X^T W(u_i, v_i) Y
\]

\( \hat{\beta} \): the estimated value of parameter \( \beta \)

\( Y \): 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

**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

<table>
<thead>
<tr>
<th>Typical Infections</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td><strong>Dengue Fever</strong></td>
<td>Natural and social factors influencing the incidence of dengue</td>
</tr>
<tr>
<td>The spatial heterogeneity of dengue fever</td>
<td>The contribution of influencing factors</td>
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<tr>
<th><strong>Schistosomiasis</strong></th>
<th>Spatiotemporal distribution and risk assessment</th>
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<tr>
<td>Spatiotemporal distribution of snail density</td>
<td>Analysis of the leading factors</td>
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<tr>
<th><strong>Plague</strong></th>
<th>Spatiotemporal distribution characteristics</th>
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<tr>
<td>The nest flea indexes cluster \ hotspot analysis</td>
<td>Influencing factors of nest indexes contribution</td>
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<tr>
<th><strong>COVID-19</strong></th>
<th>Epidemic situation, prevention and control measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meteorological factors; Location; Atmospheric factors</td>
<td></td>
</tr>
</tbody>
</table>

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

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

Spatial distribution of socioeconomic and environmental data at the township level in the PRD, China
3. Typical infections——Dengue Fever

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

✓ Generalized Additive Models (GAM)

\[
\log(\text{case}) = \beta_0 + \beta_1(\text{boundary}) + \beta_2(\text{urban & rural}) + s(\text{pop_density}) + s(\text{GDP_per_capita}) + s(\text{road_density}) + s(\text{NDVI})
\]

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

3. Typical infections——Dengue Fever

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

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.
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)

$$\log(\text{case}) = \beta_0 + \beta_1(urban_{village}) + \beta_2(urban_{village\_ring\_zone}) + s(\text{pop\_density}) + s(\text{GDP\_per\_capita}) + s(\text{NDVI}) + s(\text{road\_density})$$
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

- 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.

3. Typical infections——COVID-19

- Rapid construction of a big data information system for epidemics

  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

3. Typical infections——COVID-19

- Spatial segmentation of the epidemic risk and prevention level

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.

National spatial segmentation of the COVID-19 epidemic risk

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

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)

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!

Wang Yong, +86 -13811975689

wangy@igsnrr.ac.cn