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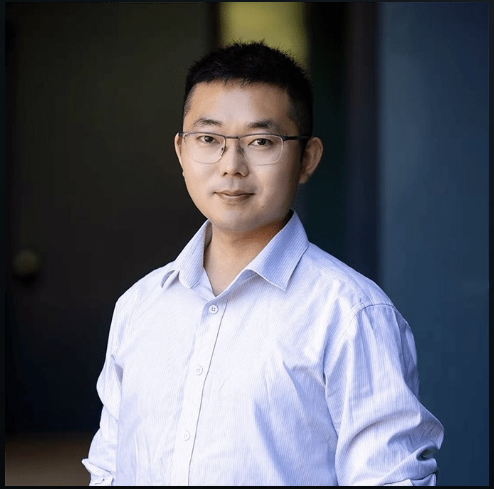
Geospatial Data Analysis, Prediction, and GeoAI: New Theories, Methods, and Software

Topic 1. Introduction to spatial modelling and prediction

Lecture website: https://yongzesong.com/lecture-20260104



Yongze Song, Associate Professor

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RGS Fellow (UK), DAAD AInet Fellow (Germany), SDL Fellow (Harvard University, US)

Email: Yongze.song@curtin.edu.au

Associate Editor: *International Journal of Earth Observation and Geoinformation* (IF 8.6, Q1)

Associate Editor: *GIScience & Remote Sensing* (IF 6.9, Q1)

Topic Editor: *Geoscientific Model Development* (IF 4.9, Q1)

Lecture outline

Lecture website: https://yongzesong.com/lecture-20260104
Password: 20260104

Tips:

1. Working in a group of 3 or 4
2. Collecting feedback at each day
3. Individual assignments and working in a group
4. Assignment feedback sections after day 2
5. Install R and Rstudio
6. Sign Up for Google Earth Engine

Install software (5 min)

Please ensure that RStudio is installed on your computer and that you have signed up for a Google Earth Engine account. Below are the instructions for installing R and RStudio, as well as signing up for Google Earth Engine. Kindly follow the steps provided in the links:

- Guide for Installing R and RStudio: https://rstudio-education.github.io/hopr/starting.html
- Guide for Signing Up for Google Earth Engine: https://courses.spatialthoughts.com/gee-sign-up.html

Why do we need spatial methods for prediction?

- Spatial prediction estimates unknown values at unsampled locations using spatial relationships.
- Spatial prediction provides evidence for decision-making across geographic space where data collection is limited or expensive.

Motivation

1) Incomplete observations
    - Ground-based observations are sparse, expensive, or infeasible (e.g., air pollution, soil nutrients).
2) Decision support
    - Required for environmental planning, infrastructure development, disaster management, etc.
3) Cost-effectiveness
    - Reduces the need for exhaustive data collection.
4) Risk assessment
    - Enables early warning systems for floods, wildfires, disease outbreaks.
5) Real-time and scalable estimation
    - Supports real-time monitoring and prediction using remote sensing and AI.

Example cases

- **Agriculture**: Predict crop yield or soil moisture at regional scale
- **Climate**: Downscale global climate models for local impact assessment
- **Urban planning**: Forecast population density or infrastructure needs
- **Public health**: Map disease hotspots
- **Disaster management**: Predict flood-prone or fire-prone zones

GeoAI

Geospatial Artificial Intelligence (GeoAI) integrates geospatial data with AI techniques to advance Earth observation, GIS, and spatial decision-making.

GeoAI can address complex challenges in:

- Sustainable urban development
- Infrastructure planning and maintenance
- Environmental monitoring and climate adaptation

Key challenges:

- How to embed unique geospatial characteristics (scale, heterogeneity, spatial association) into AI models.
- Risks of digital divide, where unequal access to data, computing, and skills may deepen social inequities.

GeoAI

Definition

- GeoAI = *Integration of geospatial data/techniques + Artificial Intelligence*
- Aims to **analyse, model, and predict** complex human–environment systems.

Core components

- **Geospatial Data**: Remote sensing, GIS, LiDAR, social media, in-situ observations.
- **AI Techniques**: Machine learning, deep learning, natural language processing, generative models.

Capabilities

- Enhance **mapping, spatial analysis, and prediction**.
- Support **real-time monitoring** of cities, infrastructure, and ecosystems.
- Enable **data-driven decision-making** in planning and policy.

Distinction

- Goes beyond traditional GIS → not only describing "where," but also explaining "why" and predicting "what next."

Brief history of GeoAI

1980s – Foundations

- Early GIScience researchers explored AI in geography.
- Symbolic AI approaches (rule-based, expert systems) applied to geospatial problems .

1990s – Statistical & computational models

- Spatial regression, geographically weighted regression (GWR), spatial interaction models.
- Decision-tree and ANN applications in land cover classification .

2000s – Machine learning era

- SVMs, random forests, ensemble models for remote sensing & spatial analysis.
- Increasing access to global geospatial datasets.

2010s – Deep learning revolution

- CNNs and RNNs widely applied to remote sensing, urban computing, and Earth system science.
- Growth of **big geospatial data + GPU/TPU computing** .

2020s – GeoAI Today

- **Geo-foundation models**, large-scale pre-trained AI models for spatial data.
- Emphasis on **explainability, fairness, and ethics**.
- Integration with generative AI (GeoGAI) for autonomous geospatial tasks .

(Mai 2025)

Emerging trends

Heterogeneity-aware and knowledge-guided GeoAI

- Incorporates spatial heterogeneity and expert knowledge into model design

Geo-foundation models and spatial representation learning

- Large-scale pre-trained models for diverse geospatial tasks
- Transfer learning across regions and applications

Fairness, privacy, explainability

- Ensuring ethical ai for geospatial data
- Promoting transparent, accountable, and socially responsible models

Summary

- GeoAI is evolving from a **mapping tool** to a **scientific paradigm**
- Moving beyond descriptive analysis toward **explainable, predictive, and integrative science**

What is your practical action?

https://www.thegef.org/news/wood-saving-cookstoves-are-helping-zambia-cut-forest-loss

Rural and vulnerable population

Education and careers

Collecting wood, cooking, boiling water, and feeding animals

Poverty

Health and well-being

Gender equality

Inequality

Social engagement

(sdgs.un.org)

Song, Yongze, et al. "Earth Observation for Sustainable Infrastructure: A Review." *Remote Sensing* 13.8 (2021): 1528.
Thacker, Scott, et al. "Infrastructure for sustainable development." *Nature Sustainability* 2.4 (2019): 324-331.

What is your practical action?

Rural and vulnerable population

(energy.economictimes.indiatimes.com)

Education and careers

Collecting wood, cooking, boiling water, and feeding animals

Poverty

Health and well-being

Gender equality

Inequality

Social engagement

Infrastructure systems

- Energy (e.g., fuel)
- Water
- Transport
- Solid waste
- Digital communications

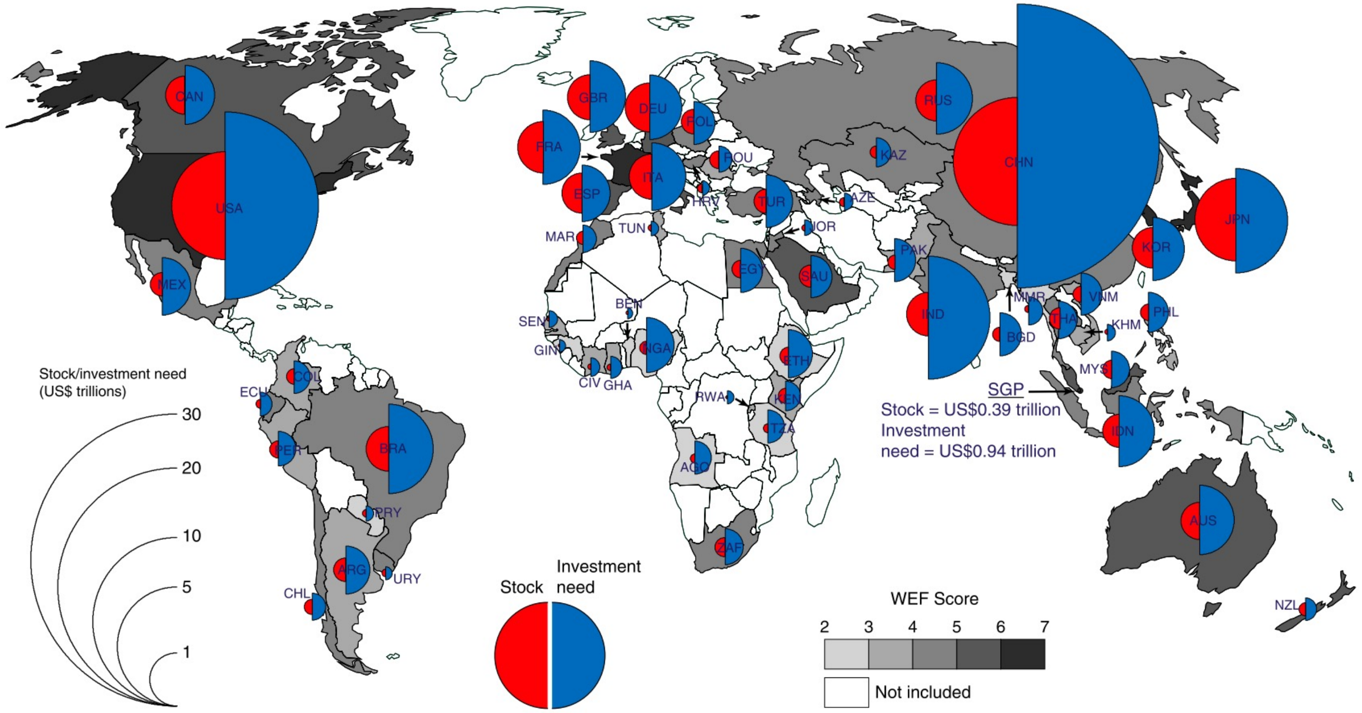
(sdgs.un.org)

Song, Yongze, et al. "Earth Observation for Sustainable Infrastructure: A Review." *Remote Sensing* 13.8 (2021): 1528.
Thacker, Scott, et al. "Infrastructure for sustainable development." *Nature Sustainability* 2.4 (2019): 324-331.

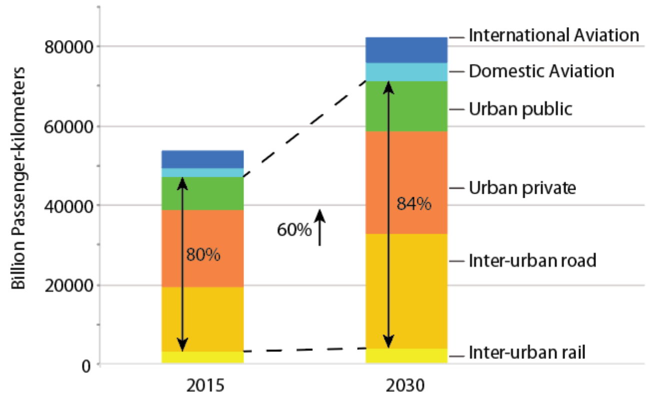
Global infrastructure needs

Current infrastructure stock and future needs to 2040

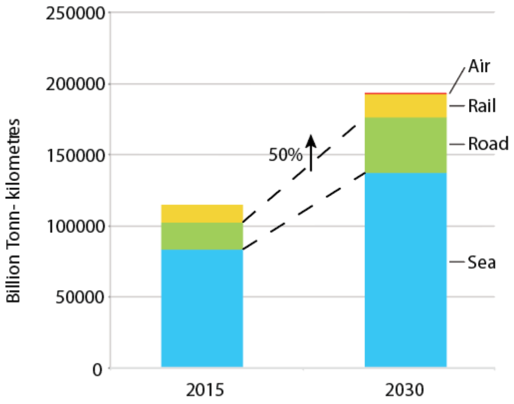
- World's existing infrastructure: US$50 trillion
- 2040: US$94 trillion of investment



Road transport for passengers



Road transport for freights



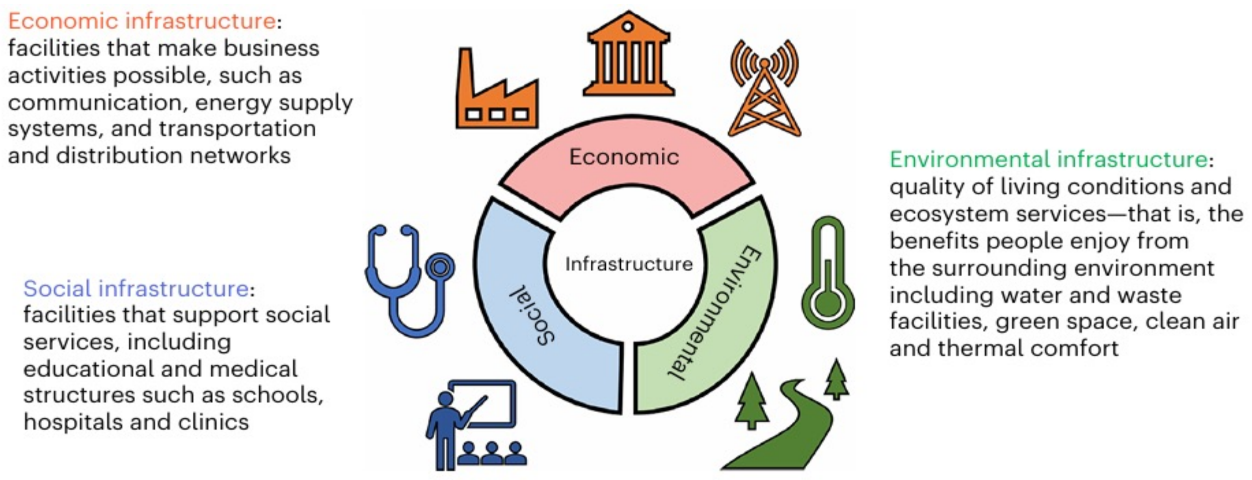
Thacker, Scott, et al. "Infrastructure for sustainable development." *Nature Sustainability* 2.4 (2019): 324-331.
Global Infrastructure Outlook: 2017 (Global Infrastructure Hub, 2017).
Bhattacharya, A. et al. Delivering on Sustainable Infrastructure for Better Development and Better Climate (2016)
Organization for economic Cooperation and Development, 2017; Sustainable Mobility for All, 2017

What is sustainable infrastructure

Sustainable infrastructure is “designed, constructed and maintained with socio-economic and environmental considerations” and it “can perpetuate and enhance the environment”.

SID

Methods and solutions → Resilient and sustainable infrastructure



Socioeconomic benefits

- Adding values for investment, finance and business
- Technology innovation
- Renewable energy implementation
- Labour standards

Environmental benefits

- Decreasing carbon and pollutant emissions
- Protecting and enhancing ecosystems
- Resilient to global climate change

Song, Yongze, et al. "Earth Observation for Sustainable Infrastructure: A Review." *Remote Sensing* 13.8 (2021): 1528.

Tu, Y., Chen, B., Liao, C., Wu, S., An, J., Lin, C., Gong, P., Chen, B., Wei, H., & Xu, B. (2025). Inequality in infrastructure access and its association with health disparities. Nature Human Behaviour, 9(11), 1669-1682. https://doi.org/10.1038/s41562-025-02208-3

GeoAI for sustainable infrastructure

GeoAI-driven decision making for large-scale and strategic infrastructure asset management.

Construction

Road use

Deterioration

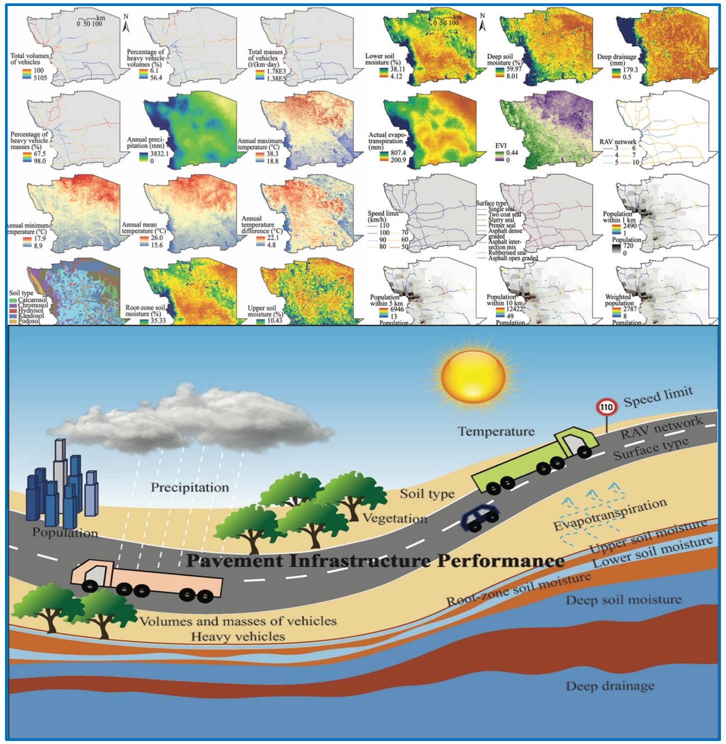
Maintenance

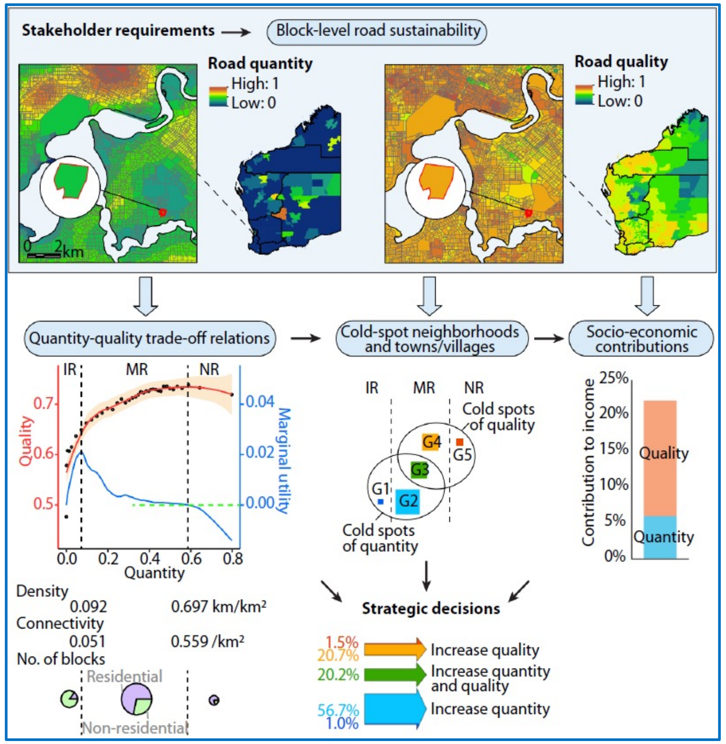
(Google.com)

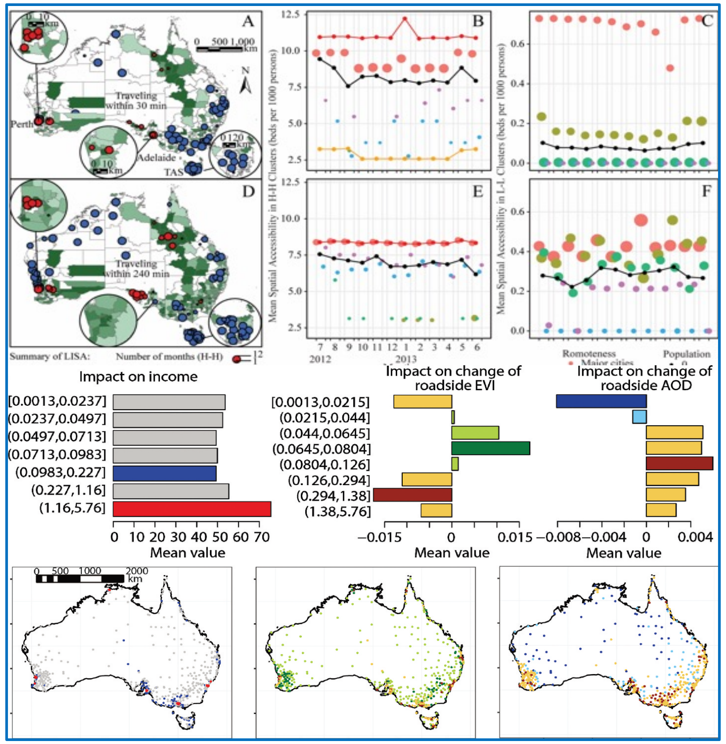
- What are the **patterns** of road deteriorations?
- What are **factors** of spatially and temporally varied road deteriorations?
- How to **understand** and **predict** road deteriorations?
- What are **impacts** of infrastructure on communities and society?

GeoAI for sustainable infrastructure ▶ Video

Factors → Performance → Impacts







Song, Yongze, et al. Segment-Based Spatial Analysis for Assessing Road Infrastructure Performance Using Monitoring Observations and Remote Sensing Data. *Remote Sensing*, 2018. 10(11): 1696.
Song, Y., et al. Assessing Block-level Sustainable Transport Infrastructure Development Using a Spatial Trade-Off Relation Model. *International Journal of Applied Earth Observation and Geoinformation*. 2021. 105, 102585.
Song, Y., Tan, Y., Song, Y.M., et al., 2018. Spatial and temporal variations of spatial population accessibility to public hospitals: A case study of rural-urban comparison. GIScience & Remote Sensing
Luo, P., Song, Y.*, Huang, X., Ma, H., et al., 2022. Identifying determinants of spatio-temporal disparities in soil moisture of the Northern Hemisphere using a geographically optimal zones-based heterogeneity model. ISPRS Journal of Photogrammetry and Remote Sensing. 185, 111-128.

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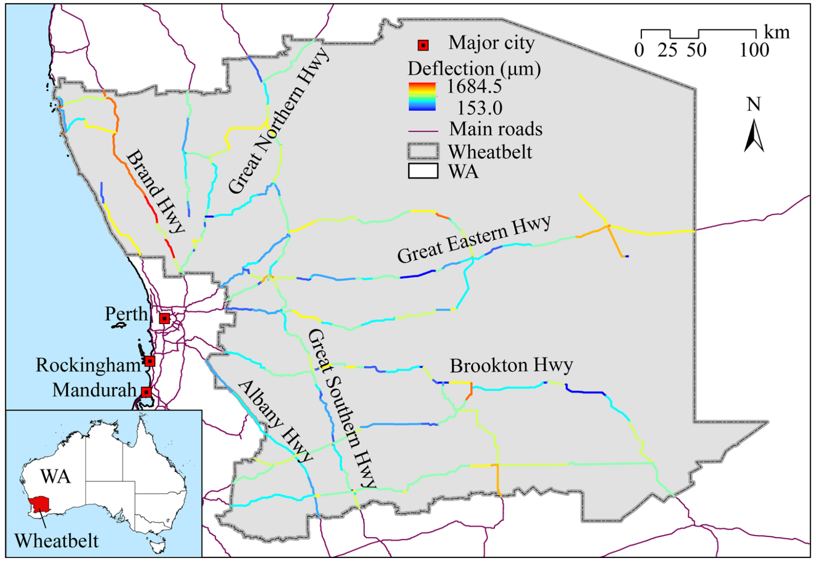
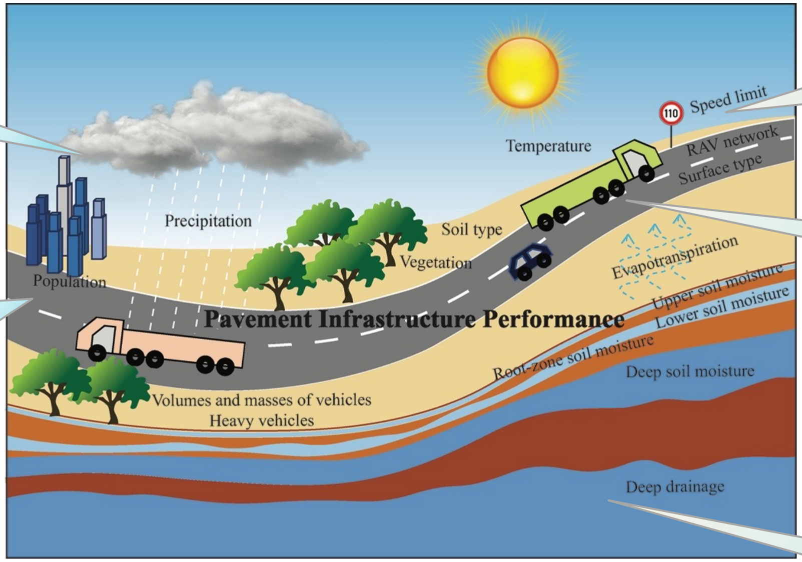
Geographical, environmental, traffic, and pavement factors

An **optimal parameters-based geographical detectors (OPGD)** model is developed for investigating road deterioration factors.



Climate

Socio-economy



Road attributes

Traffic

Geography

Song, Yongze, et al. An optimal parameters-based geographical detector model enhances geographic characteristics of explanatory variables for spatial heterogeneity analysis: cases with different types of spatial data. *GIScience & Remote Sensing*, 2020. 57(5): 593-610.

Song, Yongze, et al. Segment-Based Spatial Analysis for Assessing Road Infrastructure Performance Using Monitoring Observations and Remote Sensing Data. *Remote Sensing*, 2018. 10(11): 1696.

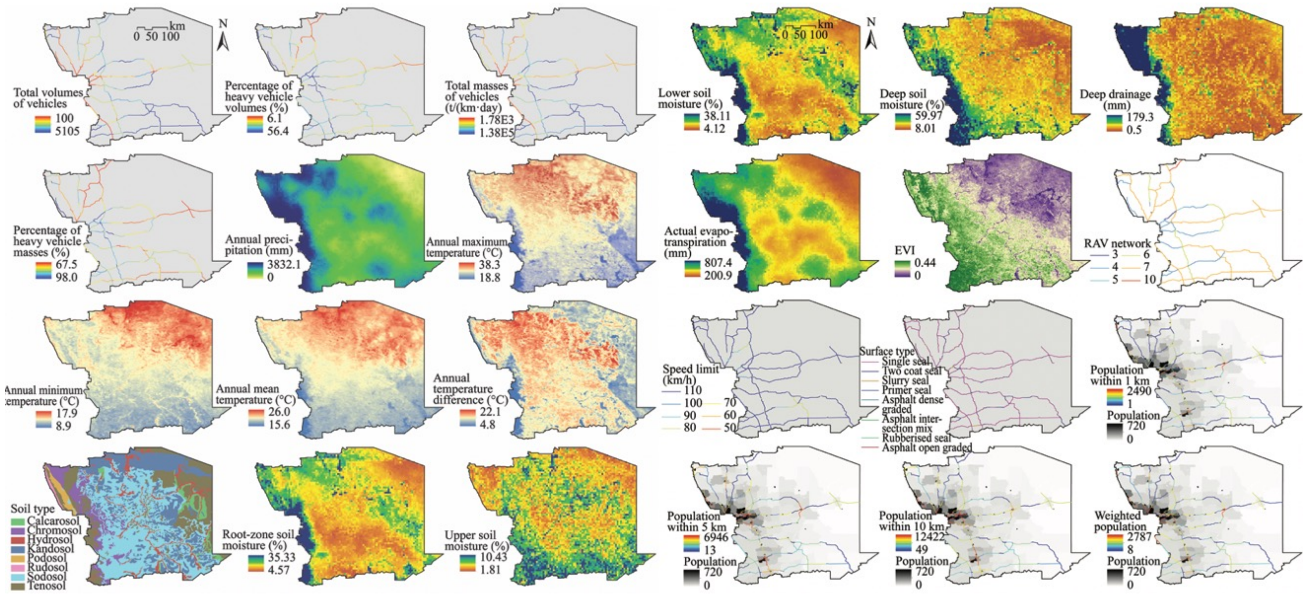
Geographical, environmental, traffic, and pavement factors

An **optimal parameters-based geographical detectors (OPGD)** model is developed for investigating road deterioration factors.

Multi-source factors data

- Pavement deterioration sensors data
- Remote sensing data
- Data products derived from spatial analysis

Spatial distributions of 24 potential variables



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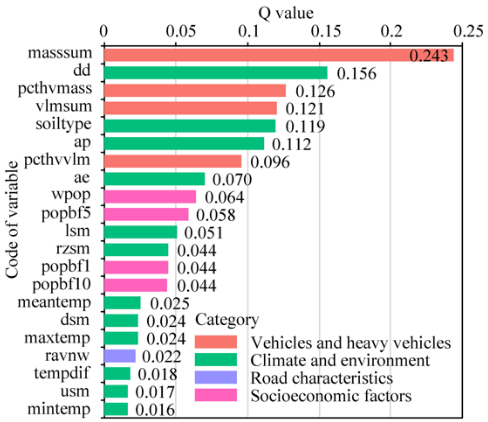
Geographical, environmental, traffic, and pavement factors

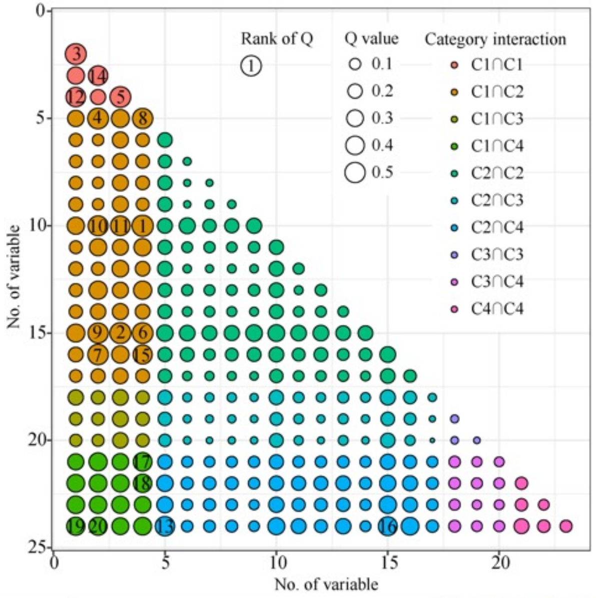
A **"GD" R package** is developed for the OPGD model. The latest version in CRAN is **Version 10.**

$$Q_v = 1 - \frac{\sum_{j=1}^{M} N_{v,j}\sigma_{v,j}^2}{N_v \sigma_v^2}$$

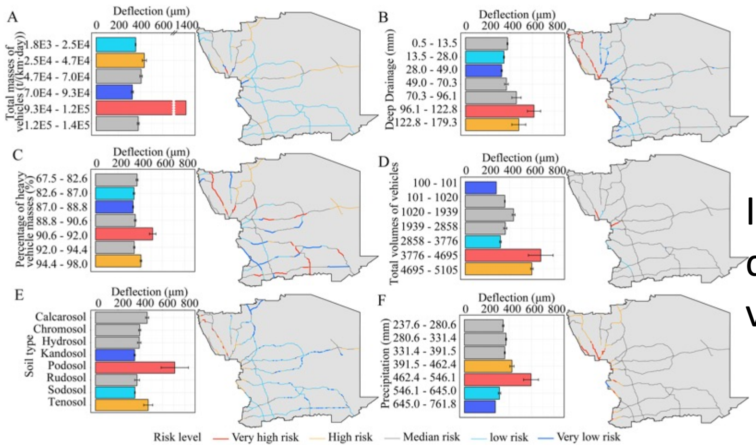
Impacts of individual variables



Impacts of variable interactions



Impacts in different data intervals of variables



Category		C1: Vehicles and heavy vehicles				C2: Climate and environment	
	Variable	vlmsum	pcthvvlm	masssum	pcthvmass	ap	dd
C1: Vehicles and heavy vehicles	vlmsum						
	pcthvvlm	0.543*					
	masssum		0.451				
	pcthvmass	0.457		0.532			
C2: Climate and environment	ap		0.535		0.505		
	soiltype		0.481	0.464	0.566*		
	dd		0.496	0.544	0.525		
	ae		0.516		0.435		
C4: Socioeconomic factors	popbf1				0.407*		
	popbf5				0.393		
	wpop	0.385	0.384			0.453*	0.423

* The largest interaction within each category, including C1∩C1, C1∩C2, C1∩C4, and C2∩C4

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"GD" R package (Version 10)

GD v10.8 | downloads 102K | downloads 3102/month

https://cran.r-project.org/web/packages/GD/vignettes/GD.html

Start from the *one-step function*: `gdm` (*Highly Recommended*)

The pacakge provides a one-step function for performing optimal discretization and geographical detectors at the same time.

The output contains all data and visualization results.

```
## install and library the pacakge
install.packages("GD")
library("GD")

## Example 1
## NDVI: ndvi_40
## set optional parameters of optimal discretization
## optional methods: equal, natural, quantile, geometric, sd and manual
discmethod <- c("equal","natural","quantile")
discitv <- c(4:6)
## "gdm" function
## In this case, Climatezone and Mining are categorical variables,
## and Tempchange and GDP are continuous variables.
ndvigdm <- gdm(NDVIchange ~ Climatezone + Mining + Tempchange + GDP,
               continuous_variable = c("Tempchange", "GDP"),
               data = ndvi_40,
               discmethod = discmethod, discitv = discitv) # ~3s
ndvigdm
plot(ndvigdm)
```

Song, Yongze, et al. An optimal parameters-based geographical detector model enhances geographic characteristics of explanatory variables for spatial heterogeneity analysis: cases with different types of spatial data. *GIScience & Remote Sensing*, 2020. 57(5): 593-610.

Song, Yongze, et al. Segment-Based Spatial Analysis for Assessing Road Infrastructure Performance Using Monitoring Observations and Remote Sensing Data. *Remote Sensing*, 2018. 10(11): 1696.

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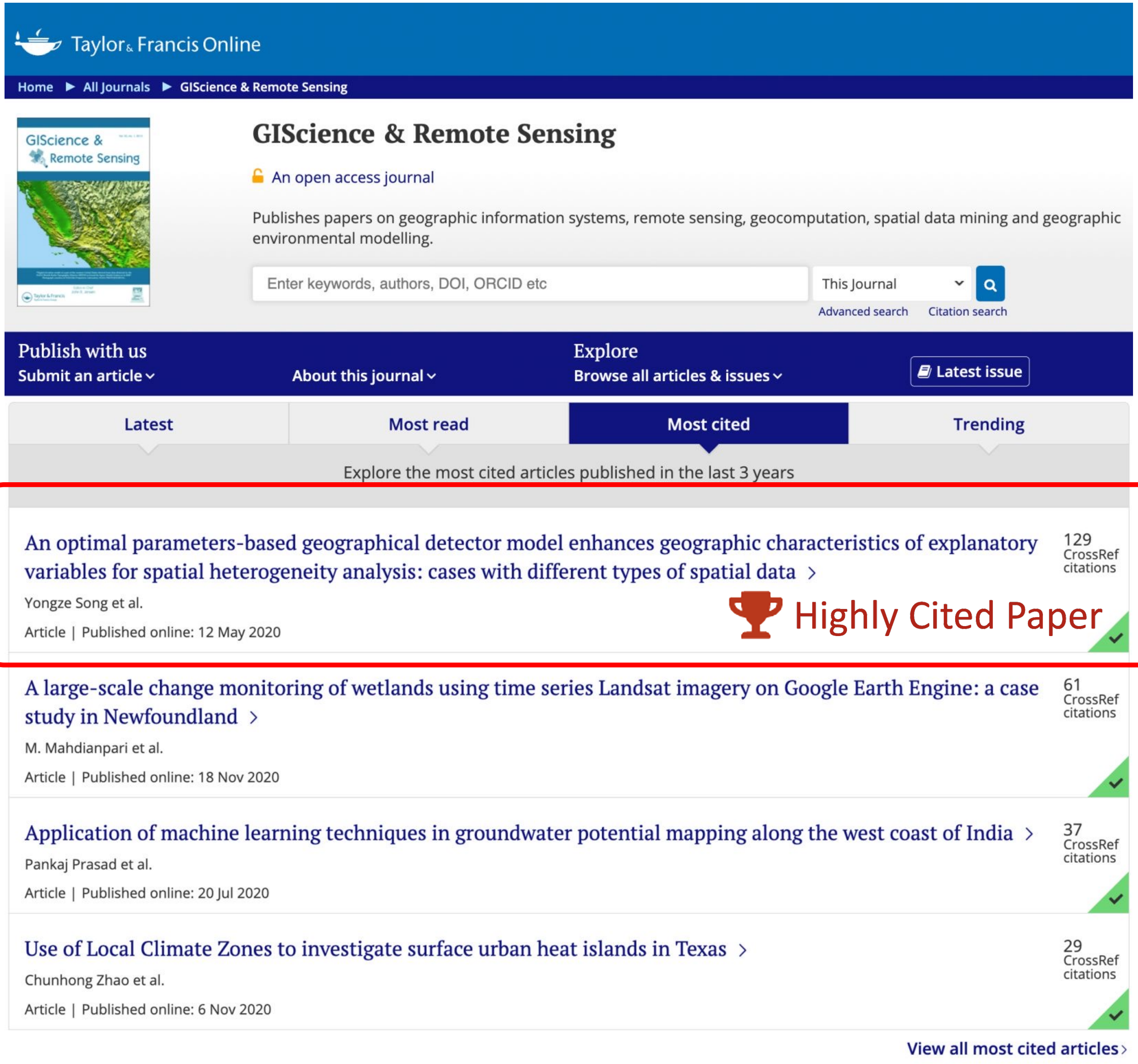
OPGD for spatial factors exploration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Explore the most cited articles published in the last 3 years

An optimal parameters-based geographical detector model enhances geographic characteristics of explanatory variables for spatial heterogeneity analysis: cases with different types of spatial data › — 129 CrossRef citations
Yongze Song et al.
Article | Published online: 12 May 2020

Highly Cited Paper

A large-scale change monitoring of wetlands using time series Landsat imagery on Google Earth Engine: a case study in Newfoundland › — 61 CrossRef citations
M. Mahdianpari et al.
Article | Published online: 18 Nov 2020

Application of machine learning techniques in groundwater potential mapping along the west coast of India › — 37 CrossRef citations
Pankaj Prasad et al.
Article | Published online: 20 Jul 2020

Use of Local Climate Zones to investigate surface urban heat islands in Texas › — 29 CrossRef citations
Chunhong Zhao et al.
Article | Published online: 6 Nov 2020

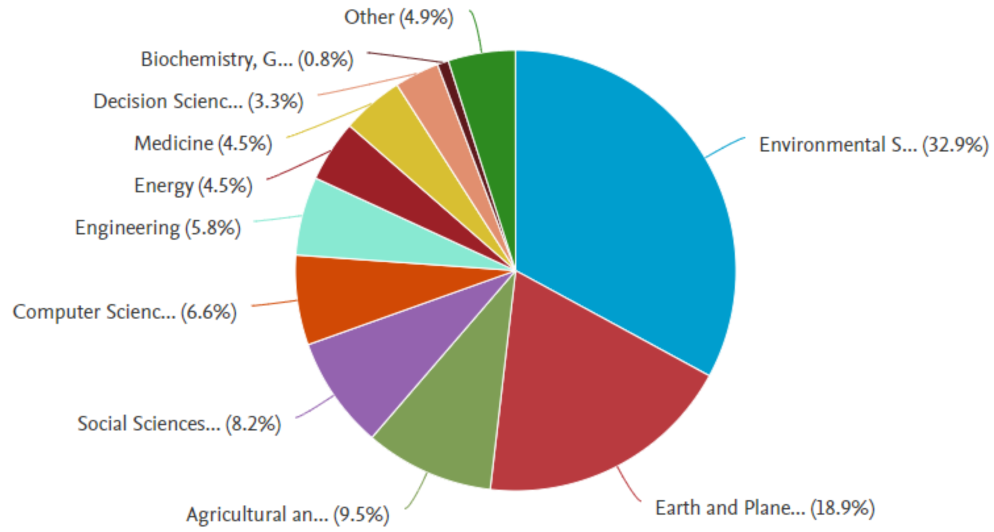
View all most cited articles ›

The article on the OPGD model (Song 2020), with **over 1000 citations**, is the **No. 1 Most Cited Article in the history** of the journal ***GIScience & Remote Sensing (IF 6.9, Q1)*** since its establishment in 1984.

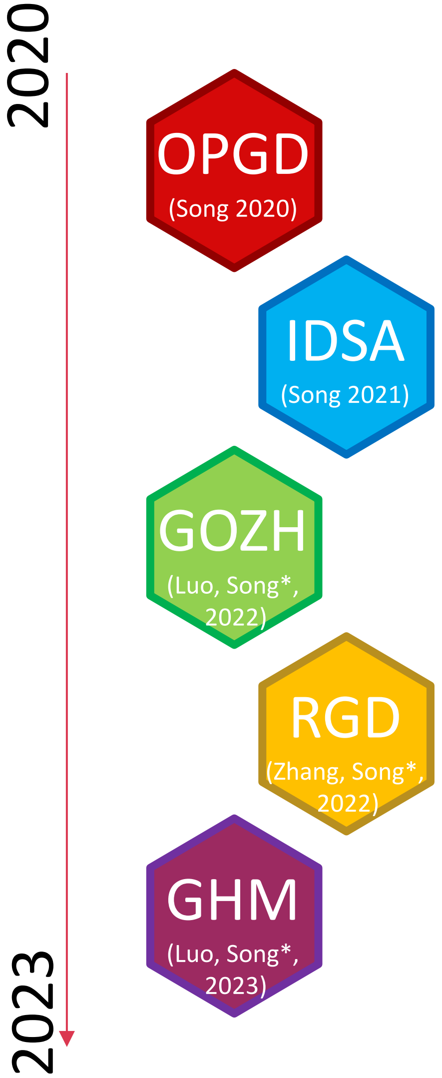
Song, Yongze, et al. An optimal parameters-based geographical detector model enhances geographic characteristics of explanatory variables for spatial heterogeneity analysis: cases with different types of spatial data. GIScience & Remote Sensing, 2020. 57(5): 593-610.

Documents by subject area

Source: Scopus



Advanced models for spatial stratified heterogeneity



Song et al. (2020) developed an **Optimal Parameters-based Geographical Detector (OPGD)** for characterising spatial heterogeneity, identifying geographical factors and interactive impacts of factors, and estimating risks. Software: R package "GD". The applications include Song et al. (2018), and Luo, Song*, et al., (2021).

Song et al. (2021) developed an **Interactive Detector for Spatial Associations (IDSA)** for estimating the power of interactive determinants (PID) from a spatial perspective. The IDSA model considers spatial heterogeneity, spatial autocorrelation, and spatial fuzzy overlay of multiple explanatory variables for calculating PID. Software: R package "IDSA".

Luo, Song*, et al. (2022) developed a **Geographically Optimal Zones-based Heterogeneity (GOZH)** for identifying individual and interactive determinants of geographical attributes (e.g., global soil moisture) across a large study area. GOZH can identify optimal spatial zones and compute the maximum power of determinant (PD) values using an Ω-index.

Zhang, Song*, et al. (2022) developed a **Robust Geographical Detector (RGD)** model for the robust estimation of PD values.

Luo, Song*, et al. (2023) developed a **Generalized Heterogeneity Model (GHM)** for more accurate spatial prediction. Local-scale spatial association is characterised using points and large-scale spatial association is characterised using strata.

Generalized Heterogeneity Model (GHM)

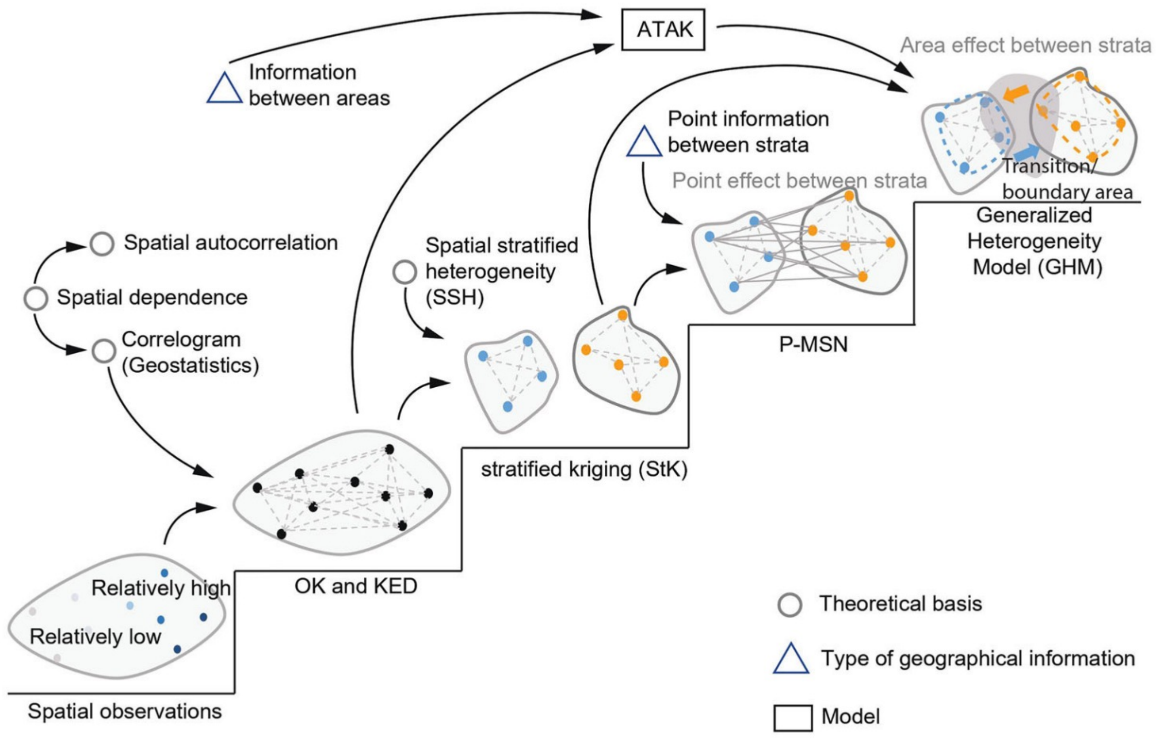
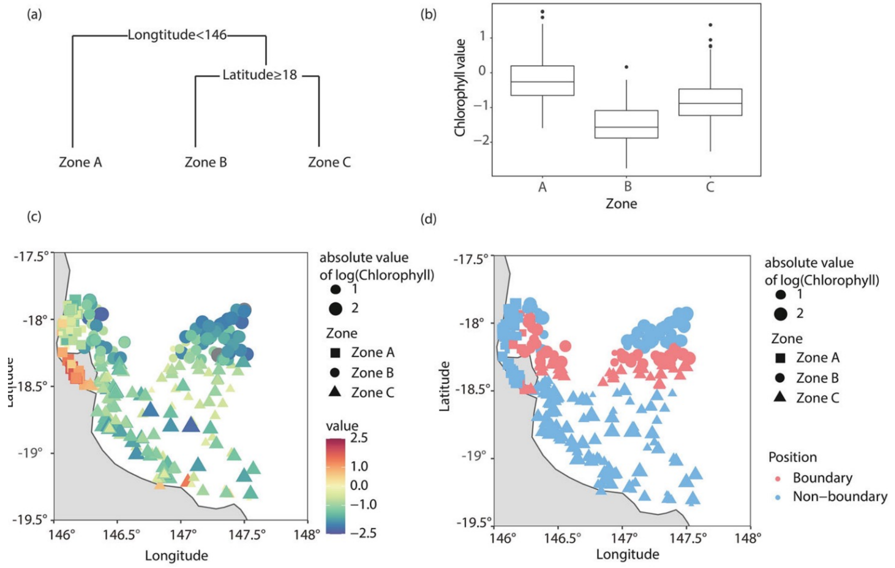
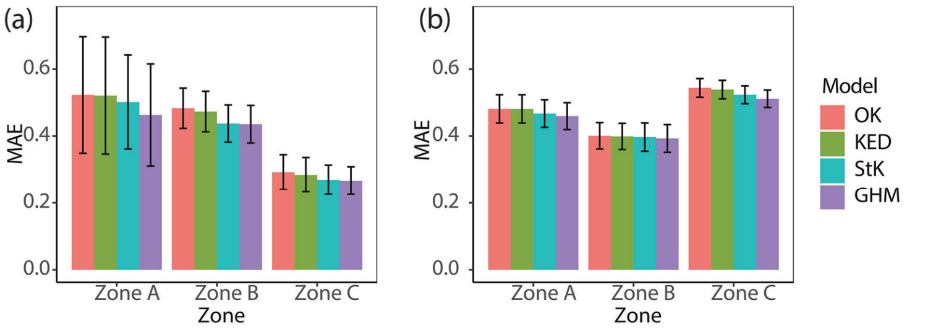


Figure 1. Theoretical basis of the Generalized Heterogeneity Model (GHM) and the relevant models: OK (ordinary kriging), KED (kriging with external drift), StK (stratified kriging), P-MSN (point mean of surface with stratified non-homogeneity) and ATAK (area-to-area kriging).

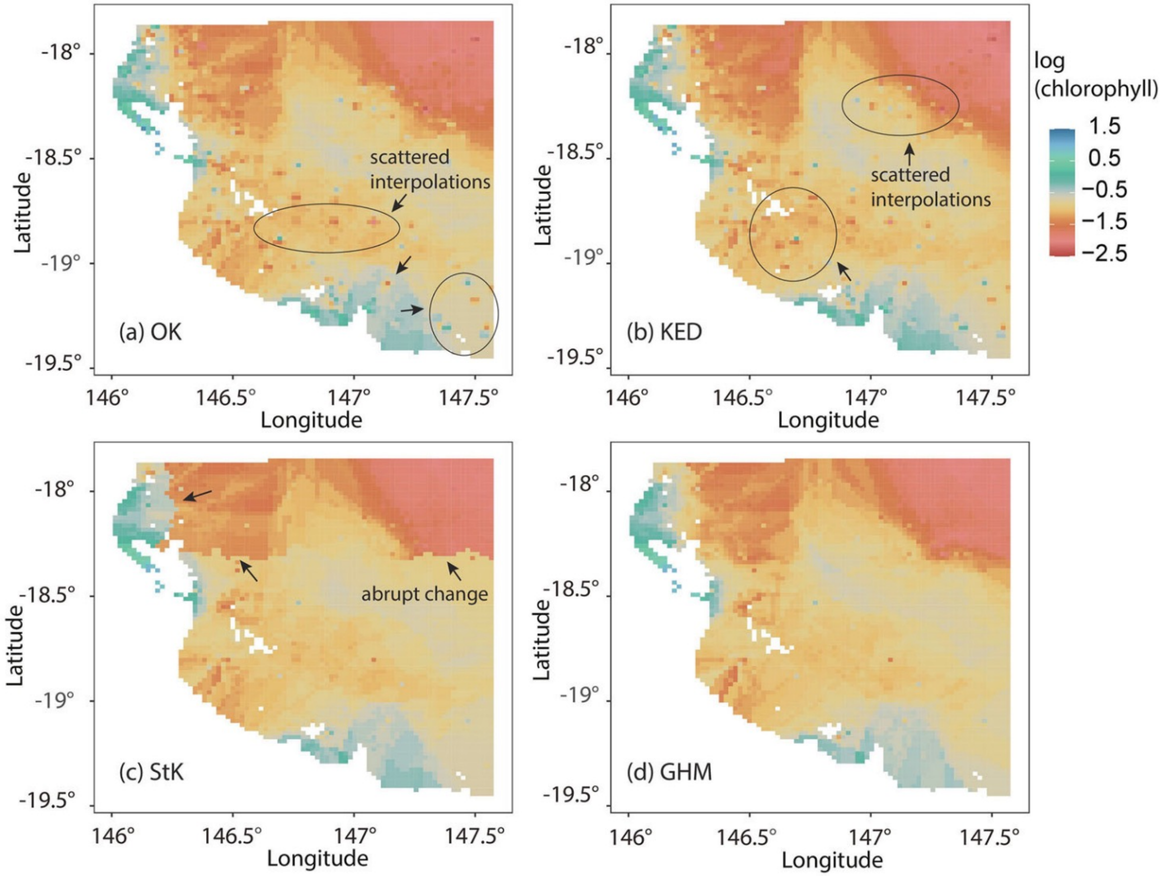




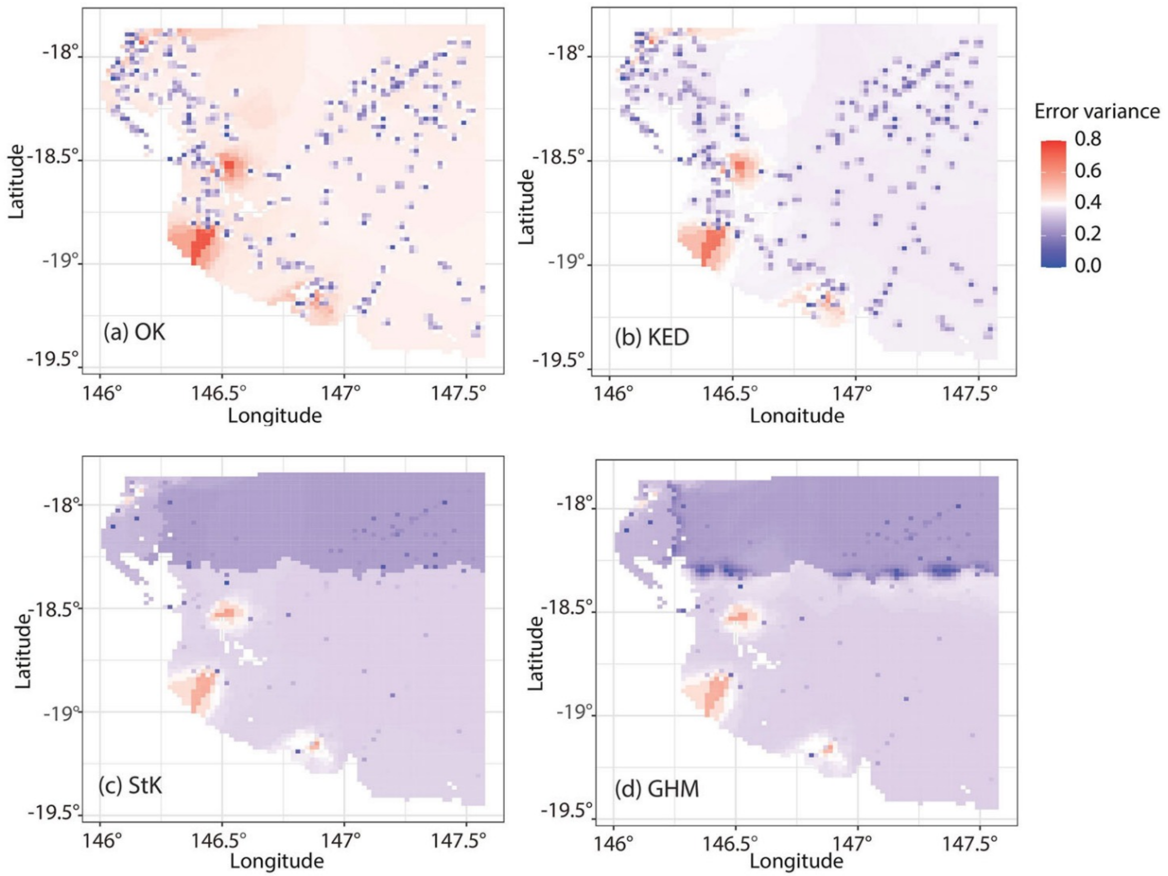
Luo, P., Song, Y.*, Zhu, D., Cheng, J. and Meng, L., 2023. A generalized heterogeneity model for spatial interpolation. International Journal of Geographical Information Science, 37(3), pp.634-659.

Generalized Heterogeneity Model (GHM)

Predictions



Prediction errors



Luo, P., Song, Y.*, Zhu, D., Cheng, J. and Meng, L., 2023. A generalized heterogeneity model for spatial interpolation. International Journal of Geographical Information Science, 37(3), pp.634-659.

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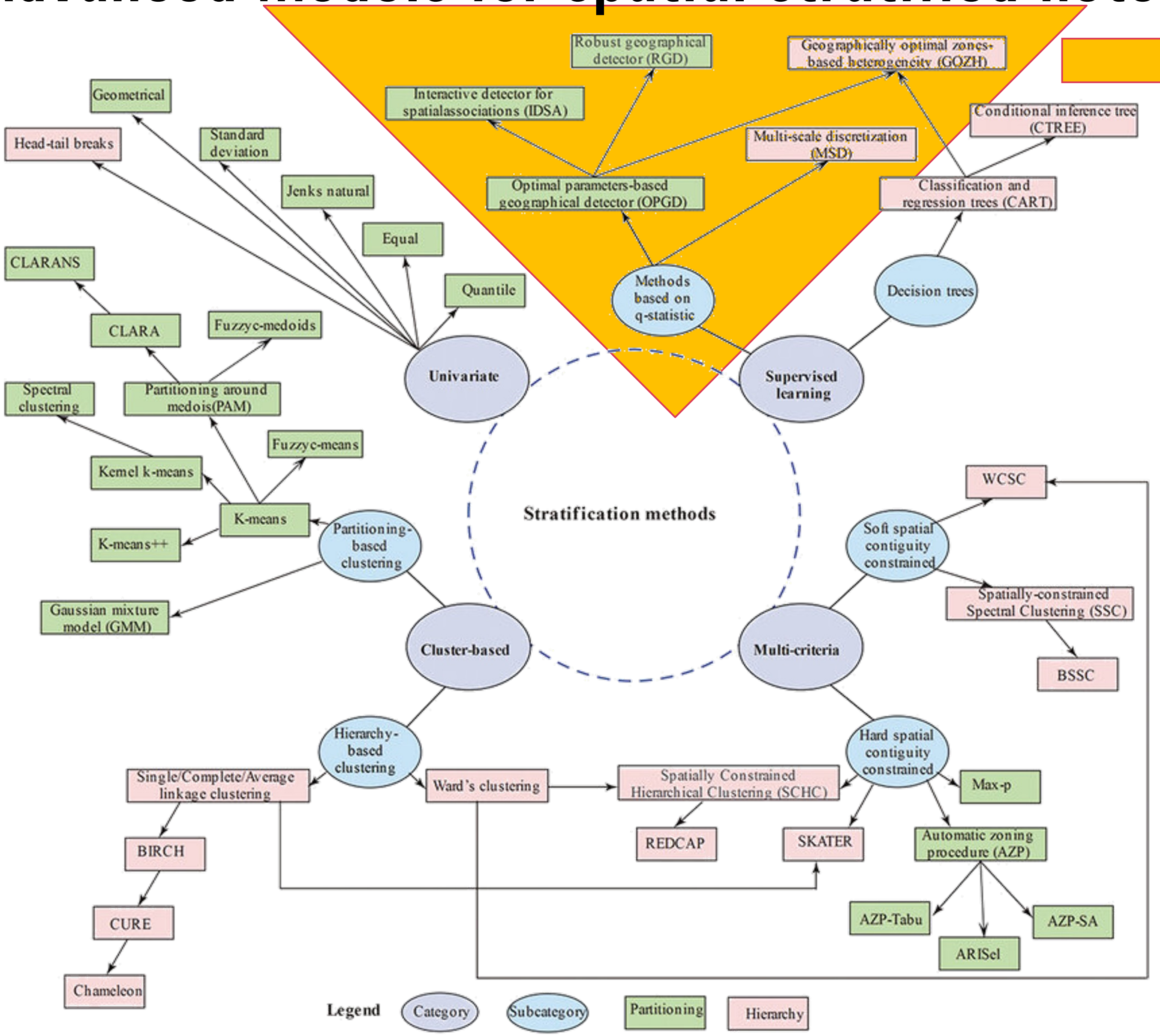
Advanced models for spatial stratified heterogeneity



We proposed advanced spatial stratification models

Guo, J., Wang, J., Xu, C. & Song, Y., 2022. Modeling of spatial stratified heterogeneity. GIScience & Remote Sensing, 59(1), 1660-1677.

GeoAI for mapping

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

Advances in geocomputation and geospatial artificial intelligence (GeoAI) for mapping

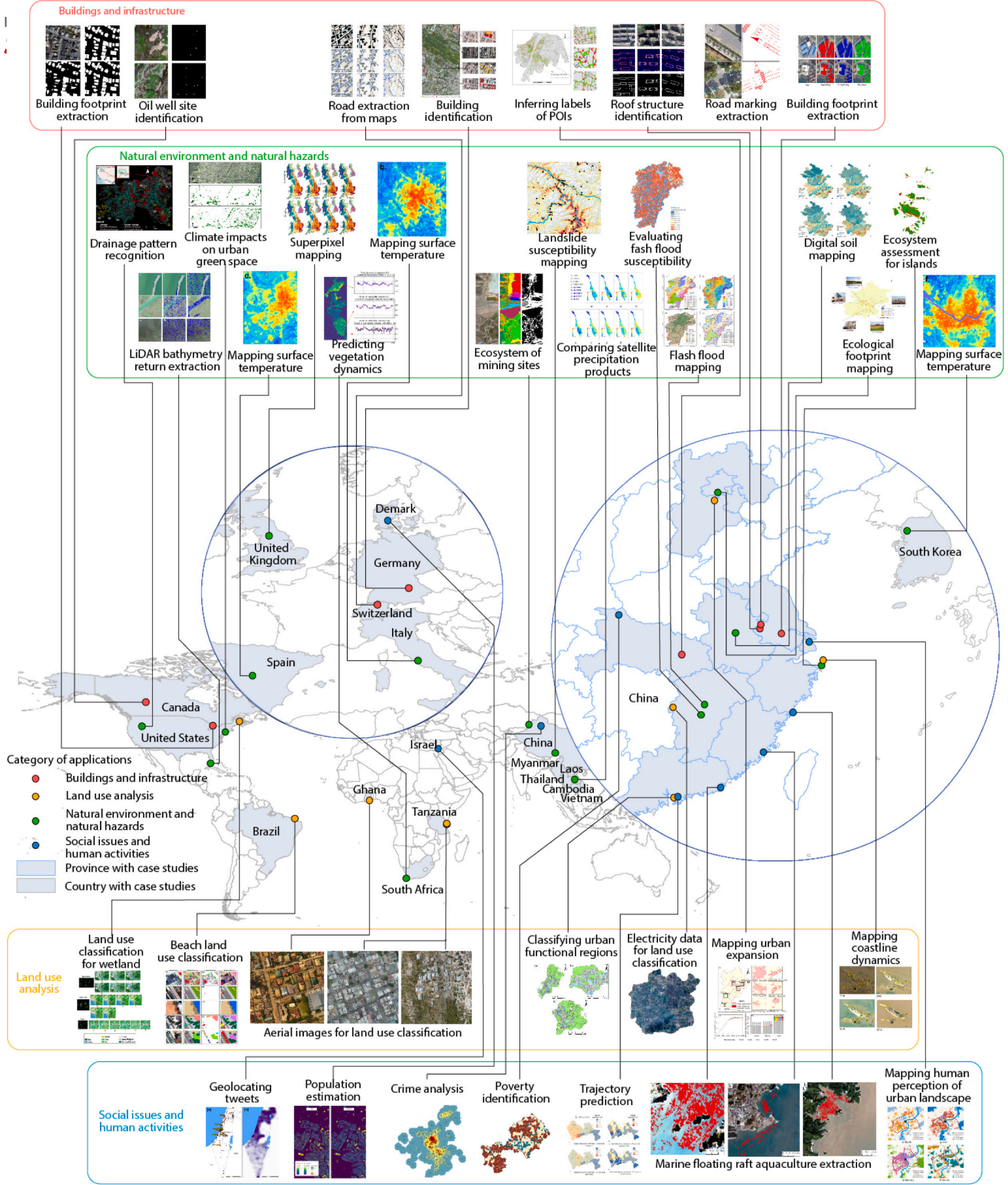
Yongze Song *, Margaret Kalacska, Mateo Gašparović, Jing Yao, Nasser Najibi

School of Design and the Built Environment, Curtin University, Perth, Australia
Applied Remote Sensing Laboratory, Department of Geography, McGill University, Montréal, QC H3A 0B9, Canada
Chair of Photogrammetry and Remote Sensing, Faculty of Geodesy, University of Zagreb, Zagreb, Croatia
Urban Big Data Centre, School of Social and Political Sciences, University of Glasgow, Glasgow, G12 8QQ, United Kingdom
Department of Biological and Environmental Engineering, Cornell University, Ithaca, NY, USA

Received over 150 submissions and published about 30 high-quality articles from over 120 authors in 17 countries. The average citation of articles published in the special issue is 11.4 by August 2023.

GeoAI are advancing GIS by enhancing mapping, pattern recognition, and decision-making across natural, built, and social environments.

Song, Y.*, Kalacska, M., Gašparović, M., Yao, J. & Najibi, N., 2023. Advances in geocomputation and geospatial artificial intelligence (GeoAI) for mapping. International Journal of Applied Earth Observation and Geoinformation. p.103300.



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GeoAI for shaping Earth and cities

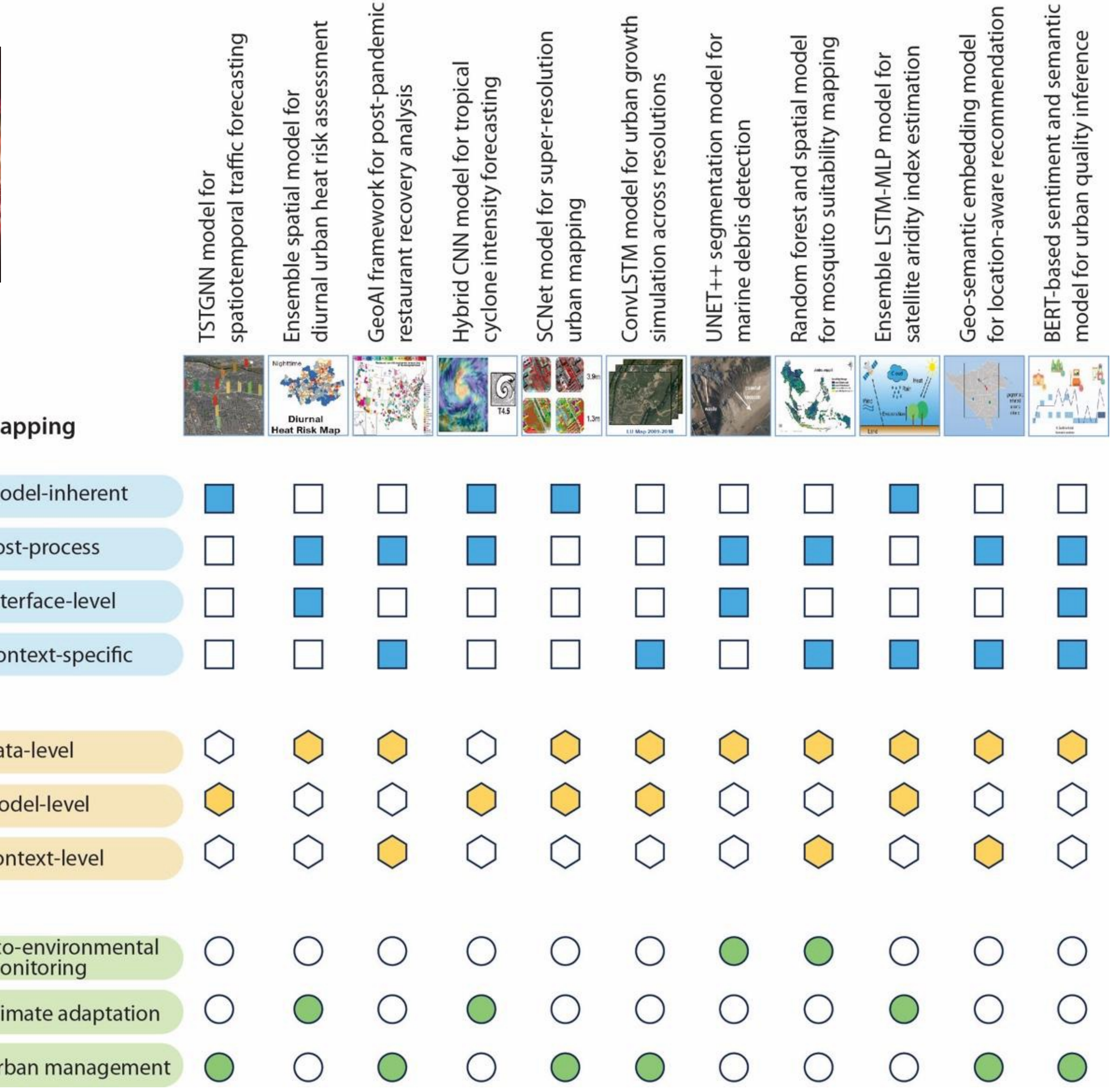
Guest editors

Yongze Song, Curtin University, Australia

Filip Biljecki, National University of Singapore

Gustau Camps-Valls, Universitat de València, Spain

Peter Atkinson, Lancaster University, United Kingdom



A conceptual framework illustrating how GeoAI advances beyond traditional mapping toward shaping Earth and city systems through the dimensions of explainability, adaptability and sustainability.

Curtin University | Geospatial Intelligence Lab | International Society for Spatial Methods | HARVARD UNIVERSITY | Spatial Data Lab @Center for Geographic Analysis, IQSS

Advancing geospatial methods for global resource and sustainability

Resources, Conservation and Recycling (IF 10.9, Q1)

Resources, Conservation and Recycling

Available online 16 July 2025, 108517

In Press, Corrected Proof ⓘ What's this?

Editorial

Advancing geospatial methods for addressing global resource and sustainability challenges

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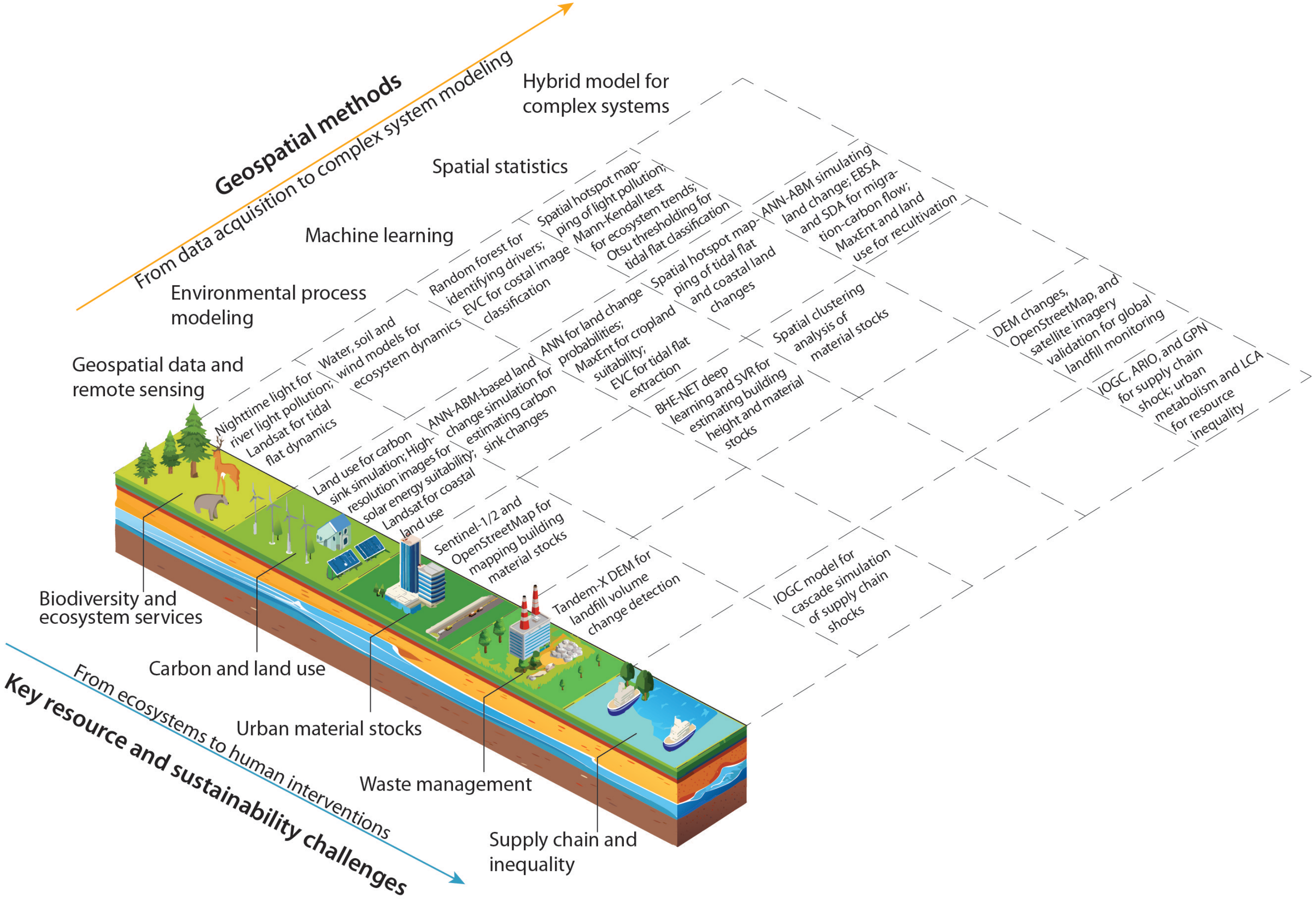
d Department of Pathology, Microbiology, and Immunology, School of Veterinary Medicine, University of California, Davis, USA

e School of Environmental Sciences, University of Haifa, Haifa, Israel

f Centre for Demographic Urban and Environmental Studies, El Colegio de México, Mexico City, Mexico

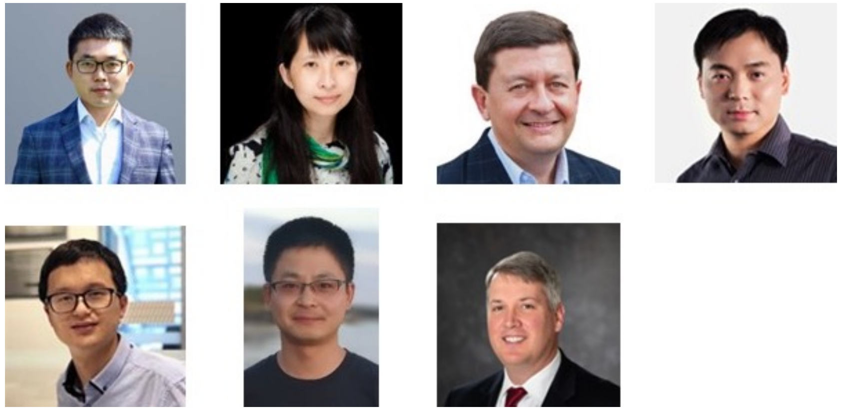
g School of Environment, University of Auckland, Auckland, New Zealand



Song, Y.*, Helmholz, P., Su, F., Zhou, C., Lotfata, A., Zohar, M., González Leonardo, M., & Sila-Nowicka, K. 2025. Advancing geospatial methods for addressing global resource and sustainability challenges. Resources, Conservation and Recycling.

Foundation models for Earth observation

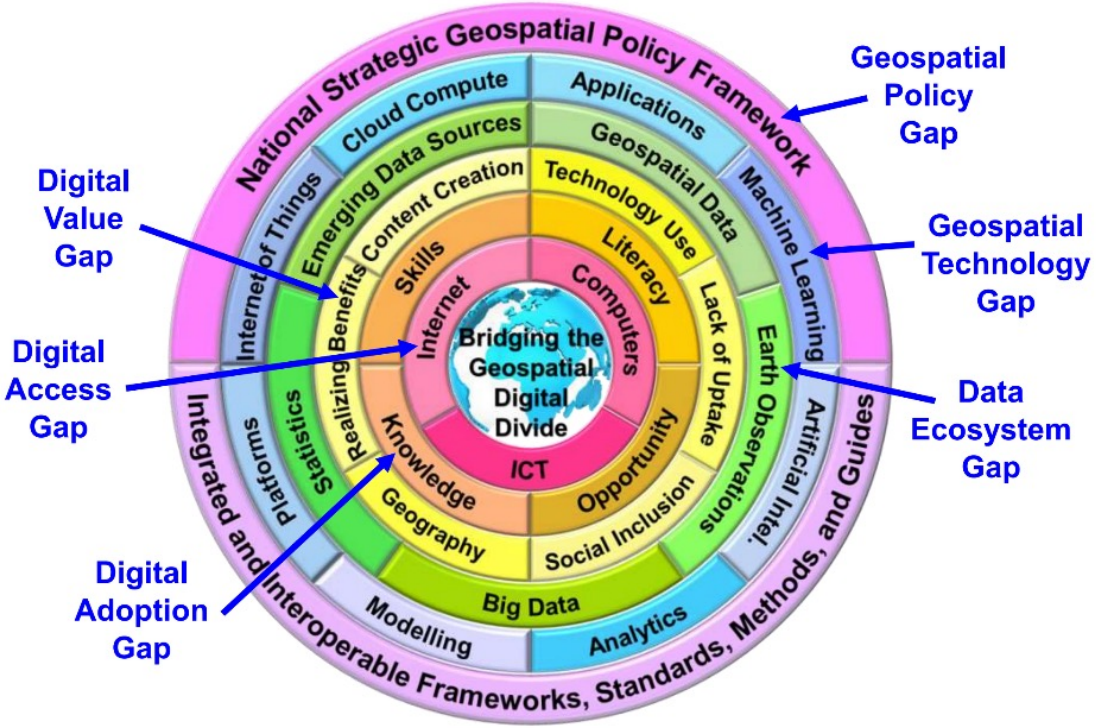
JAG: https://www.sciencedirect.com/special-issue/1053N56JT2Z



Guest Editors:
- **Dr. Yongze Song** Curtin University, Australia
- **Dr. J. Jaime Gómez-Hernández** Spain
- **Prof. Wei Liu** The University of Western Australia, Australia
- **Prof. Dacheng Tao** University of Technology Sydney, Australia
- **Prof. Shirui Pan** Griffith University, Queensland, Australia
- **Dr. Lei Gao** Commonwealth Scientific and Industrial Research Organisation, Canberra, Australia
- **Dr. William Blackwell** MIT, USA

- The emergence of foundation models (i.e., large pre-trained models) in Earth observation represents a revolutionary advancement in using satellite and aerial imagery for environmental monitoring.
- Foundation models, trained on large datasets and employing self-supervised learning techniques, provide broad capabilities that can be adapted for various tasks, such as accurate land cover classification and rapid disaster response. This innovative approach improves the efficiency and accuracy of data analysis and generates opportunities for applications, such as climate change studies, urban planning, and environmental conservation.
- By exploring the complex patterns present in large-scale Earth observation big data, foundation models are revolutionising our understanding and management of the Earth natural resources, making them critical research areas in Earth sciences.

Digital divide and GeoAI



The components of the geospatial digital divide, presented by Greg Scott in the First International Workshop on Operationalizing the Integrated Geospatial Information Framework. Source: https://www.cepal.org/sites/default/files/presentations/igif-geospatial-digital-divide-greg-scott-un-ggim.pdf.

Important concepts in geospatial analysis (proposed by our team)

1. Spatial association: second-dimension spatial association, interactive detector for spatial association, local pathways of association
2. Spatial autocorrelation: heterogeneous spatial autocorrelation,
3. Geostatistics or Kriging: segment-based regression kriging,
4. Spatial heterogeneity: spatial stratified heterogeneity, local stratified heterogeneity, generalized heterogeneity, geographically optimal zones-based heterogeneity, locally explained heterogeneity, wavelet geographically weighted regression, spatio-temporal unmixing with heterogeneity,
5. Spatial interaction: robust Interaction, interactive detector for spatial association, geographical pattern interaction,
6. Geographical similarity: geographically optimal similarity,
7. Geocomplexity: geocomplexity,
8. Spatial local outliers: second-dimension outliers,
9. Spatial graph network: geographical graph neural network, dynamic spatiotemporal graph network,
10. Spatial fusion: spatial context-aware fusion,
11. Spatial anisotropy: spatial irregular anisotropy,
12. Spatial accessibility: D2SFCA spatiotemporal accessibility,
13. Spatial decision-making: MFSD spatial decision making,
14. Spatial big data: spatial big data-based city redefinition,
15. Spatial path analysis: local pathways of association
16. Spatial segmentation: spatial heterogeneity-based segmentation, gaussian mixture segmentation,
17. Spatial trade-off: spatial trade-off relation, dynamic trade-off, spatial delta model,
18. Spatial unmixing: spatio-temporal unmixing with heterogeneity
19. Robust spatial models: robust geographical detector, robust interaction detector
20. Advanced geographical detector models: Optimal Parameters-based Geographical Detector (OPGD), Robust Interaction Detector (RID), Local indicator of stratified power (LISP), Geographically Optimal Zones-based Heterogeneity (GOZH), Geographical Pattern Interaction (GPI), Interactive Detector for Spatial Associations (IDSA), Robust Geographical Detector (RGD), Locally explained heterogeneity model, Generalized Heterogeneity Model (GHM), Heterogeneous spatial autocorrelation (HSA)

Read more at https://yongzesong.com/methods/

Developed 30 New Geospatial Theories and Methods

https://yongzesong.com/methods/

Part I. Spatial prediction

1. Second-Dimension Spatial Association (SDA). *International Journal of Applied Earth Observation and Geoinformation.*
   - R package "SecDim"
2. Geographically Optimal Similarity (GOS). *Mathematical Geosciences.*
   - R package "geosimilarity"
3. Heterogeneous spatial autocorrelation (HSA). *International Journal of Geographical Information Science.* (**Top 4 Most Read Article in the last 1 year**, 2025)
   - R Code for HSA model
4. Geocomplexity explains spatial errors. *International Journal of Geographical Information Science.* (**Top 30 Most Cited Article in the last 3 years**, 2025; **No. 1 Most Read Article**, 2023)
   - R package "geocomplexity"
5. Generalized Heterogeneity Model (GHM). *International Journal of Geographical Information Science.* (**Top 4 Most Cited Article in the last 3 years**, 2025; **Top 10 Most Read Article**, 2024)
6. Segment-based Regression Kriging (SRK). *IEEE Transactions on Intelligent Transportation Systems.* Highly Cited Paper
7. Dynamic Trade-Off Model (DTOM). *IEEE Transactions on Intelligent Transportation Systems.* Highly Cited Paper
8. Dynamic spatiotemporal graph network. *GIScience & Remote Sensing.*
9. Geographically informed graph neural network (GIGNN). *Spatial Statistics*
10. Spatial context-aware fusion (SCAF). *International Journal of Digital Earth.*

Part II. Spatial heterogeneity and driver analysis

11. Optimal Parameters-based Geographical Detector (OPGD). *GIScience & Remote Sensing.* Highly Cited Paper (**No. 1 Most Cited Article**, 2022)
    - R package "GD"; Q & A
12. Robust Interaction Detector (RID). *Spatial Statistics.* Highly Cited Paper
13. Local indicator of stratified power (LISP). *International Journal of Geographical Information Science.*
    - R Code for LISP model
14. Geographically Optimal Zones-based Heterogeneity (GOZH). *ISPRS Journal of Photogrammetry and Remote Sensing.*
    - R Code for GOZH model: Code 1; Code 2
15. Geographical Pattern Interaction (GPI). *International Journal of Geographical Information Science.* (**Top 1 Most Rear Article in the last 30 days**, 2025)
16. Interactive Detector for Spatial Associations (IDSA). *International Journal of Geographical Information Science.* (**No. 2 Most Cited Article**, 2023)
    - R package "IDSA"
17. Robust Geographical Detector (RGD). *International Journal of Applied Earth Observation and Geoinformation.*
    - Python Code for RGD model
18. Locally explained heterogeneity model. *International Journal of Digital Earth.*
    - R Code for LESH model
19. Local pathways of association (LPA). *International Journal of Applied Earth Observation and Geoinformation.*
    - R Code for LPA model
20. Spatio-temporal unmixing with heterogeneity (STUH). *International Journal of Applied Earth Observation and Geoinformation.*
21. Spatial Heterogeneity-based Segmentation (SHS) for the homogeneous segmentation of line data. *IEEE Transactions on Intelligent Transportation Systems.*
22. Wavelet Geographically Weighted Regression (WGWR). *Scientific Reports.*

Part III. Spatial patterns and decision-making

23. Spatial Delta Model (SDM) for quantifying the difference between access and accessibility. *International Journal of Applied Earth Observation and Geoinformation*
24. D2SFCA model for the spatiotemporal accessibility analysis. *GIScience & Remote Sensing.* Highly Cited Paper
25. Spatial Trade-Off Relation (STOR) for spatial quantity-quality relationship modelling. *International Journal of Applied Earth Observation and Geoinformation.*
26. MFSD model for spatial decision making. *Renewable and Sustainable Energy Reviews.*
27. Spatial Big Data Method for redefining cities. *International Journal of Geographical Information Science.*
28. Gaussian Mixture Segmentation (GMS). *IEEE Transactions on Intelligent Transportation Systems.*

Software

Open-Source Geospatial Software (*200,000+ downloads*)

Optimal Parameters-based Geographical Detectors (OPGD) for spatial factor exploration. **R package "GD"** | publication
– Highly Cited Paper
– No. 1 Most Cited Article in GIScience & Remote Sensing in 2021-2023
– No. 1 Monthly Most Cited Article in GIScience & Remote Sensing in each month since May 2023 until now (ResearchGate)
downloads 109.3K | downloads 2900/month

Geographically Optimal Similarity (GOS) for spatial prediction. **R package "geosimilarity"** | publication
downloads 8.9K | downloads 184/month

Second-Dimension Spatial Association (SDA) for spatial prediction. **R package "SecDim"** | publication
downloads 5.2K | downloads 19/month

Geocomplexity. **R package "geocomplexity"** | publication
downloads 7.2K | downloads 467/month

Interactive Detector for Spatial Association (IDSA) for spatial factor exploration. **R package "IDSA"** | publication
– No. 2 Most Cited Article in International Journal of Geographical Information Science (IJGIS) in 2021-2023
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Homogenous Segmentation (HS) for segmenting spatial lines data. **R package "HS"** | publication
downloads 21.8K | downloads 24/month

Segment-based Kriging (SK) for spatial prediction. **R package "SK"** | publication
– Highly Cited Paper
downloads 15.3K | downloads 10/month

Energy Decomposition Analysis (EDA) for analysing carbon emission factors. **R package "EDA"** | publication
downloads 31.2K | downloads 35/month

SDGdetector: Detecting Sustainable Development Goals (SDGs) in Text. **R package "SDGdetector"** | publication
downloads 7.2K | downloads 145/month

gdverse: Analysis of Spatial Stratified Heterogeneity. **R package "gdverse"** | publication
downloads 6.8K | downloads 340/month

localsp: Local Indicator of Stratified Power. **R package "localsp"** | publication
downloads 1.6K | downloads 128/month

cisp: A Correlation Indicator Based on Spatial Patterns. **R package "cisp"** | publication
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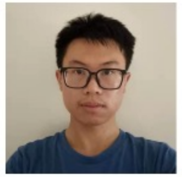
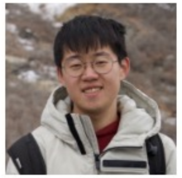
Acknowledgement



Zehua Zhang

Postdoc Researcher: Curtin University
PhD: Curtin University (*Chancellor Commendation Award*)
Master: University of Melbourne (*with Distinction*)

- Robust Interaction Detector (RID). *Spatial Statistics.* **Highly Cited Paper**
- Heterogeneous spatial autocorrelation (HSA). *International Journal of Geographical Information Science.* **(Top 4 Most Read Article in the last 1 year**, 2025**)**
    - R Code for HSA model
- Geocomplexity explains spatial errors. *International Journal of Geographical Information Science.* **(Top 30 Most Cited Article in the last 3 years**, 2025; **No. 1 Most Read Article**, 2023**)**
    - R package "geocomplexity"
- Robust geographical detector (RGD). *International Journal of Applied Earth Observation and Geoinformation.*
    - Python Code for RGD model
- Geographically informed graph neural network (GIGNN). *Spatial Statistics*



Peng Luo

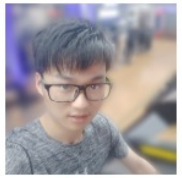
Postdoc Researcher: Massachusetts Institute of Technology (MIT)
PhD: Technical University of Munich
Master: Peking University

- Generalized Heterogeneity Model (GHM). *International Journal of Geographical Information Science.* **(Top 4 Most Cited Article in the last 3 years**, 2025; **Top 10 Most Read Article**, 2024**)**
- Geocomplexity explains spatial errors. *International Journal of Geographical Information Science.* **(Top 30 Most Cited Article in the last 3 years**, 2025; **No. 1 Most Read Article**, 2023**)**
- Geographically Optimal Zones-based Heterogeneity (GOZH). *ISPRS Journal of Photogrammetry and Remote Sensing.*
    - R Code for GOZH model: Code 1; Code 2
- Geographical Pattern Interaction (GPI). *International Journal of Geographical Information Science.* **(Top 1 Most Rear Article in the last 30 days**, 2025**)**
- Locally explained heterogeneity model. *International Journal of Digital Earth.*
    - R Code for LESH model
- Spatio-temporal unmixing with heterogeneity (STUH). *International Journal of Applied Earth Observation and Geoinformation.*

Pengcheng Zhang

PhD Researcher: The Hong Kong Polytechnic University

- Dynamic spatiotemporal graph network. *GIScience & Remote Sensing.*
- Gaussian Mixture Segmentation (GMS). *IEEE Transactions on Intelligent Transportation Systems.*



Jiao Hu

Research Associate: Curtin University
PhD: Chengdu University of Technology

- Local indicator of stratified power (LISP). *International Journal of Geographical Information Science.*
    - R Code for LISP model
- Local pathways of association (LPA). *International Journal of Applied Earth Observation and Geoinformation.*
    - R Code for LPA model

Xinyue Yang

PhD Researcher: Curtin University

- Spatial irregular anisotropy in urban heat effects. *Sustainable Cities and Society*

Yang Li

Postdoc Researcher: Beihang University
PhD: Beijing Normal University

- Geographical Pattern Interaction (GPI). *International Journal of Geographical Information Science.*
- Locally explained heterogeneity model. *International Journal of Digital Earth.*
    - R Code for LESH model

Rui Qu

Research Associate: Curtin University
PhD: Chengdu University of Technology

- Local pathways of association (LPA). *International Journal of Applied Earth Observation and Geoinformation.*
    - R Code for LPA model

Kai Ren

Research Associate: Curtin University

- Second-Dimension Outliers (SDO). *International Journal of Geographical Information Science.*
- Spatial irregular anisotropy in urban heat effects. *Sustainable Cities and Society*

Practice (1 hour)

Any questions?

Guide for Installing R and RStudio:
https://rstudio-education.github.io/hopr/starting.html

Optimal Parameters-based Geographical Detectors (OPGD) Model for Spatial Heterogeneity Analysis and Factor Exploration
https://cran.r-project.org/web/packages/GD/vignettes/GD.html

Assignment 1

Write a 200 word essay on using Optimal Parameters-based Geographical Detectors (OPGD) model and "GD" R package to analyze the power of determinant of climatic drivers on bushfire or your own data. Please try to use figures and maps to explain your analysis. (refer IGARSS 2025 part 3.2)

Send to Email before 10 am next day:
Yongze.song@outlook.com

Document name: A1_YourName.docx

Any questions?