Urban Fire Dynamics and Location Optimization of Urban Fire Stations

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Wildfire

Residential Structure Fire

Terrorist Bombing

Vehicle

Hi-Challenge Warehouse

Outline

- Background
- Study Area and Data
- Research Objectives & Methods
- Results
- Summary & Future Research

Background (1)

- Urban transformation in China
  - changing landscape:
    - the built-up area of Chinese metropolis has expanded by almost 60% since 2000
    - high-rise buildings and shanty towns
  - changing population differentiation:
    - more than 50% of the population living in cities
    - “ant tribe” and rural migrant workers (0.27 billion in 2014)

China (2013): total fires – 388,821, deaths – 2,113, casualties: 1,637

Source: http://www.119.gov.cn/

2010: Shanghai high-rise building fire

2015: Henan nursing home fire

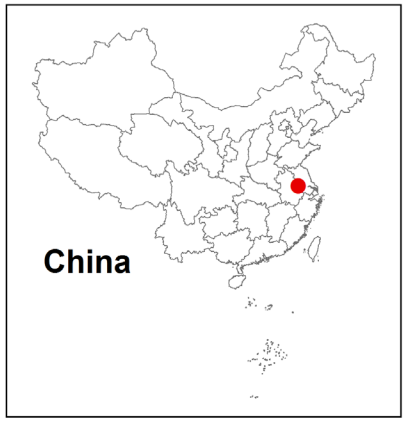
2015: Tianjin Explosion

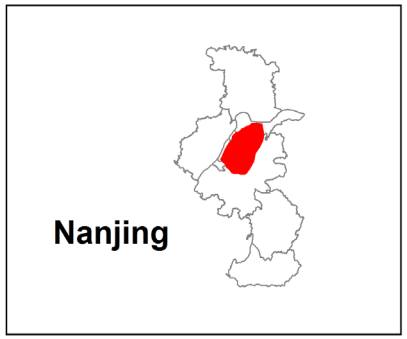
Source: http://www.chinadaily.com.cn/

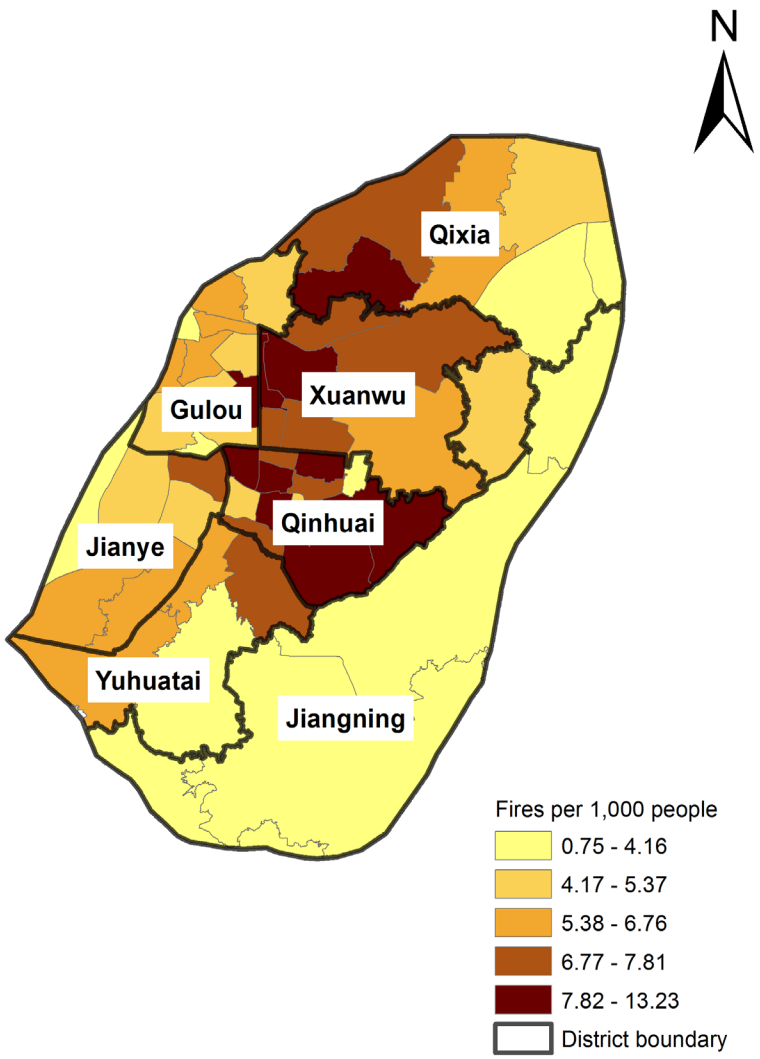
Background (2)

- The investment in fire infrastructure and management has failed to be commensurate with the needs of economic development
  - In 2013, the 262 Chinese prefecture-level cities overall lacked 22.5 % of fire stations and 15.2 % of fire hydrants required by the national fire safety regulations (FDMPS, 2014).

Study Area and Data



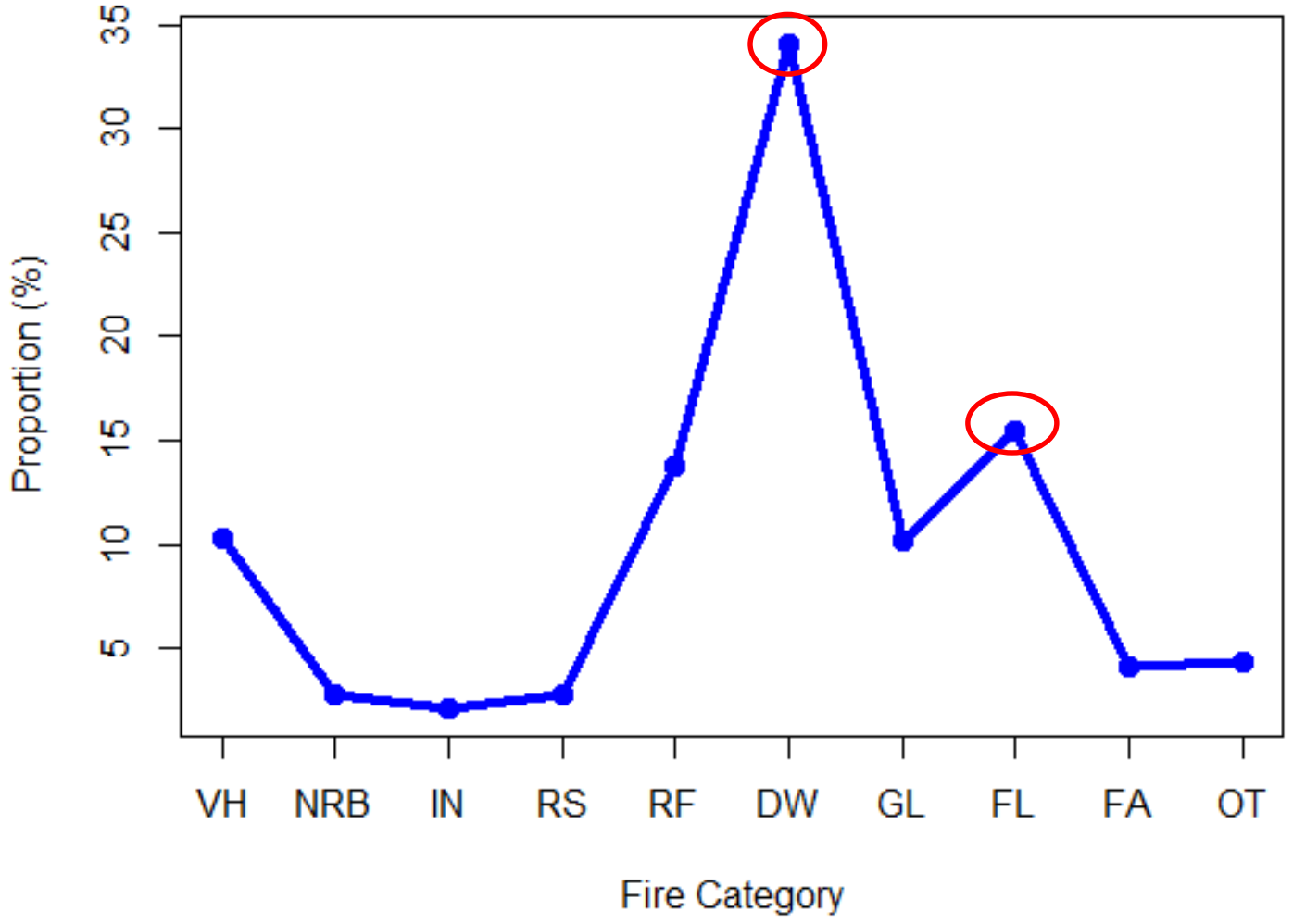




- Study Area
  - Central Nanjing, China
  - Total area: about **598.1** km^2 (about 9.1% of total area of Nanjing)
  - total population of **5.06** million (2010) (about 54.4% of total population of Nanjing)
- Data
  - 12-year (2002 – 2013) urban fire incidents for the seven districts in central Nanjing.
  - About **28,400** fires in total.

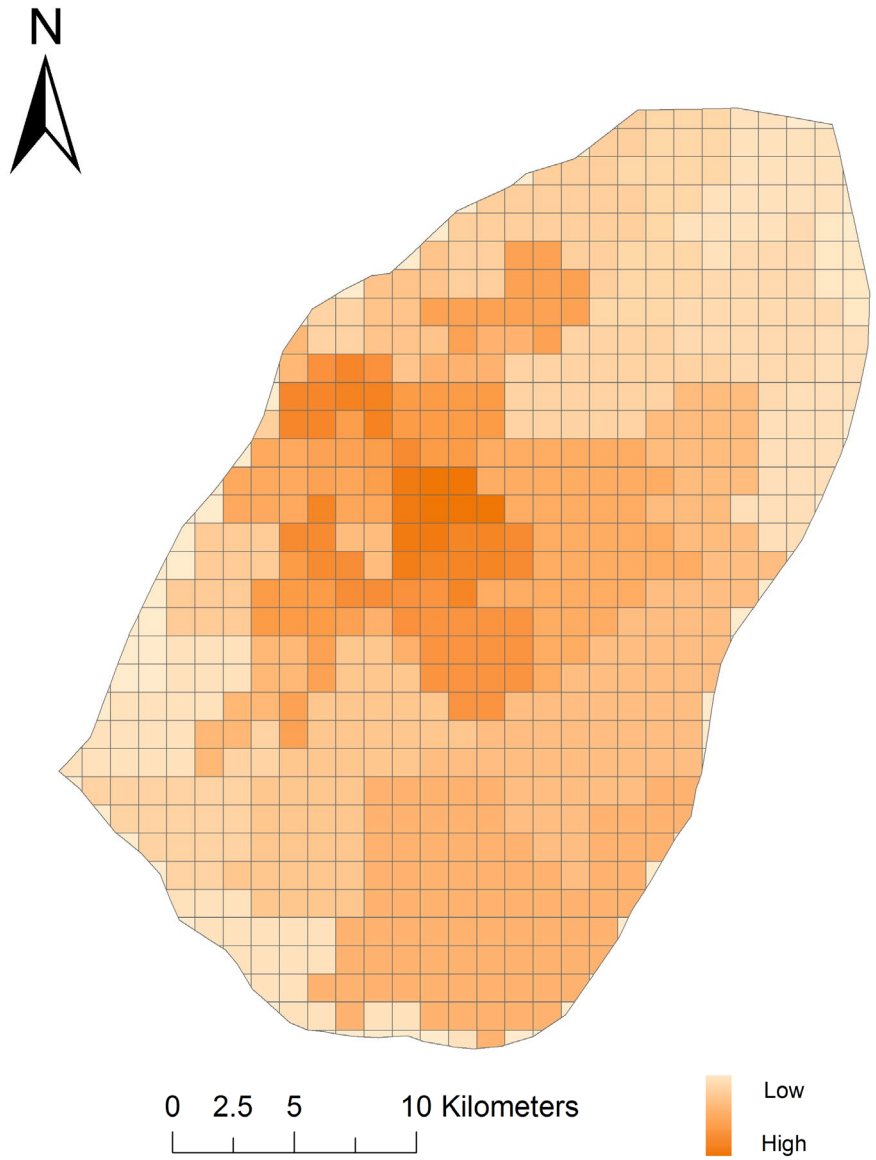
Fire Incidents by Type (2002 – 2013)

1. VH: vehicles
2. NRB: non-residential buildings
3. IN: industries
4. RS: retail stores
5. RF: refuse
6. DW: dwellings
7. GL: grassland
8. FL: facilities
9. FA: false alarm
10. OT: others



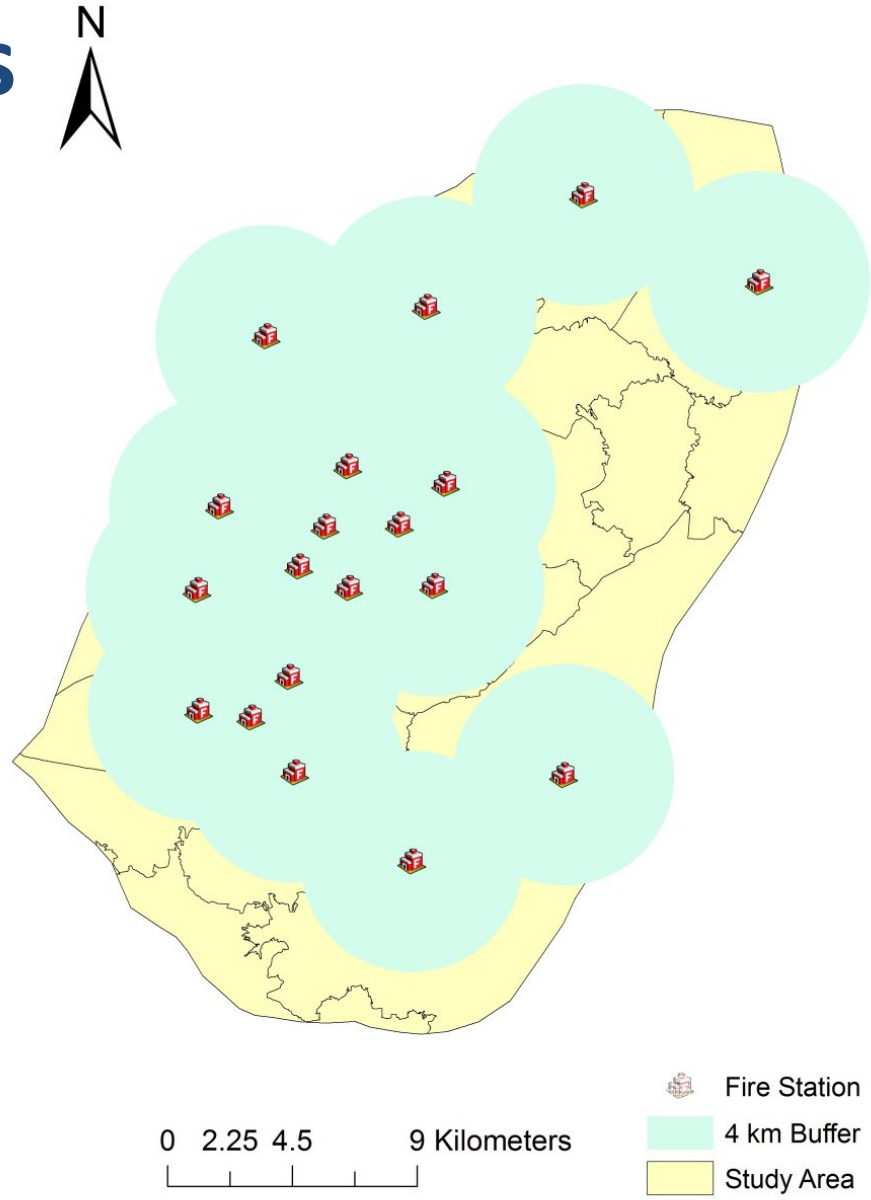
Spatial Representation

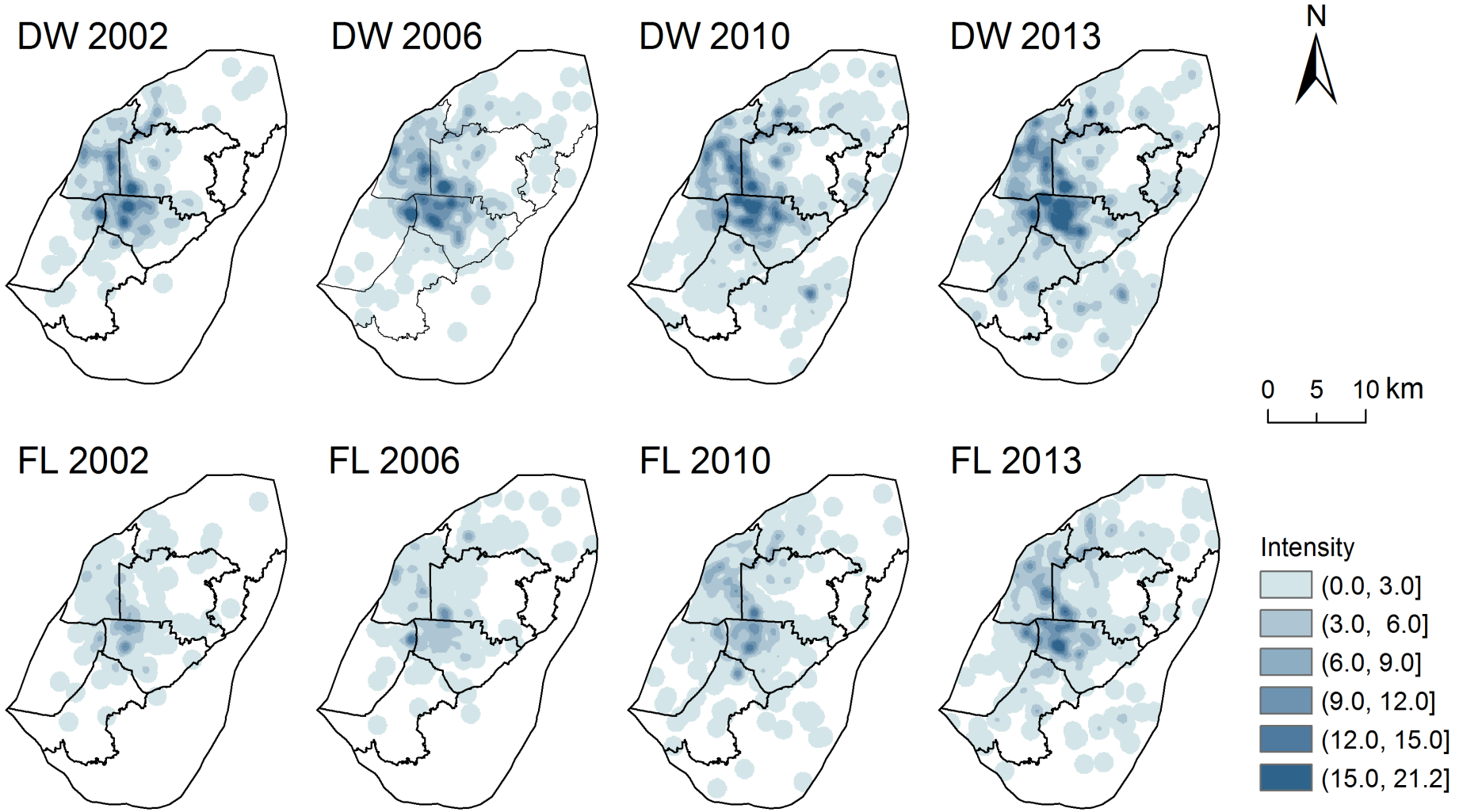
- Grid size: 1 *km* *1 *km*
- 658 cells in total



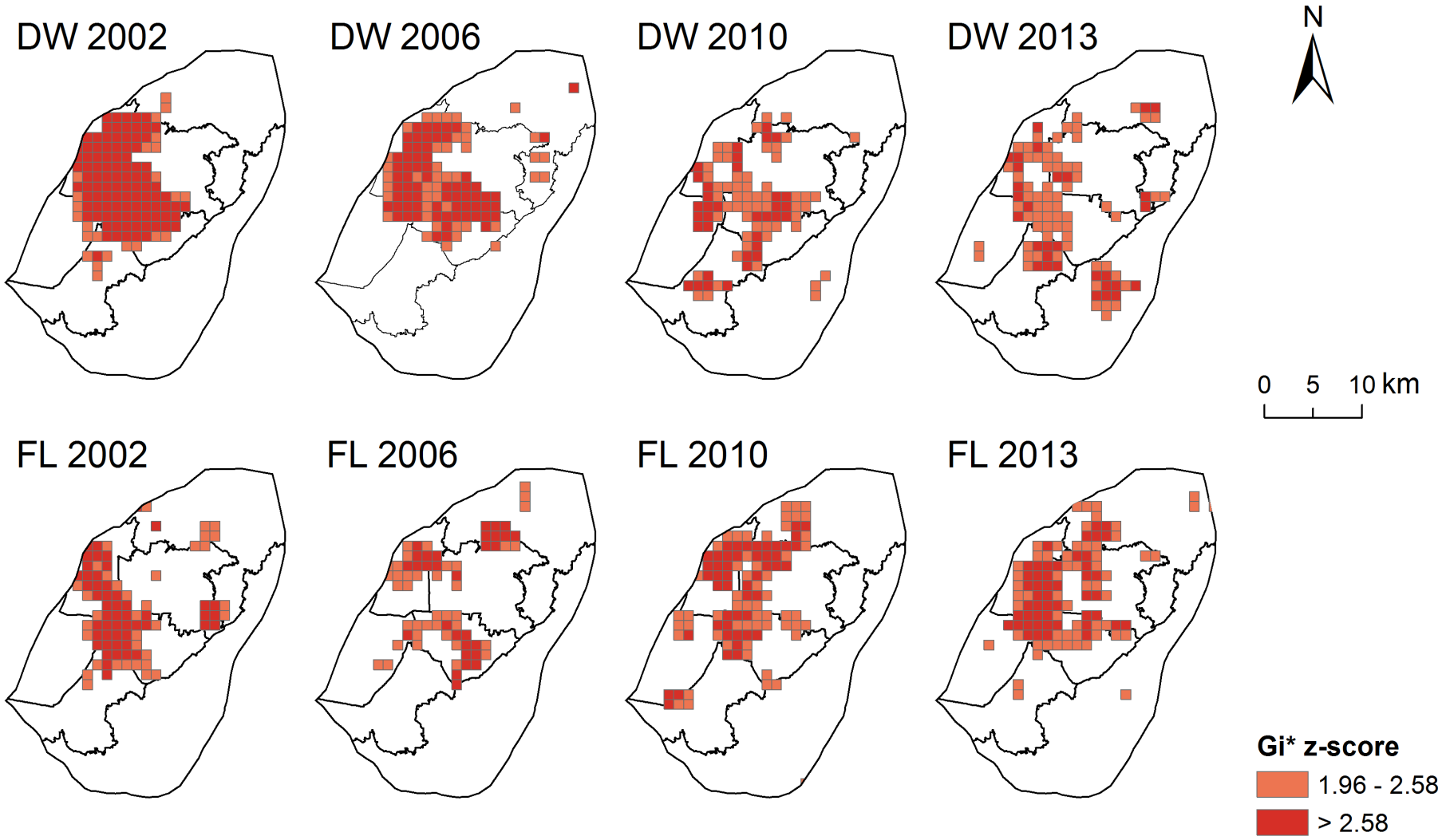
Research Objectives & Methods

- ESDA
  - Exploring urban fire dynamics
- Spatial optimization
  - Evaluating locational efficiency of existing fire stations
  - Locating new fire stations based on estimated fire risks to ensure service coverage and geographic access.

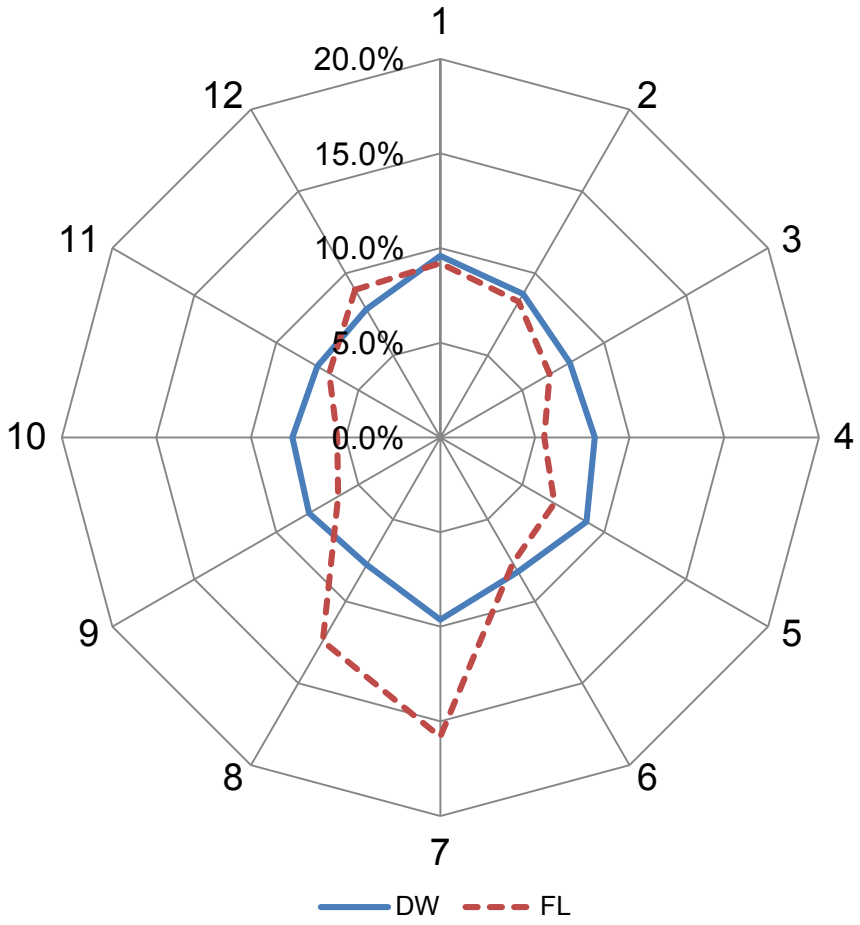




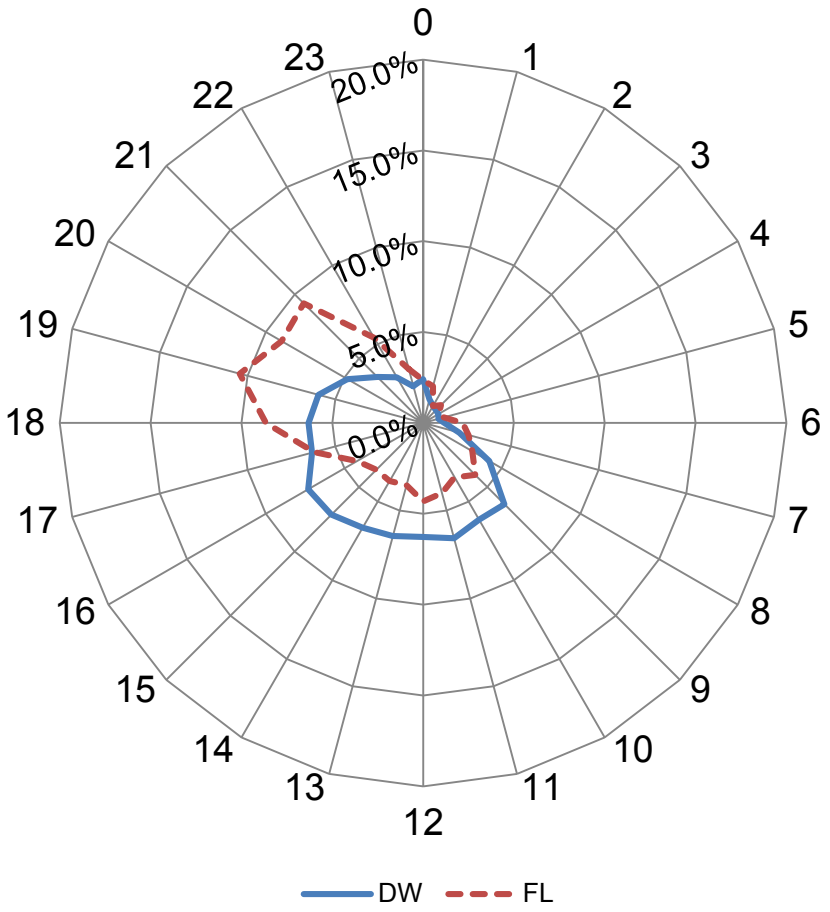
Kernel Density Estimation of DW and FL fires



Spatial clusters of relative DW and FL fire risks

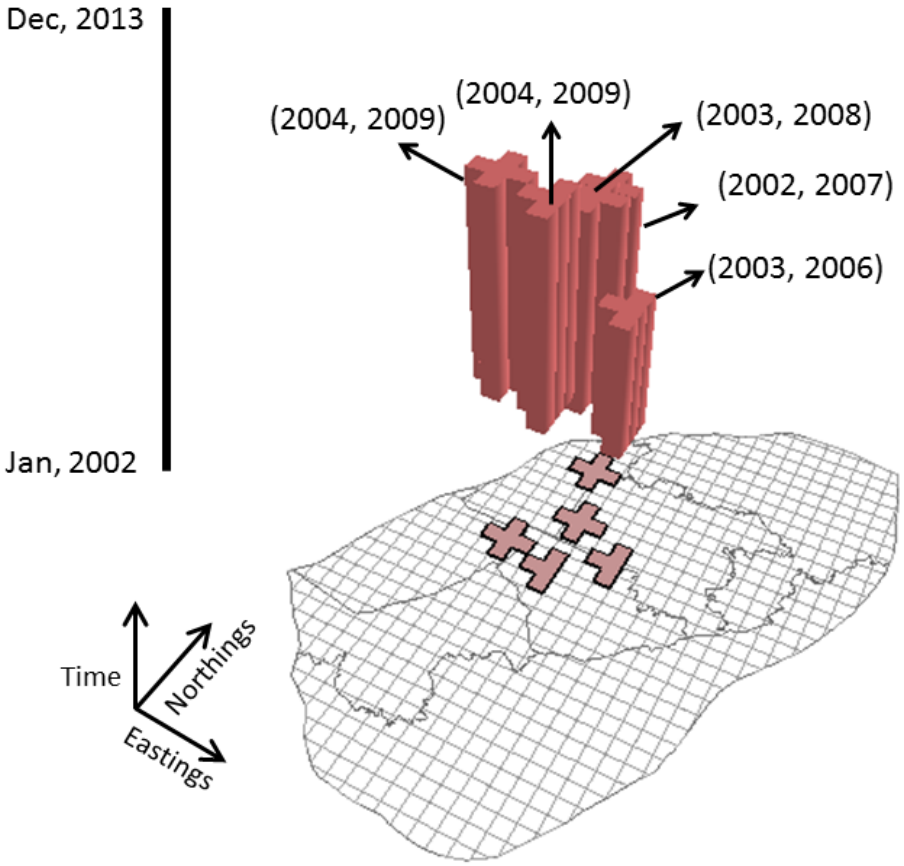


Monthly Variations

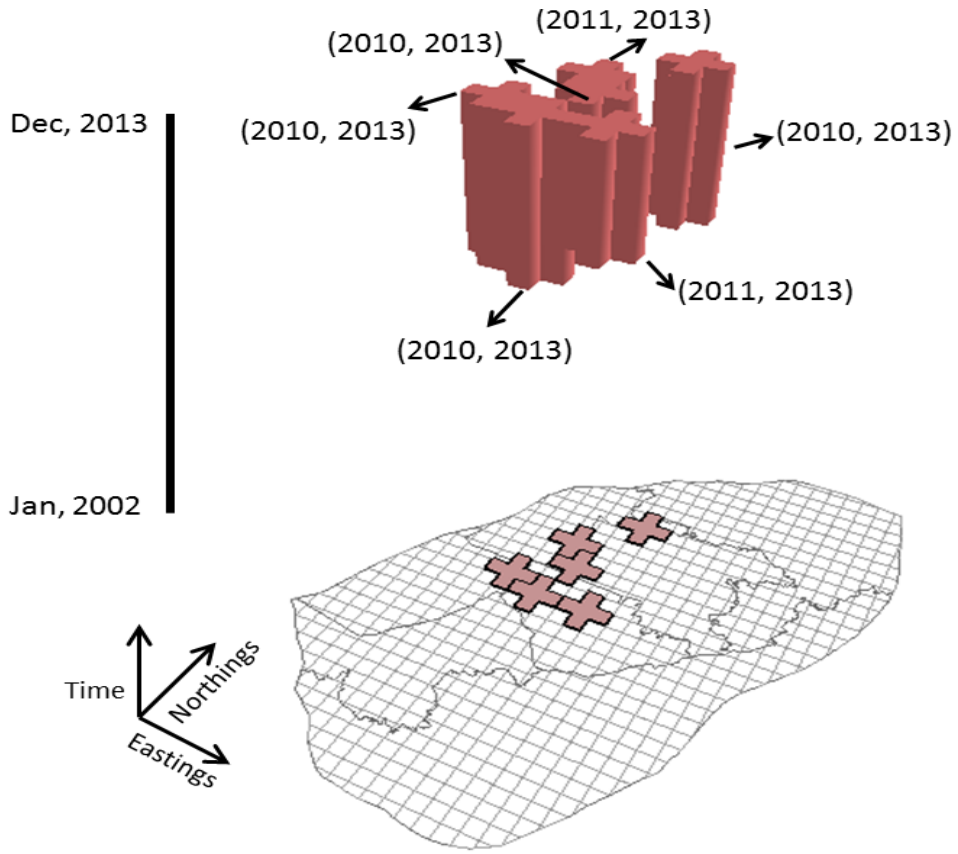


Daily Variations

Spatiotemporal Clusters of Fire Incidents



DW fires



FL fires

A Bi-objective Spatial Optimization Model

Parameters

I, J: set of demand areas and potential fire station locations, respectively;
i, j: index of demand areas and potential fire station locations, respectively;
w_i: estimated fire risk in demand area i;
d_{ij}: distance or travel time between i and j;
S: service standard;
Ω_i: set of fire stations capable of suitably serving demand i, $\{j | d_{ij} \leq S\}$;
Φ: set of existing fire stations;
q: number of existing fire stations that are to remain in service system

Decision Variable

$$Y_j = \begin{cases} 1 & \text{if a fire station is sited at } j \\ 0 & \text{otherwise} \end{cases}$$

X_{ij} = the fraction of demand at i that receives service from facility j

A Bi-objective Spatial Optimization Model

$$\textit{Minimize} \quad \sum_{j \in J} Y_j \tag{1}$$

$$\textit{Minimize} \quad \sum_{i \in I} \sum_{j \in \Omega_i} w_i d_{ij} X_{ij} \tag{2}$$

$$\textit{Subject to} \quad \sum_{j \in \Omega_i} X_{ij} = 1 \quad \forall i \in I \tag{3}$$

$$X_{ij} \leq Y_j \quad \forall i, j \in \Omega_i \tag{4}$$

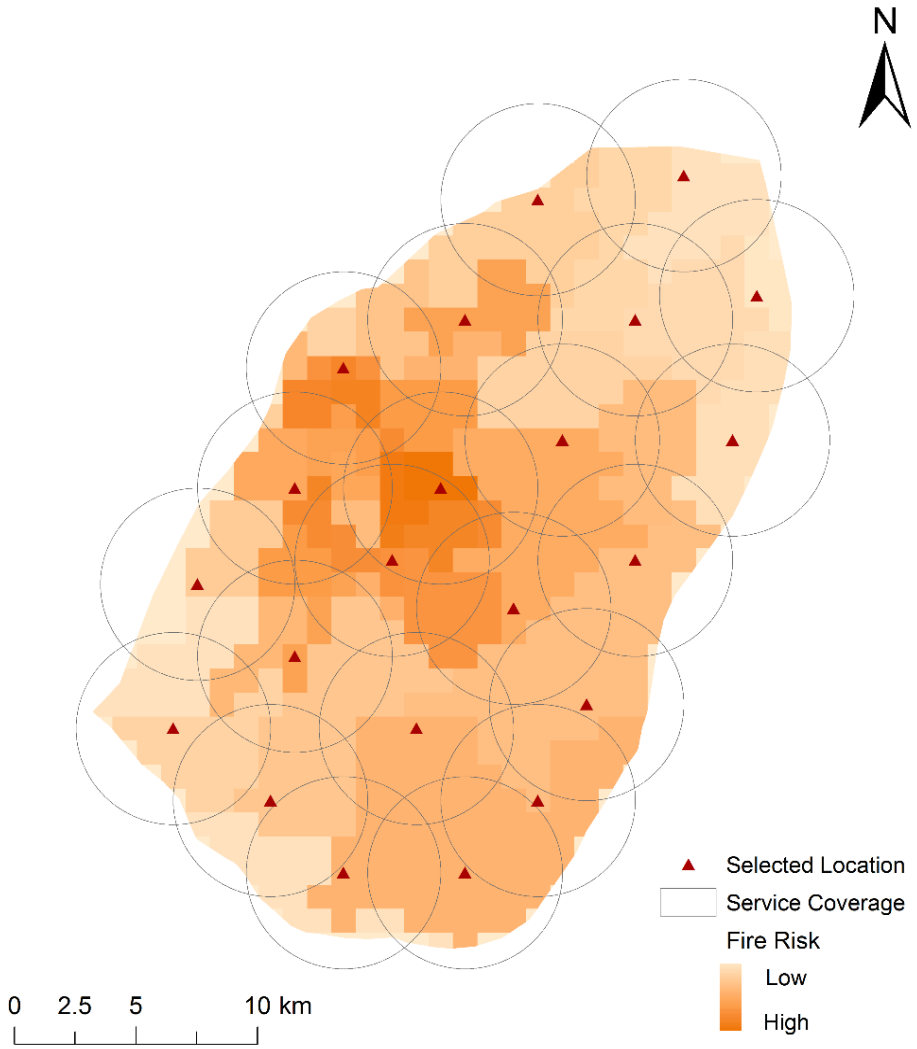
$$\sum_{j \in \Phi} Y_j = q \tag{5}$$

$$Y_j = \{0, 1\} \ \forall j \in J \tag{6}$$

$$X_{ij} \geq 0 \ \forall i, j \in \Omega_i \tag{7}$$

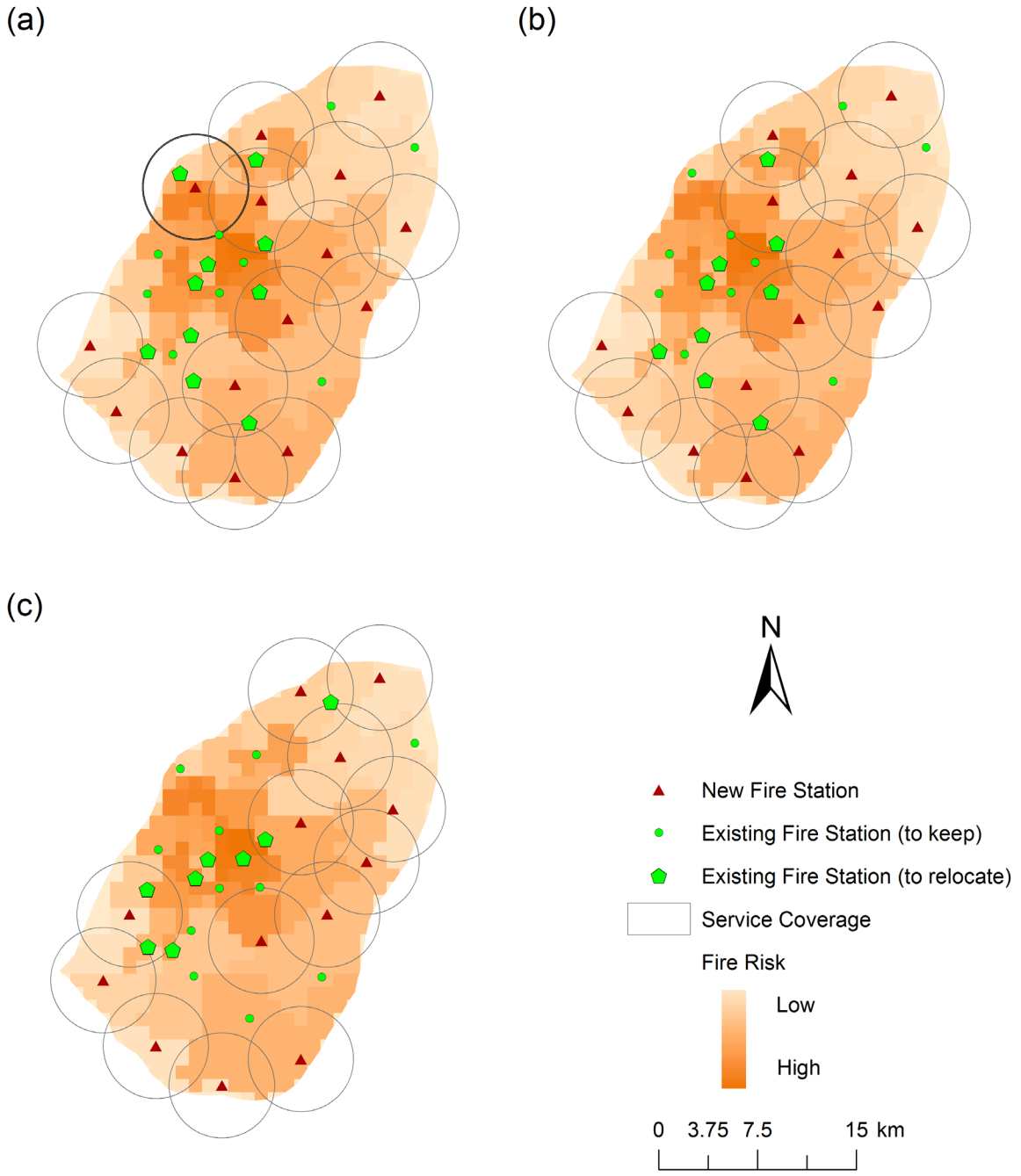
Optimal Locations of Fire Stations
(Scenario I: assuming no existing fire stations)

Obj (1) = 22

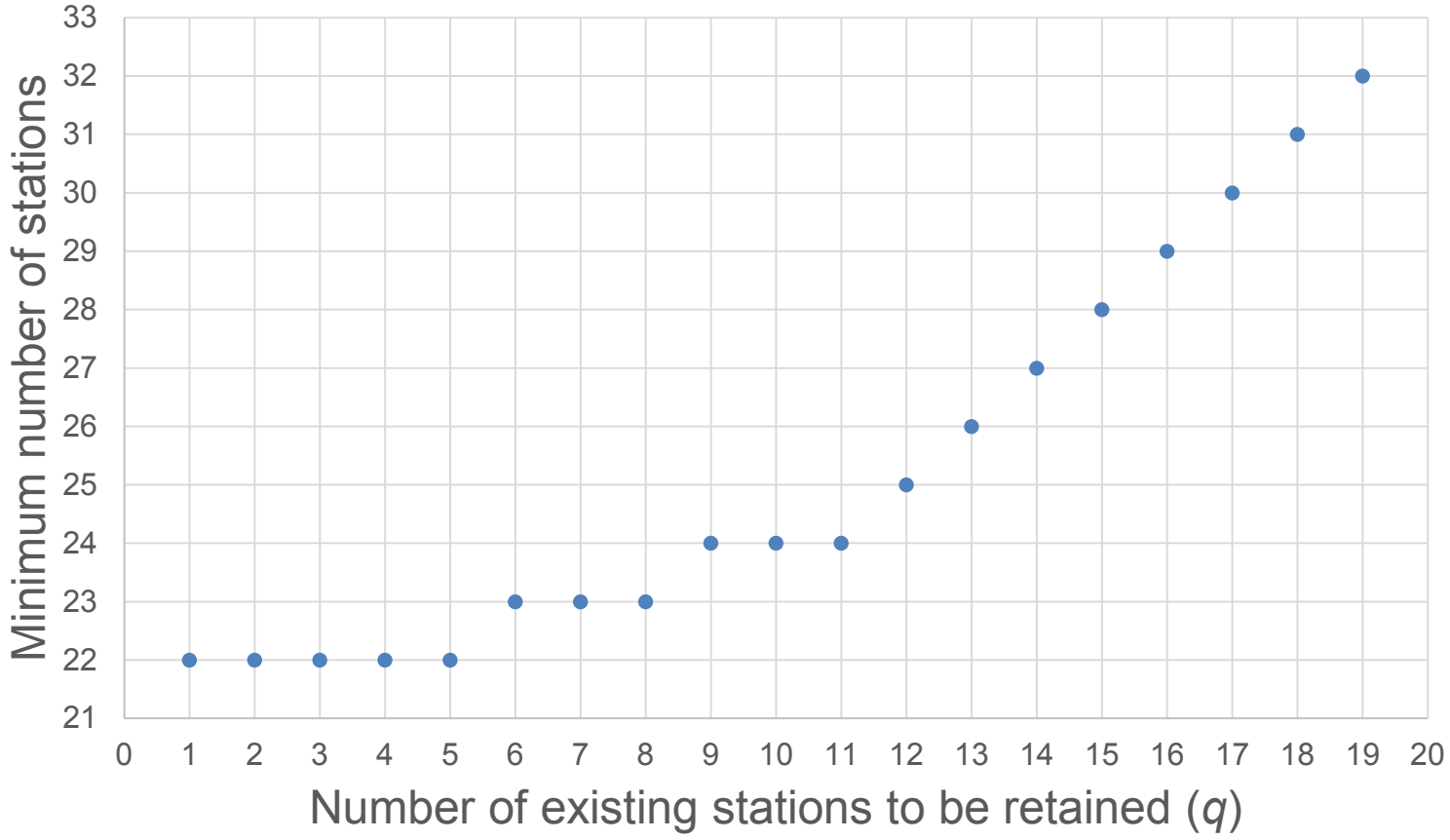


Selected fire station locations for scenario II (Obj (1) $= 24$):

- **(a)** $q = 9$;
- **(b)** $q = 10$;
- **(c)** $q = 11$



Scenario II
The minimum number of stations for all possible *q* values



Summary

- Most fires are in Gulou, Xuanwu and Qinhuai districts, where major business, government departments, schools and health services are located.
- About one third fires are related to dwellings for every month and every hour during one day.
- Spatial optimization approaches allow to explore different planning scenarios and achieve a trade-off among different objectives in fire station location selection.
- GIS-based spatial analysis can be effective tool to assist the decision-making in urban fire safety management and planning.

Future Research

Real-time Analyses and Communication

- Integrate with other information
- Fire expansion simulation
- Emergency Evacuation Plan

Support Decision-making

- Firefighting resource & fire service deployment
- Multi-objective decision making

Smart Fire Fighting

innovative ways to utilize the vast amount of data to help work tasks in a highly effective and efficient manner.

Fire Service

The End
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Thank You!

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