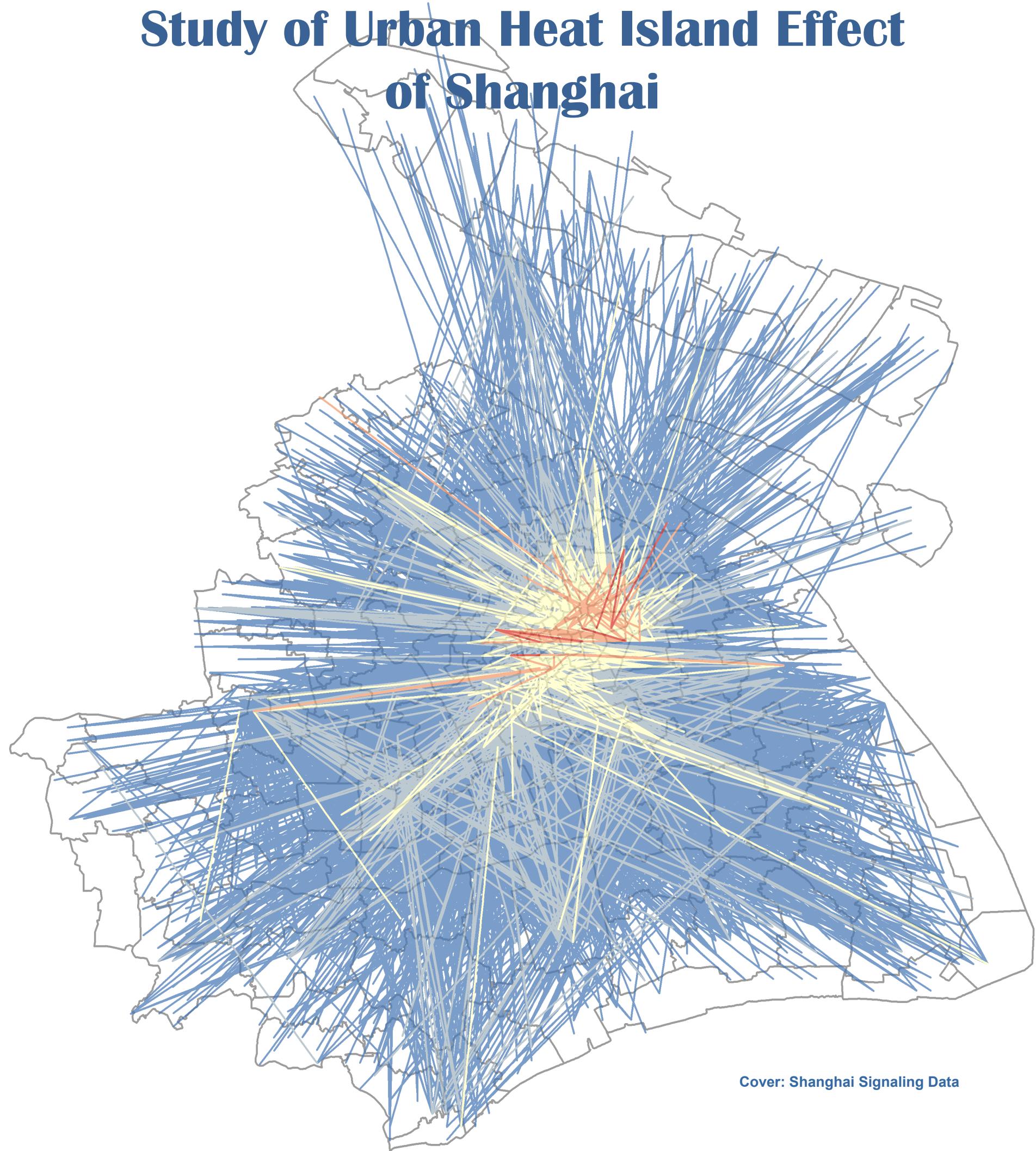


Study of Urban Heat Island Effect of Shanghai



Cover: Shanghai Signaling Data

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1. How Urban Spatial Forms affect Heat Island Effect

—Shanghai, China

Abstract

How to alleviate Heat Island Effect of urban areas interests many researchers but still leaves a lot of questions to be answered. For instance, the selection of typical space forms that affect Heat Island Effect is blurred and suspicious. The absence of spatial non-spationarity and what can urban planning do with according to researches. This analysis uses a data driven approach to identify which indexes have significant effect on urban ground surface temperature. A combination of variables based on functional development, ground cover, development intensity were considered. Regression models and residual analysis are used to select significant indexes. Suggestions are given according to results.

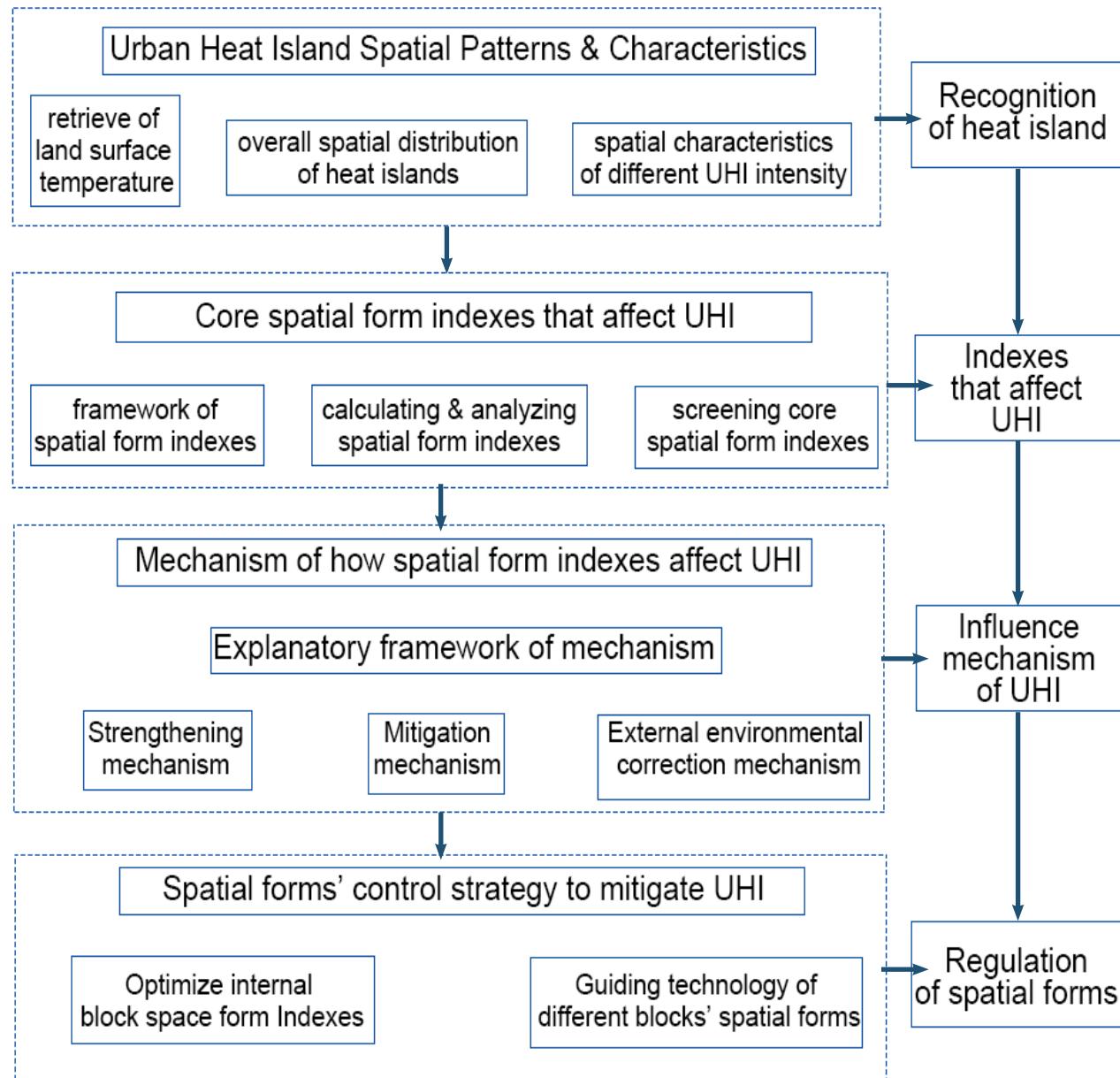
1. Introduction

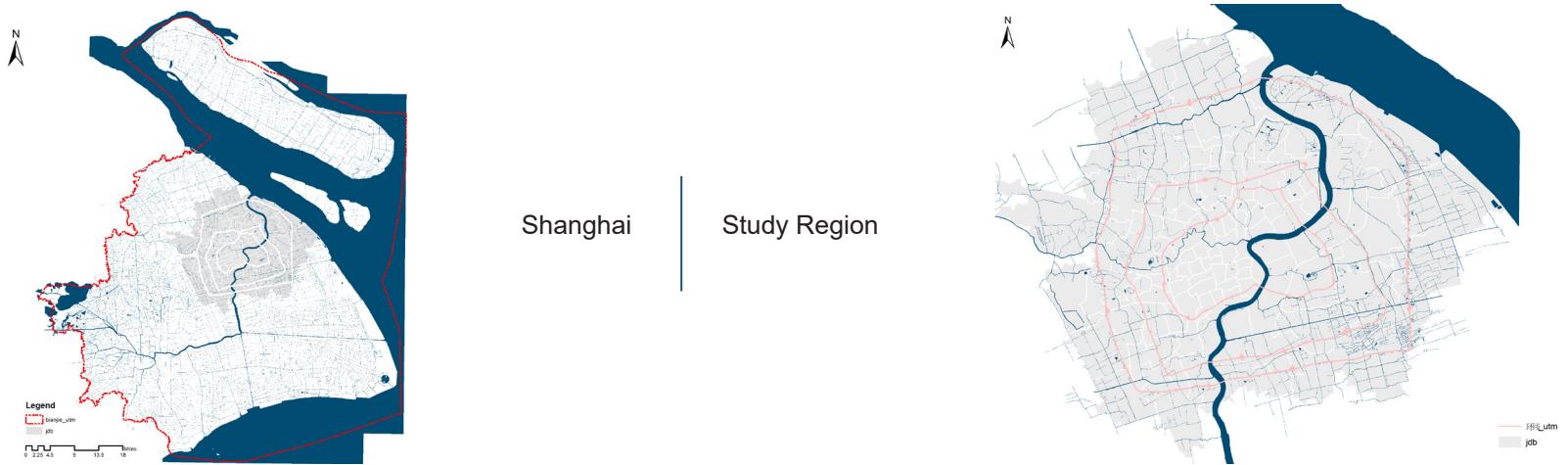
1.1: Data & Study Area

Choosing urban area inside the outer circle line of Shanghai due to concentrate construction and plenty spatial forms. Study area is about .

There are two main types of datas: 1) Satellite imaginaries of Shanghai of 2017&2018 from USGS to retrieve land surface temperature. 2) Urban spatial datas that have potential effects on Heat Island Effect. Detailed datas will be stated in later part.

1.2: Methods





2. Analysis

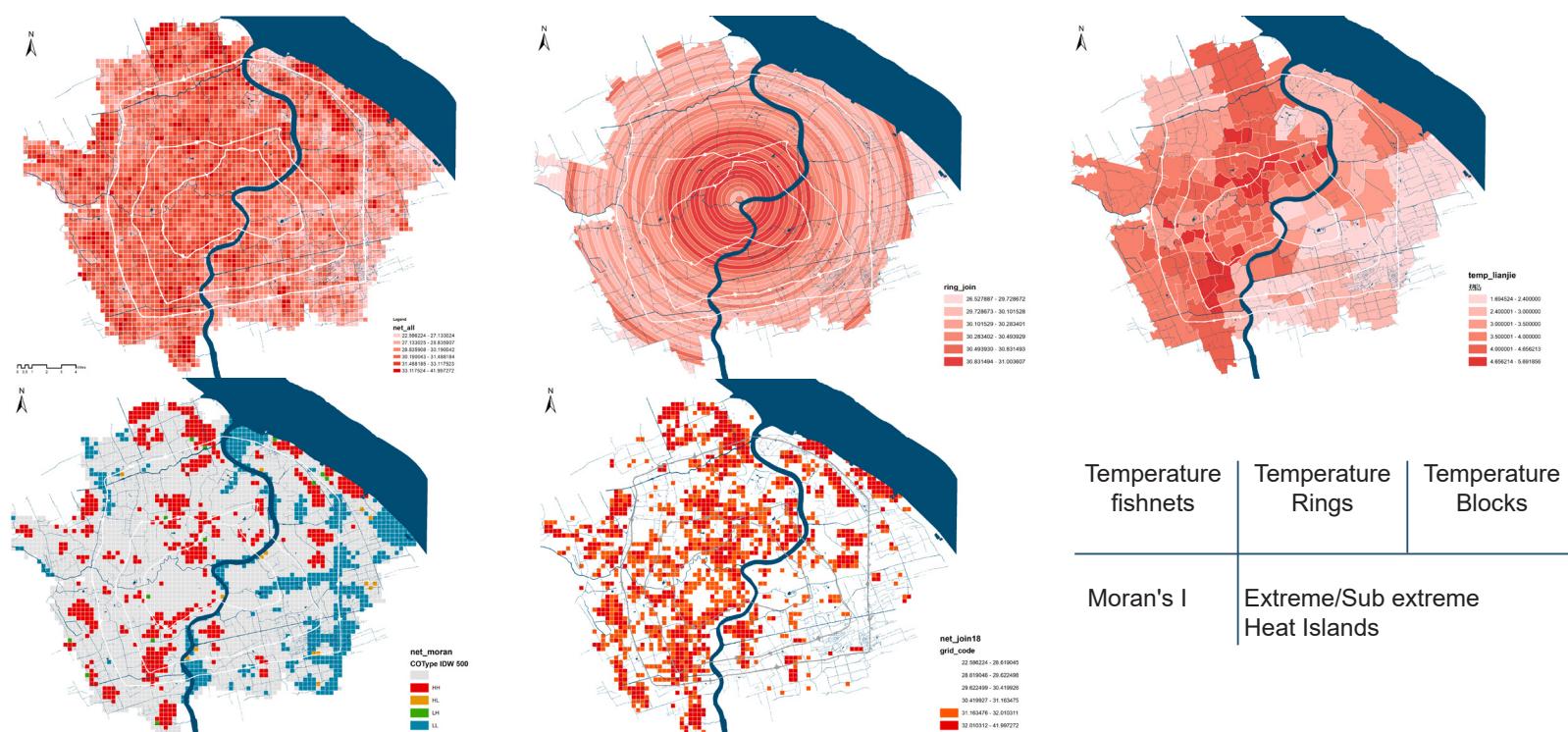
Before creating models to screen core indexes, I want to find out distributions of heat islands in Shanghai first. Then I select several indexes that may affect UHI and divide them into 3 categories: functional development, land surface coverage and construction intensity.

2.1 Overall Spatial distribution of heat island

To calculate the intensity of heat island in Shanghai, the average farmland temperature in suburbs is counted as reference value, and then divided into six categories. The distribution characteristics of the whole heat island are studied from three different perspectives of Shanghai blocks, multi-rings with 500 m interval and 500 m*500 m fishnet. At the same time, in order to extract typical and stable hot/cold island area of Shanghai, the temperature in 2017/18 is compared and falls on fishnets.

The study find that heat island area in Shanghai has a patchy distribution, mainly for large ports, industrial zones, transportation hubs, large residential communities, etc. At the same time, the intensity of heat islands gradually weakens from the city center and strong areas are concentrated in the Middle Circle; In terms of Pudong's overall heat island intensity is less than Puxi, and is concentrated in the Inner Circle and the Middle Circle; Overall heat island area is concentrated in Puxi and Pudong's Port and Industrial zones.

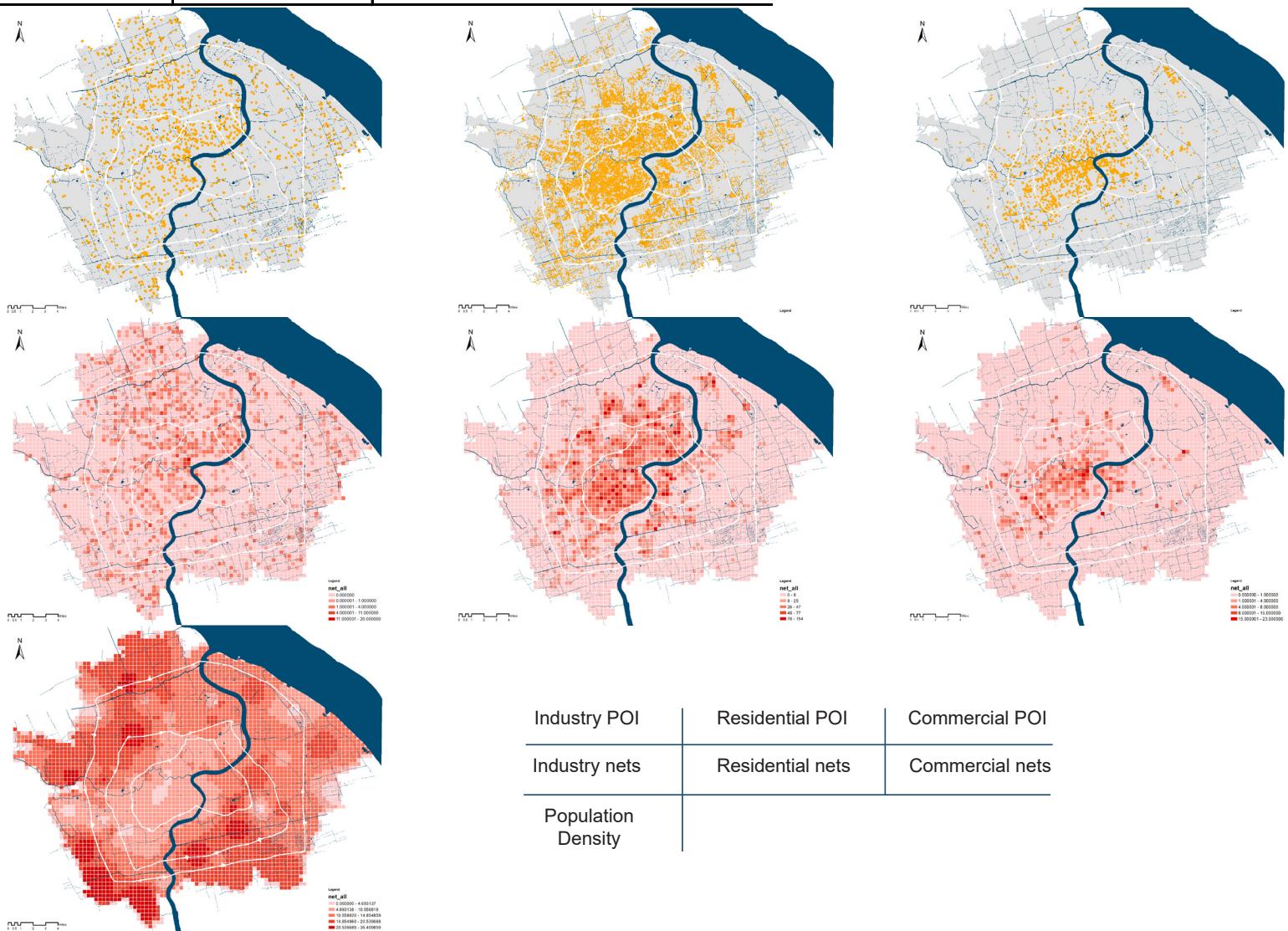
Calculating Moran's I is 0.66



2.2 Analysis of Functional Development Variables

Combined with literature and available data, functional development indicators are broken down into four categories: industrial, commercial, residential POI and resident population density. Due to the large difference between administrative divisions of Pudong and Puxi, which Pudong's administrative area is generally larger and may not accurately reflect the differences of its indicators. Therefore, the research area is divided into 4340 500m*500m fishing nets, and the above indicators in each fishing net are calculated separately.

| | Name of Indexes | Data Sources |
|------------------------|---------------------|--|
| Functional Development | Industrial POI | From Baidu Map API |
| | Commercial POI | From Baidu Map API |
| | Residential POI | From Baidu Map API |
| | Population Density | From Sixth National Population Census |
| Surface Coverage | PCT of Earthing | Supervised Classification of Satellite Images |
| | PCT of Plant | Supervised Classification of Satellite Images |
| | PCT of Construction | Supervised Classification of Satellite Images |
| | NDVI | Retrieve from Satellite Images |
| | Road Density | From Baidu Map API |
| Construction Intensity | PCT of Water | From Baidu Map API |
| | Building Density | From Baidu Map API |
| FAR | | Calculate from Building Density Data with info of Floors |

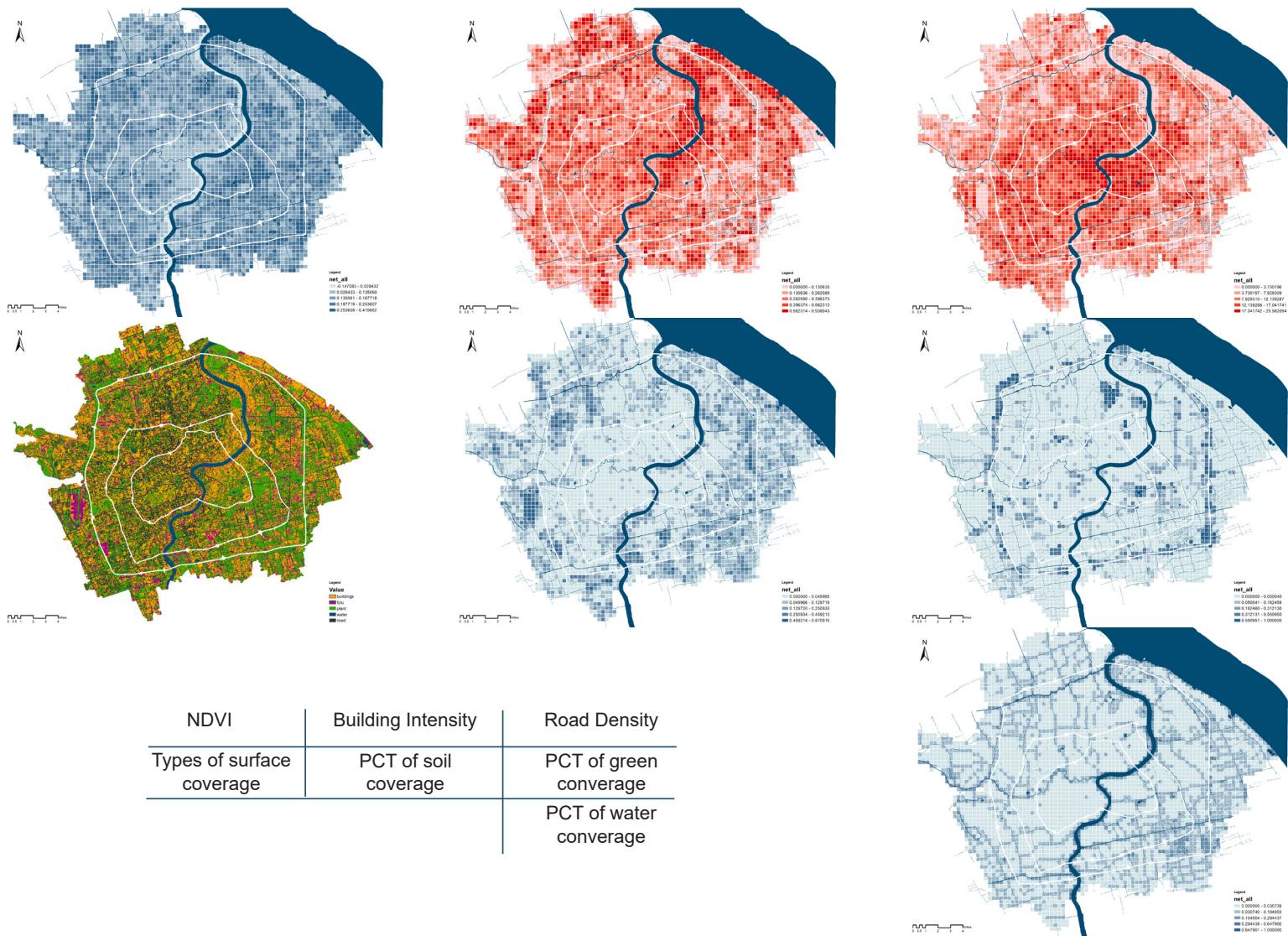


| Industry POI | Residential POI | Commercial POI |
|--------------------|------------------|-----------------|
| Industry nets | Residential nets | Commercial nets |
| Population Density | | |

2.3 Analysis of Surface Coverage Variables

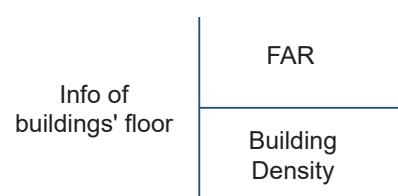
Such indexes include: proportion of vegetation coverage, NDVI, proportion of building coverage, road density, proportion of coverage of cover soil, and proportion of water cover. Among them, buildings, covering soil, vegetation and water bodies are obtained through supervised classification of satellite images of 2018 of Shanghai.

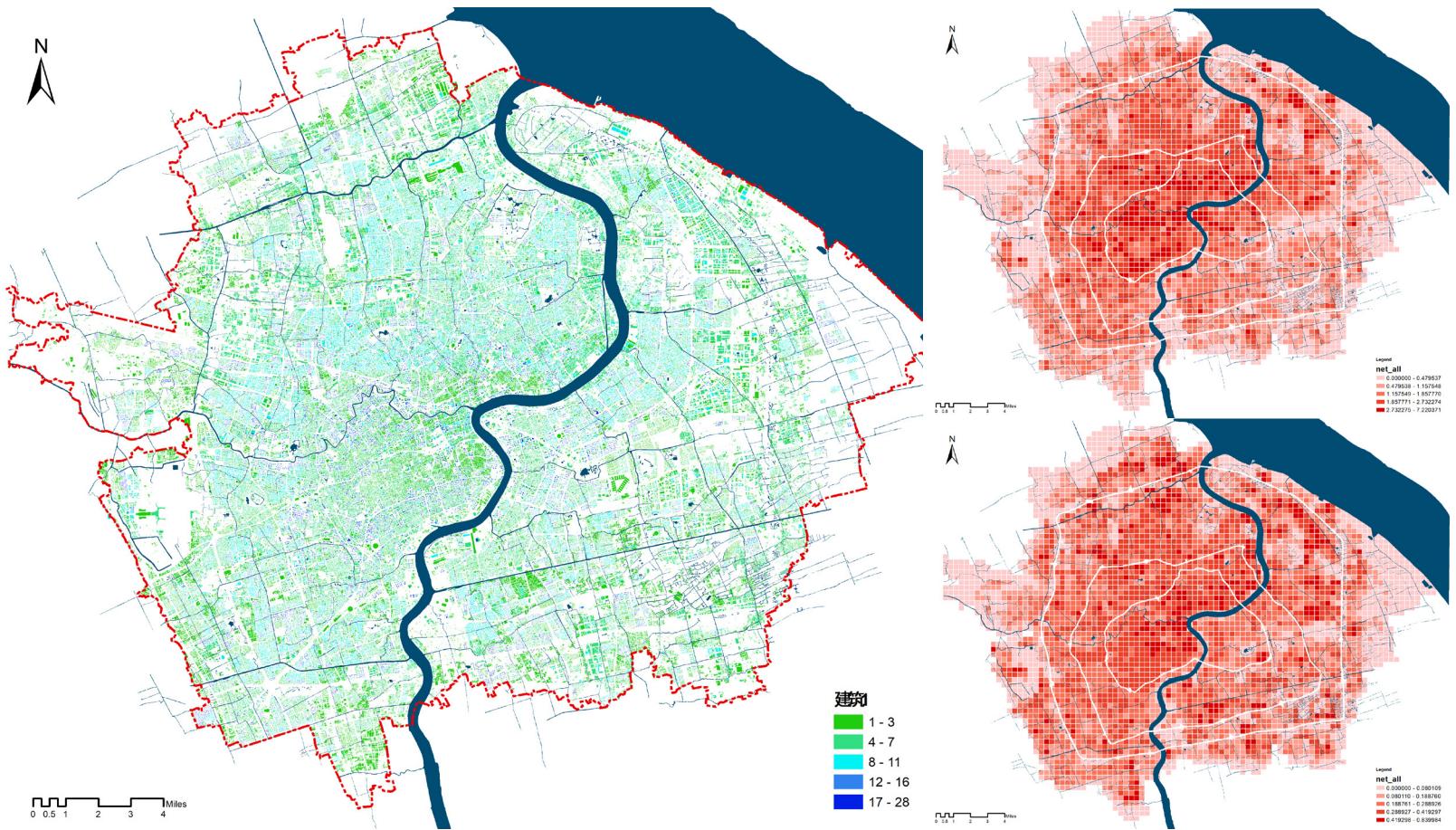
In figures below,natural variables(cover soil,NDVI,vegetation) tend to locate around the Outer Circle Line,while artificial variables like road density,PCT of building coverage have distinct difference inside and outside of the Inner Circle Line.



2.4 Analysis of Construction Intensity Variables

Now considerng influences of construction variables,I calculated FAR(floor area ratio) and building density of each fishnets from the building data that I collected from Baidu Map API which contains information of how many floors every building has.(As the larger one figure on the left below shows)



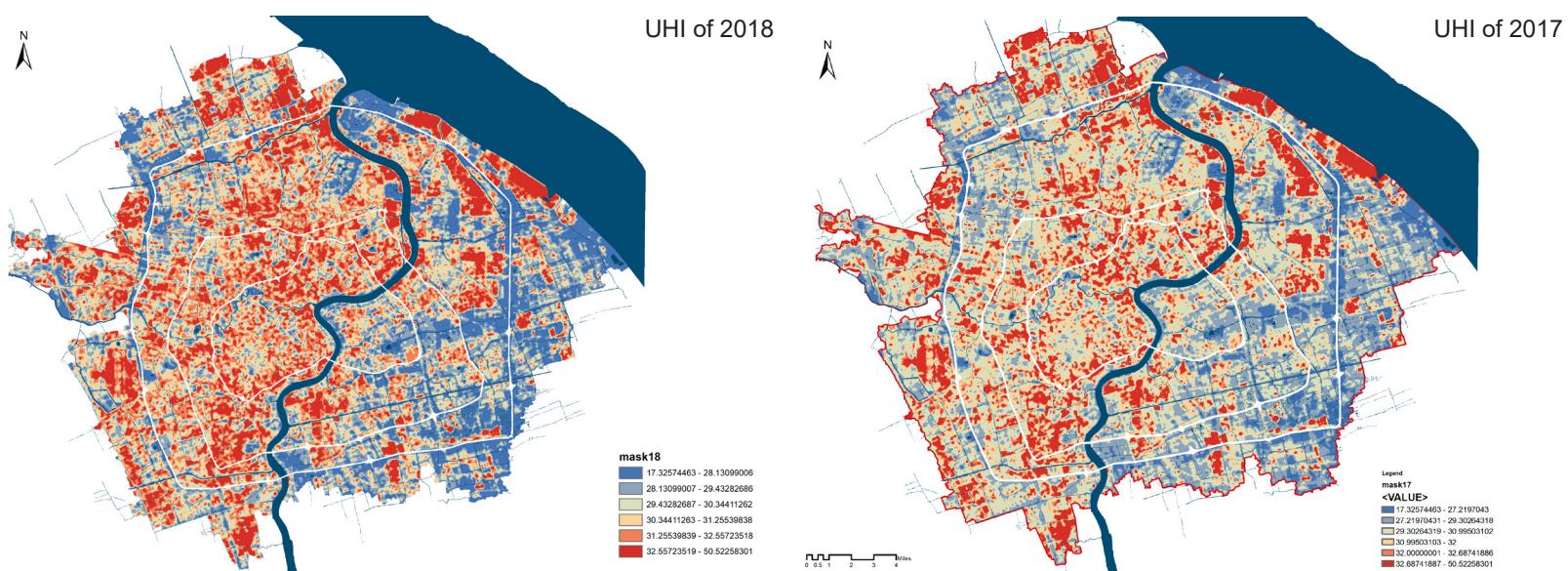


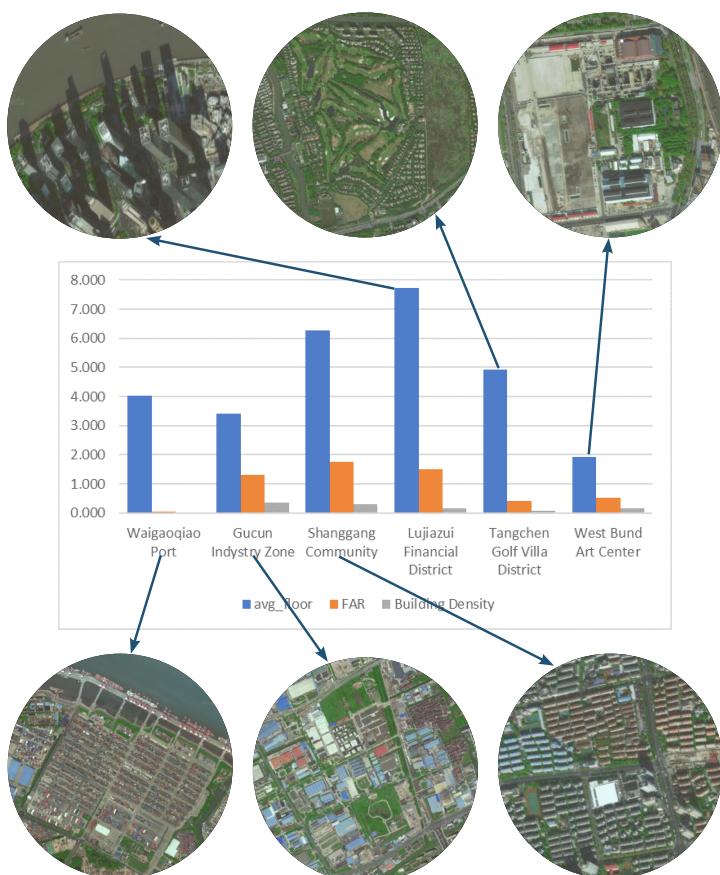
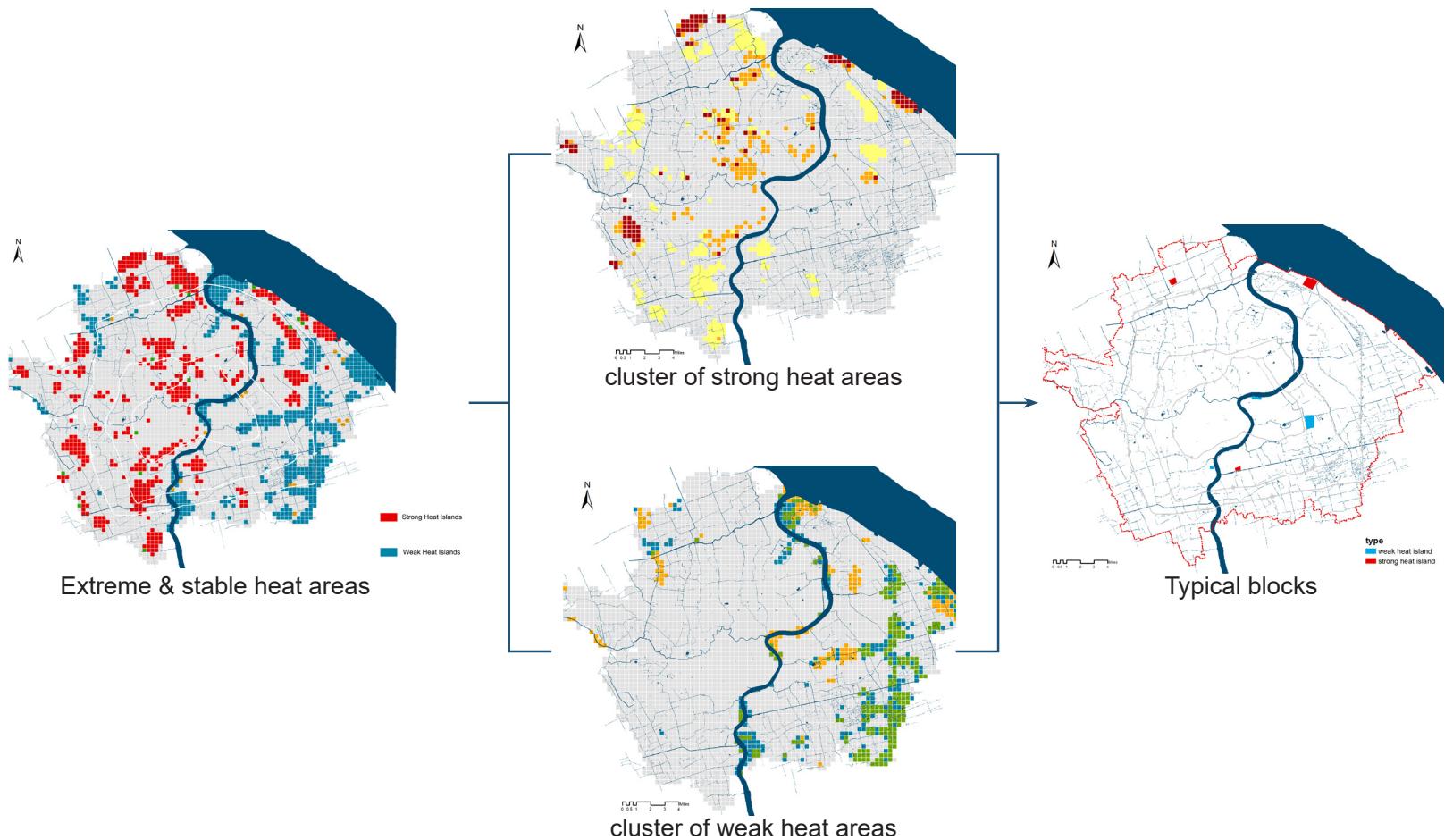
2.5 Characteristics of Typical & Stable Heat Islands

First, overlaying Landsat8 raster files of retrieve of surface temperature on 2017/5/23 and 2018/8/31, calculating heat island intensity of each fishnets to get extreme and stable temperature nets , that is, the extremely strong heat island areas and weak heat island areas.

Then, using SPSS to cluster and analyze the three categories (12 sub-categories) of two types of heat islands, and obtaining three types of stable extremely strong heat islands and three types of weak heat islands .

Based on map, typical 6 types of blocks in different heat island areas are selected as research cases.





| | | Name |
|----------------------|---------------------------|---------------------------|
| Extreme Heat Islands | low density,logistics | Waigaoqiao Port |
| | low density, industry | Gucun Industry Zone |
| | high density, residential | Shanggang Community |
| Stable Weak Islands | high density,financial | Lujiazui Finance District |
| | low density, residential | Tangchen Golf Villas |
| | low density,exhibition | West Bund Art Center |

| | Extreme & Stable Heat Island | Stable Weak Heat Island |
|------------------------|---|--|
| Functional Development | Concentrated industries, commercial districts or high-density communities | High-end residential area, sparse function, riverside financial district |
| Surface Coverage | Mainly impervious surface, lacking ecological elements | Impervious surface is mixed with green space and has plenty of ecological elements |
| Building Intensity | Dense,concentrated | high-rise tower blocks/slab buildings, point distribution |

3. Screening Variables

Performing correlation analysis on above mentioned 12 categories of each nets in SPSS, (result shows in the table below) and screening variables with significant correlations to heat island intensity.

The indexes screening follows the following principles: at least one index of each category's spatial form is selected; avoiding the collinear index; does not violate the spatial morphological characteristics of typical heat island area; core spacial form should change regularly with change of heat island intensity.

| Type of Indexes | Name of Indexes | Spearman's Correlation Coefficient |
|------------------------|---------------------|------------------------------------|
| Functional Development | Industrial POI | 0.124** |
| | Commercial POI | 0.224** |
| | Residential POI | 0.340** |
| | Population Density | -0.025 |
| Surface Coverage | PCT of Earthing | -0.120** |
| | PCT of Plant | -0.062** |
| | PCT of Construction | 0.560** |
| | NDVI | -0.262** |
| | Road Density | 0.294** |
| | PCT of Water | -0.432** |
| Construction Intensity | Building Density | 0.593** |
| | FAR | 0.514** |

Screening

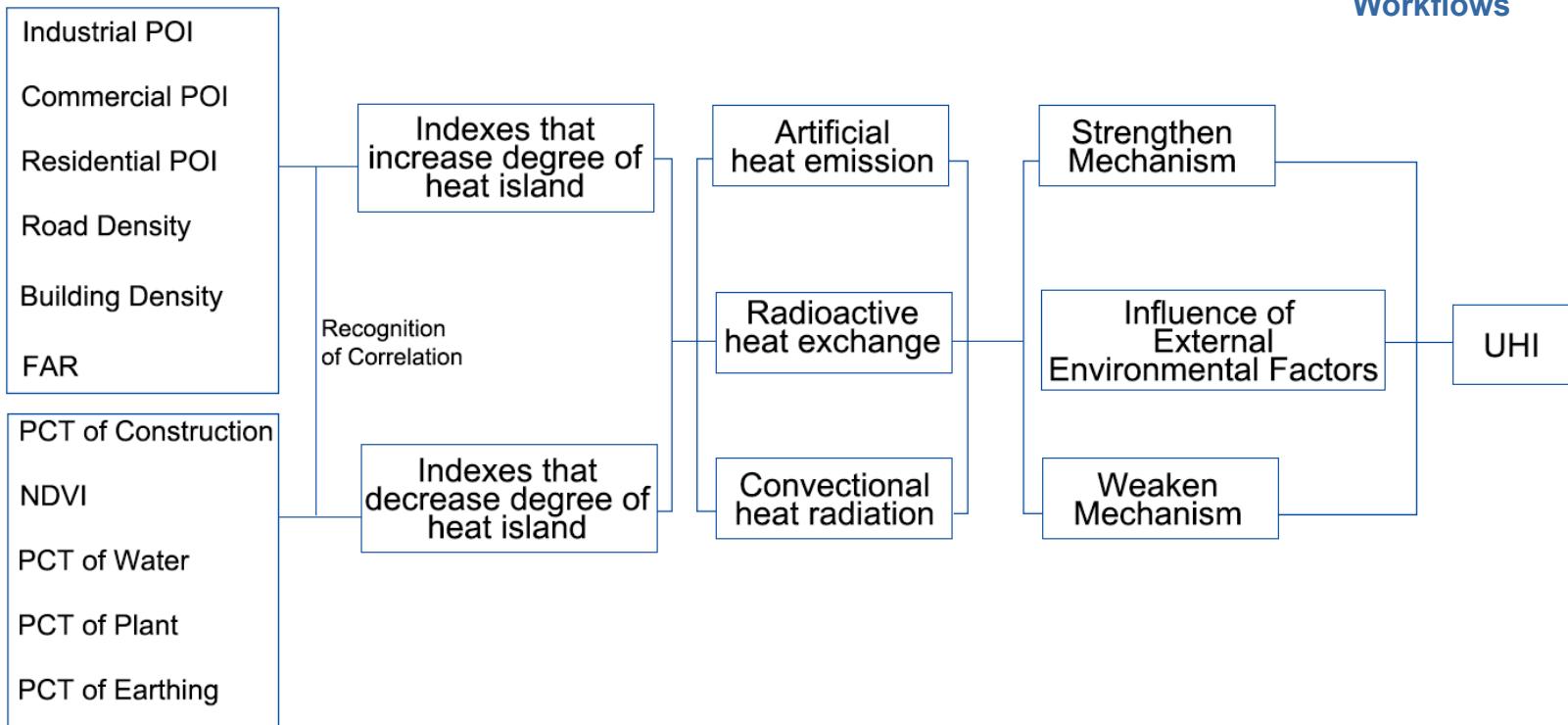
Which indexes have significant influence on UHI?

1. Industrial POI
2. Commercial POI
3. Residential POI
4. PCT of Earthing
5. PCT of Plant
6. PCT of Construction
7. NDVI
8. Road Density
9. PCT of Water
10. Building Density
11. FAR

Core Indexes
That
Affect UHI

4. Mechanism of UHI

The formation of UHI is explained on three aspects: strengthening mechanism, weakening mechanism and external environmental factor correction mechanism. On the basis of strengthening and weakening, the residual distribution of regression models are found to have regularity of residual distribution, so the factors outside spatial forms are need to be considered. Places where have larger residuals tend to be industrial zones, ports, large green spaces, transportation hubs, etc. and they are included in later UHI analysis.

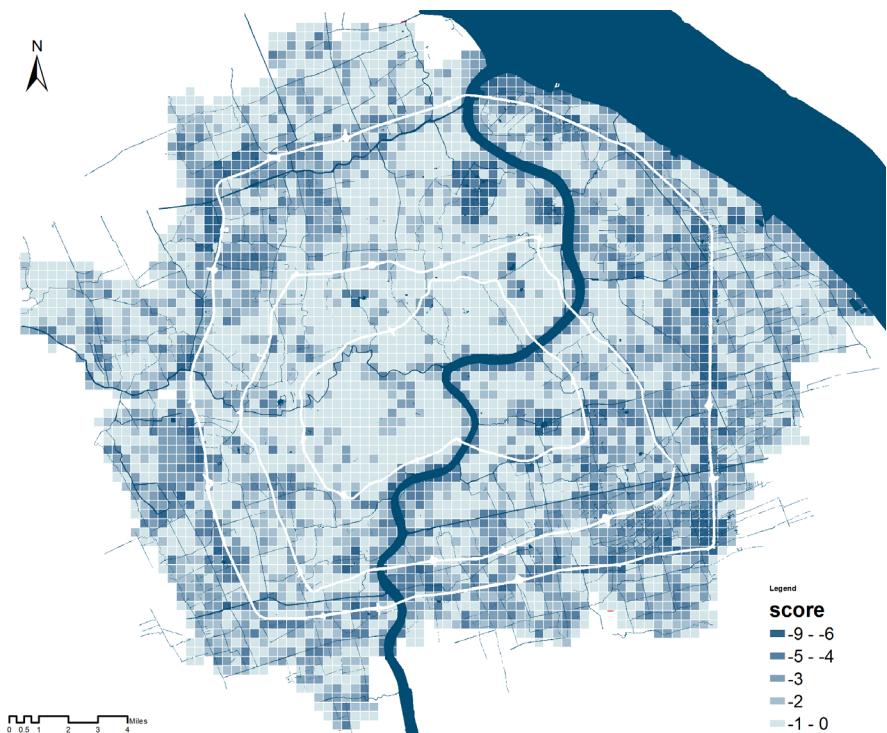


4.1 Weakening Mechanism of Spatial Forms

Spatial patterns: low-score areas are regularly distributed around the Outer Circle Line, and high-score areas are concentrated in the Inner Circle Line of both Puxi and Pudong.

Important areas: Areas with the lowest scores are concentrated around the Ouyer Circle Line and along the Huangpu River.

| Evaluation of weakening mechanism | | |
|-----------------------------------|-----------|------------|
| Spatial Form Indexes | Intervals | Evaluation |
| PCT of Earthing | >25% | -3 |
| | 10%-25% | -2 |
| | 0%-10% | -1 |
| | 0 | 0 |
| PCT of Plant | >50% | -4 |
| | 25%-50% | -3 |
| | 10%-25% | -2 |
| | 0%-10% | -1 |
| | 0 | 0 |
| NDVI | >0.6 | -4 |
| | (0.5,0.6] | -3 |
| | (0.4,0.5] | -2 |
| | (0.3,0.4] | -1 |
| | <0.3 | 0 |
| PCT of Water | >30% | -3 |
| | 10%-30% | -2 |
| | 0%-10% | -1 |
| | 0% | 0 |



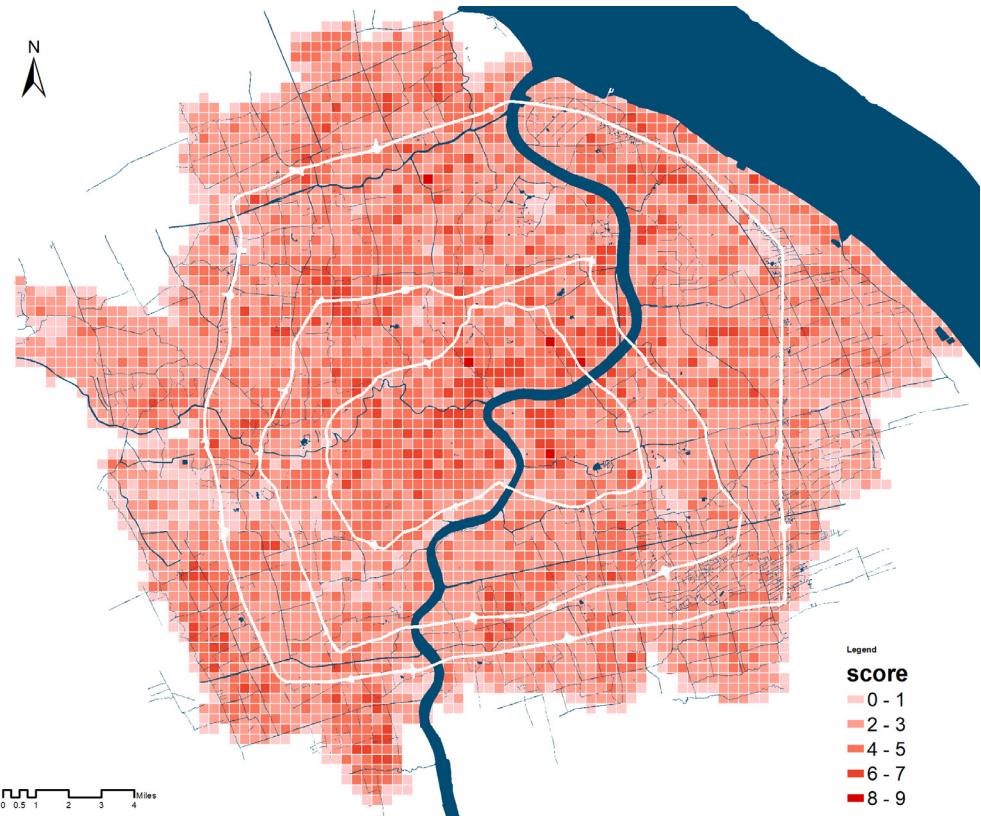
4.2 Strengthening Mechanism of Spatial Forms

Spatial patterns: high-score areas concentrate centralized distribute inside the Inner Circle. And some industry zones, ports or hubs far away from downtown.

Important areas: The areas with the highest scores are concentrated in Lujiazui CBD and Puxi dense construction areas.

| Spatial Form Indexes | Intervals | Evaluation |
|-----------------------------------|-----------|------------|
| Industrial POI | >15 | 3 |
| | (5,15] | 2 |
| | (0,5] | 1 |
| | 0 | 0 |
| | | |
| Commercial POI | >25 | 4 |
| | (15,25] | 3 |
| | (5,15] | 2 |
| | (0,5] | 1 |
| | 0 | 0 |
| Residential POI | >50 | 4 |
| | (25,50] | 3 |
| | (10,25] | 2 |
| | (0,10] | 1 |
| | 0 | 0 |
| PCT of Construction | >75% | 3 |
| | 60%-75% | 2 |
| | 30%-60% | 1 |
| | <30% | 0 |
| Building Density | >75% | 3 |
| | 60%-75% | 2 |
| | 30%-60% | 1 |
| | <30% | 0 |
| FAR | >5 | 4 |
| | (2.5,5] | 3 |
| | (1,2.5] | 2 |
| | (0,1] | 1 |
| | 0 | 0 |
| Road Density(Km/km ²) | >25 | 4 |
| | (15,25] | 3 |
| | (5,15] | 2 |
| | (0,5] | 1 |
| | 0 | 0 |

Evaluation of strengthening mechanism

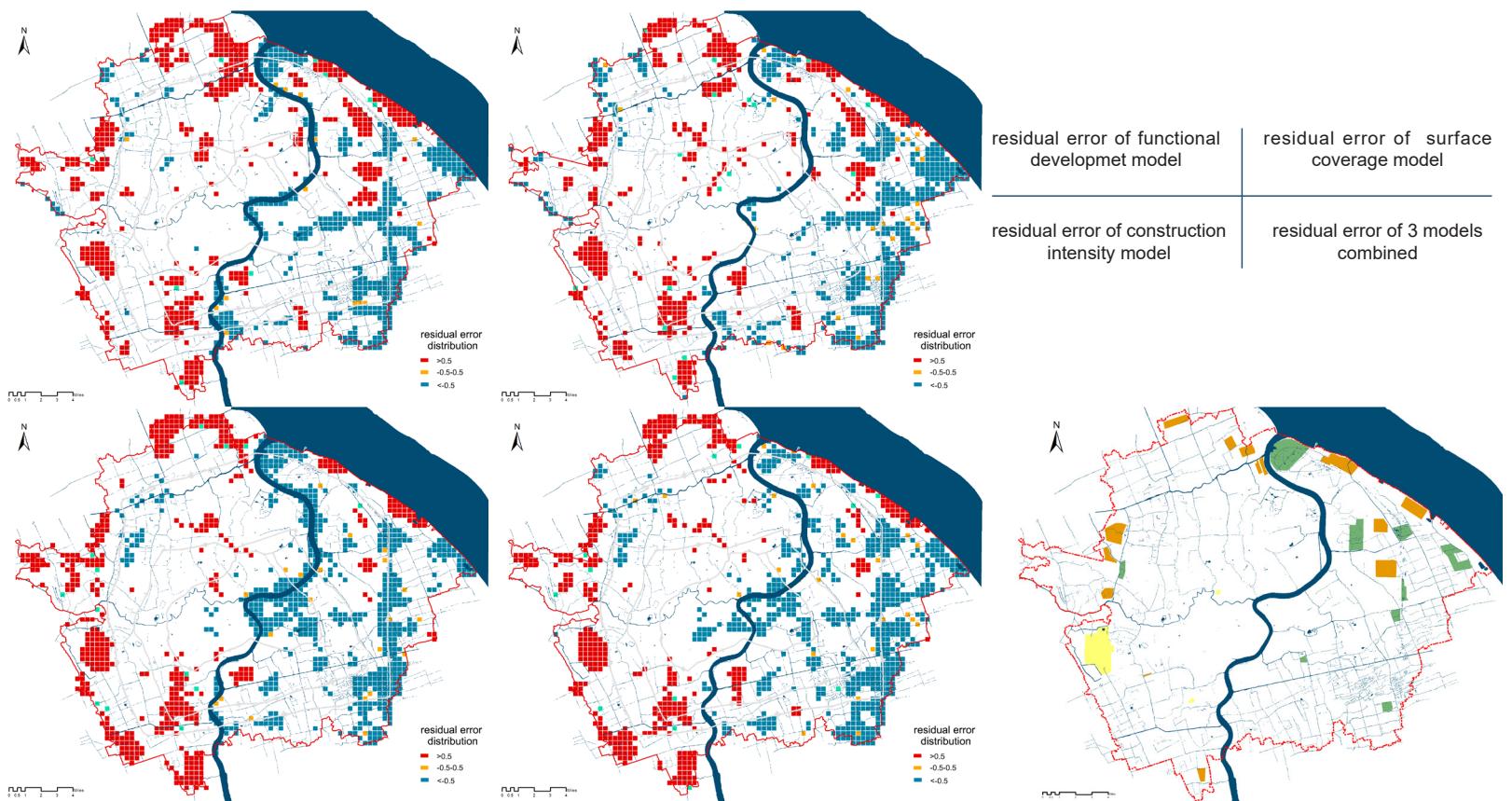


4.3 Recognition of External Environmental Factors

What other factors that have influences on UHI?

To answer this question, I created 3 regression models and calculate residuals of each nets under each models(statistical result shows below). Also I showed the results on maps to see directly what regularity they have.

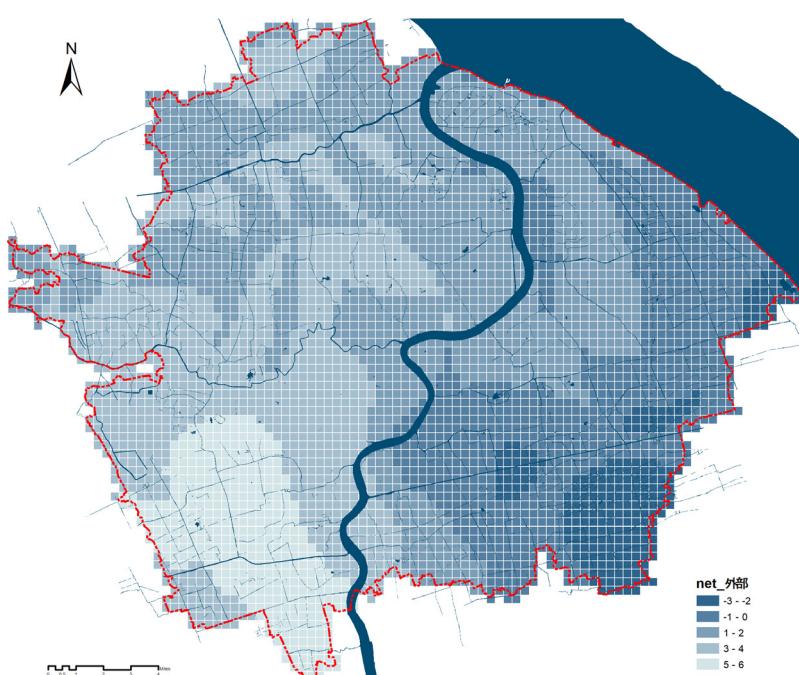
| Linear Regression | | Distribution of Residual | | |
|--|---------------------|--------------------------|---------|---------|
| | Indexes | Moran I Coefficiece | Z Score | P-value |
| Model 1:Functional Development(Adjusted R ² =0.412) | Industrial POI | 0.34 | 13.11 | 0.00 |
| | Residual POI | 0.29 | 13.68 | 0.00 |
| | Commercial POI | 0.34 | 14.51 | 0.00 |
| Model 2:Surface Coverag(Adjusted R ² =0.337) | PCT of Plant | 0.35 | 17.84 | 0.00 |
| | PCT of Earthing | 0.27 | 15.79 | 0.00 |
| | PCT of water | 0.29 | 16.42 | 0.00 |
| | NDVI | 0.31 | 15.38 | 0.00 |
| Model 3:Building Intensity(Adjusted R ² =0.360) | Building Density | 0.35 | 14.81 | 0.00 |
| | PCT of Construction | 0.27 | 17.65 | 0.00 |



Obviously, on figures above, distributions of residuals of each models have regular patterns in Shanghai, positive high residual(>0.5)areas and negative low residual areas(<-0.5)are highly coincide.

Looking those areas on map and find out that red areas tend to be large industry zones, ports, hubs and large residual communities; While blue areas tend to be large green spaces and large flakes of farms lands.

Thus 6 factors newly discoverd above need to be considered to see whether they have significant impacts on UHI.



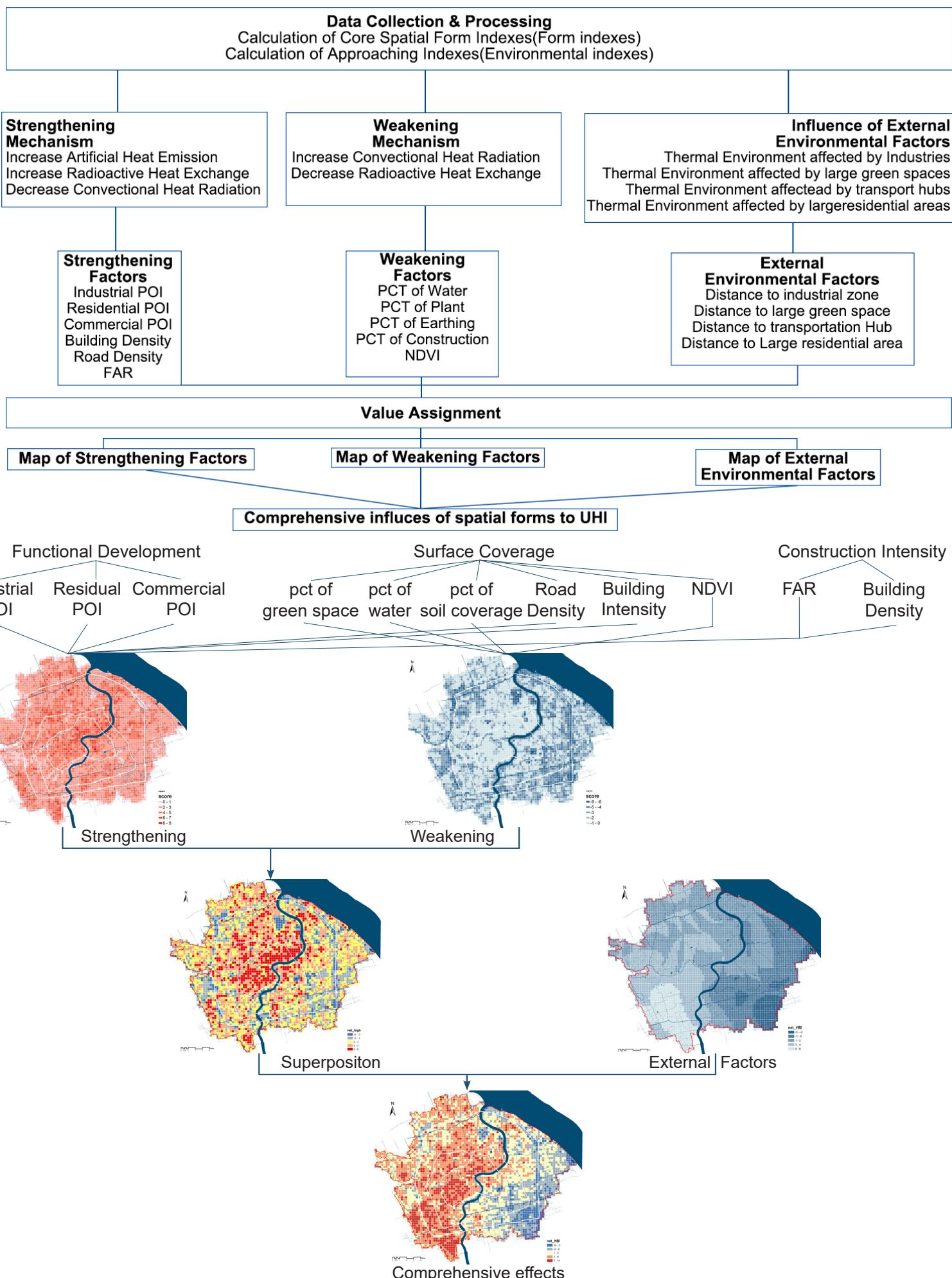
What else factors that can affect UHI besides spatial forms considered above?

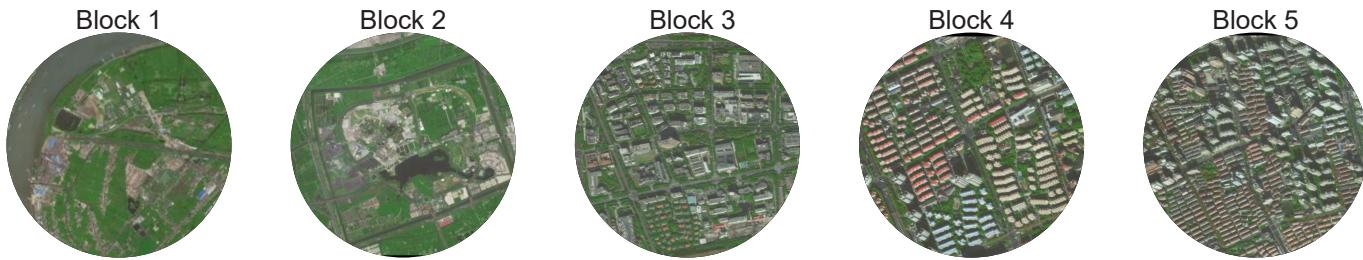
Recognition of external environmental factors

1. distance to industry zones
2. distance to large ports
3. distance to large communities
4. distance to large green spaces
5. distance to transport hubs
6. distance to farmlands

4.4 Comprehensive Mechanism of Spatial Forms to UHI

Weakening+strengthening+external environmental factors correction=comprehensive impacts on UHI.





Block 1: weak heat load, strong radiation; Block 2: weak heat load, less strong radiation;
 Block 3: less strong heat load, less strong radiation;
 Block 4: less strong heat load, weak radiation;
 Block 5: strong heat load, weak radiation.

5.2 Differences of spatial forms of 5 types of blocks

Functional development factors: In block 4&5, it shows significant positive correlation with UHI.

Surface Coverage factors: It shows significant positive correlation with UHI in all blocks, but mainly in block 1, 2, & 3.

Building Intensity factors: Building density shows significant correlation with UHI in all blocks except block 1, and has larger coefficient in block 2, 3&4.

| | Block 1 | Block 2 | Block 3 | Block 4 | Block 5 |
|---------------------|----------|----------|----------|----------|-----------|
| R ² | 0.531 | 0.621 | 0.431 | 0.558 | 0.698 |
| Industry POI | 0.087 | 0.034 | 0.093 | 0.239*** | 0.249*** |
| Residential POI | 0.046 | -0.063 | 0.469*** | 0.263 | 0.043 |
| Commercial POI | 0.168 | 0.167 | 0.572 | 0.058** | 0.167** |
| PCT of Plant | 0.642** | 0.53** | -0.009 | 0.051 | 0.025* |
| PCT of Earthing | 0.383 | 0.141 | -0.364 | 0.279 | 0.078 |
| PCT of water | 0.451*** | 0.404 | 0.36 | 0.197 | 0.085 |
| NDVI | -0.562 | -0.079 | 0.134 | -0.013 | -0.223*** |
| Building Density | 0.318 | 0.615*** | 0.354*** | 0.420*** | 0.154** |
| PCT of Construction | 0.316 | 0.565* | 0.224 | 0.148** | 0.142** |
| FAR | 0.047 | 0.522 | 0.227 | 0.529 | 0.564** |
| Road Density | 0.021 | 0.393 | 0.332 | 0.288 | 0.131 |

6. Conclusion

This study analyzes the spatial characteristics of overall heat island in Shanghai, build a core indicator system (including 11 urban spatial patterns) that affect the intensity of heat islands, and explains how three mechanisms affect UHI (enhancement, mitigation, and external environment correction mechanism), and finally based on this, propose an operational implementation path to reduce UHI, namely:

1. Avoid superposition of high temperature areas, in order to avoid negative impacts of industrial areas and transportation hubs on surrounding residential areas, green coverage need to be increased in concentrated industrial areas.
2. Extend water body, green area, and reduce construction intensity of waterfront area. There are many water systems in Shanghai, but the cooling effect of water bodies has not been fully reflected. Therefore, construction intensity around large-scale water bodies and green areas should be strictly controlled to increase the spatial depth of its cooling effect.