

Supplementary information for

Big geodata reveals patterns of spatialized built environment stocks across and within cities in China

Zhou Huang ^{*a,b,#}, Yi Bao ^{a,b,#}, Ruichang Mao ^{c,d,#}, Han Wang^a, Ganmin Yin^a, Lin Wan^e, Houji Qi^a, Qiaoxuan Li^f, Hongzhao Tang^g, Qiance Liu^{c,h}, Linna Liⁱ, Bailang Yu^f, Qinghua Guo^a, Yu Liu^a, Huadong Guo^{†b,j}, and Gang Liu ^{‡k}

^aInstitute of Remote Sensing and Geographical Information Systems, School of Earth and Space Sciences, Peking University, Beijing 100871, China

^bInternational Research Center of Big Data for Sustainable Development Goals, Beijing 100094, China

^cSDU Life Cycle Engineering, Department of Green Technology, University of Southern Denmark, Odense 5230, Denmark

^dDepartment of Construction Management, School of Civil Engineering, Tsinghua University, Beijing 100084, China

^eSchool of Computer Science, China University of Geosciences, Wuhan 430074, China

^fSchool of Geographical Sciences, East China Normal University, Shanghai 200062, China

^gLand Satellite Remote Sensing Application Center, Ministry of Natural Resources, Beijing 100048, China

^hInstitute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

ⁱDepartment of Geography, California State University, Long Beach, California 90840, USA

^jAerospace Information Research Institute, Chinese Academy of Sciences, Beijing 100094, China

^kCollege of Urban and Environmental Sciences, Peking University, Beijing 100871, China

[#]These authors contributed equally: Zhou Huang, Yi Bao, Ruichang Mao

*Corresponding author: huangzhou@pku.edu.cn

†Corresponding author: hdguo@radi.ac.cn

‡Corresponding author: gangliu@pku.edu.cn

Contents

1	Data collection and pre-processing	4
1.1	The socioeconomic characteristics of the 50 Chinese cities	4
1.2	Building footprint data	6
1.3	Point of Interest (POI) data	9
1.4	Transportation infrastructure footprint data	11
1.5	National land use data	13
1.6	Spatial distribution of population data	15
1.7	Material Composition Indicators (MCIs) of building, road, railway and subway in China . . .	16
2	Material stocks calculation and prediction	21
2.1	Building material stocks estimation in the remaining 47 cities	21
2.2	Building material stocks model validation	22
2.3	The urban built environment stocks in the 50 Chinese cities	23
2.4	The comparison of urban built environment stocks in Chinese cities with cities in the literature	33
3	Spatial analysis	34
3.1	Clustering analysis of grids with high building material stocks	34
3.2	Calculation of dispersion index	37
3.3	Spatial unbalanced rate of building material stocks distributions	39
3.4	Exponential distribution of building material stocks accumulation	42
3.5	Correlations between population and building stocks	44
3.6	Log-normal distribution of BtR ratio at grid level	45
4	Carbon replacement value calculation	47
	References	52
A.1	The building geometries collected in the 50 Chinese cities	54
A.2	The spatial distributions of building stocks in 500m*500m grid across the 50 cities	63
A.3	The spatial distributions of transportation infrastructures material stocks in 500m*500m grid across the 50 cities	72
A.4	The spatial distributions of undeveloped, developed, top, and clusters of building stocks grids across the 50 cities	81
A.5	The Lorentz curves for building stocks in the 50 Chinese cities	90
A.6	The CCDF curves for building stocks in the 50 Chinese cities	99
A.7	Correlations between population and building stocks at grid level in the 50 Chinese cities . . .	116

A.8 Log-normal distribution of BtR ratio at grid level in the 50 Chinese Cities 125

1 Data collection and pre-processing

1.1 The socioeconomic characteristics of the 50 Chinese cities

The socioeconomic factors of the 50 Chinese cities are retrieved from respective statistical yearbooks in 2019. The tier rating information is derived from the “2019 City Business Glamour Ranking” released by China Business News on May 24, 2019ⁱ. The socioeconomic data used in this study are shown in the Table S1.

Supplementary Table S1: The socioeconomic characteristics of the 50 Chinese cities

City	Population Million 2018	GDP Billion Yuan 2018	Built-up Area (km^2)	Geographical region	Tier	Urbanization Rate (2018)
Baoding	11.19	339.6	187.44	North	Third	51.80%
Beijing	21.512	3032	1419.66	North	First	86.50%
Changchun	7.68	708.5	519.04	North East	Second	58.80%
Changsha	7.04	1152.7	322.73	Central	New-first	77.60%
Chengdu	16.33	1534.2	837.27	South West	New-first	74.40%
Chongqing	31.02	2036.3	1350.66	South West	New-first	65.50%
Dalian	6.69	782.5	433.3	North East	Second	72.00%
Foshan	7.19	1055	160.78	South	Second	94.90%
Fuzhou	7.12	785.6	265.33	East	Second	70.80%
Guangzhou	14.5	2300	1249.11	South	First	86.10%
Guiyang	4.32	380	299	South West	Second	75.40%
Ha’erbin	10.86	700.2	435.81	North East	Second	65.30%
Haikou	2.05	151	140.59	South	Second	78.20%
Handan	9.17	384.6	172.27	North	Third	55.30%
Hangzhou	8.7	1350	541.38	East	New-first	77.40%
Hefei	5.7	782.2	460	East	Second	75.00%
Hohhot	2.87	290.3	260	North	Third	69.80%
Jinan	6.81	886.2	447.69	East	Second	72.10%
Kunming	6.72	535	435.81	South West	New-first	59.50%
Lanzhou	3.62	258.2	321.75	North West	Second	69.40%
Lhasa	0.56	54.08	82.82	South West	Fourth	31.00%
Linyi	10.04	475	219.7	East	Third	48.30%

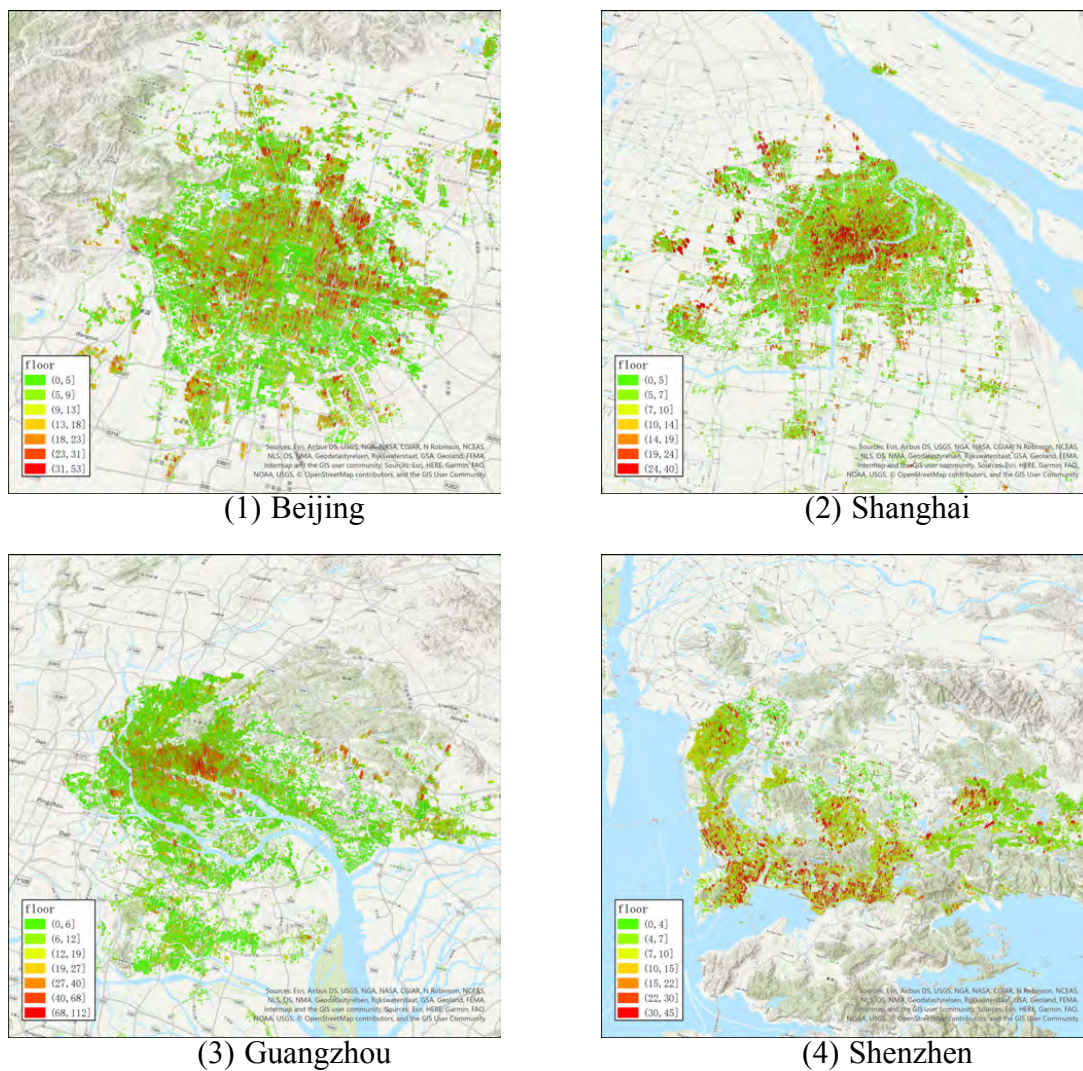
ⁱ<https://www.yicai.com/topic/100201048>

Continuation of Supplementary Table S1

City	Population Million 2018	GDP Billion Yuan 2018	Built-up Area (km^2)	Geographical region	Tier	Urbanization Rate (2018)
Luoyang	6.82	464.08	216.37	Central	Third	56.00%
Nanchang	5.04	527.4	317.3	East	Second	74.20%
Nanjing	8	1282	773.79	East	New-first	82.50%
Nanning	6.66	448	310.47	South	Second	62.40%
Nantong	7.28	842.7	215.62	East	Second	67.10%
Nanyang	11.98	317.6	150.14	Central	Third	46.20%
Ningbo	7.61	1074.5	330.75	East	New-first	73.60%
Qingdao	8.72	1256.1	599.32	East	New-first	73.70%
Quanzhou	8.13	846.7	214	East	Second	66.60%
Shanghai	24.24	3267.9	998.75	East	First	88.10%
Shenyang	8.1	635	588.26	North East	New-first	80.50%
Shenzhen	13.03	2469.1	923.25	South	First	100.00%
Shijiazhuang	10.95	696.3	283.72	North	Second	63.20%
Suzhou	10.68	1859.7	461.65	East	New-first	75.80%
Taiyuan	4.2	388.4	340	North	Second	84.40%
Tangshan	7.84	695.5	249	North	Third	63.10%
Tianjin	15.6	1880.9	1007.91	North	New-first	83.20%
Urumqi	2.23	309.96	436	North West	Third	74.60%
Weifang	9.09	680.5	179.34	East	Third	61.80%
Wenzhou	9.12	600.6	241.4	East	Second	70.00%
Wuhan	11.08	1484.7	585.61	Central	New-first	80.30%
Wuxi	6.57	1143.8	332.01	East	Second	76.30%
Xiamen	4.01	479.141	334.64	East	Second	89.00%
Xi'an	10	834.9	517.74	North West	New-first	74.00%
Xining	2.21	128.64	129	North West	Fourth	72.10%
Yinchuan	1.99	190.1	170.7	North West	Third	77.60%
Zhengzhou	10.14	1020	422.35	Central	New-first	73.40%
Zhoukou	8.95	268.7	269	Central	Fourth	42.80%

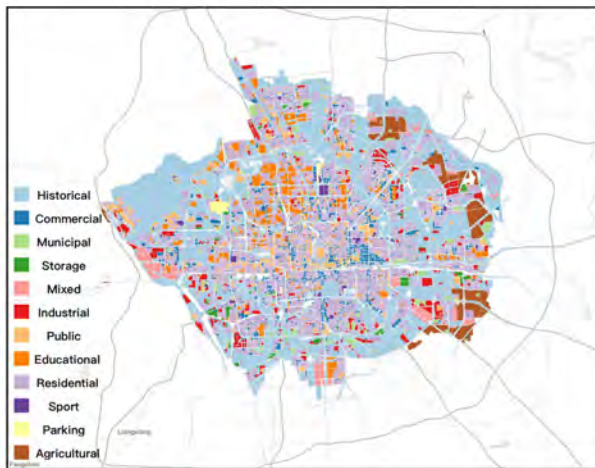
1.2 Building footprint data

Figure S1 shows the building geometries of Beijing, Shanghai, Guangzhou and Shenzhen respectively (see in Appendix A.1 of building geometries in the 50 cities). Table S2 displays the quantity statistics of each city. As for Beijing, Shenzhen and Guangzhou, an attribute assignment method (elaborated in literature[1]) is utilized to obtain the typology and year properties for buildings by overlapping high-resolution land use data and the building age data. The 30-meter fine-grained land use data with 12 types (shown in Figure S2) are collected from planning administrations of the three cities. The building age data are obtained from SouFun (China's largest real-estate agency Web site ⁱⁱⁱ).

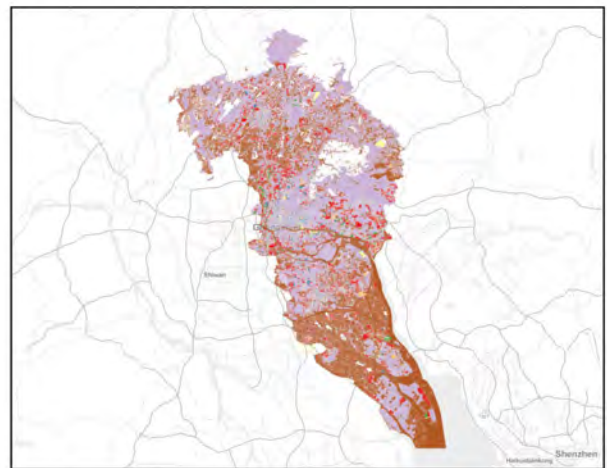


Supplementary Figure S1: Building geometries of Beijing, Shanghai, Guangzhou and Shenzhen respectively

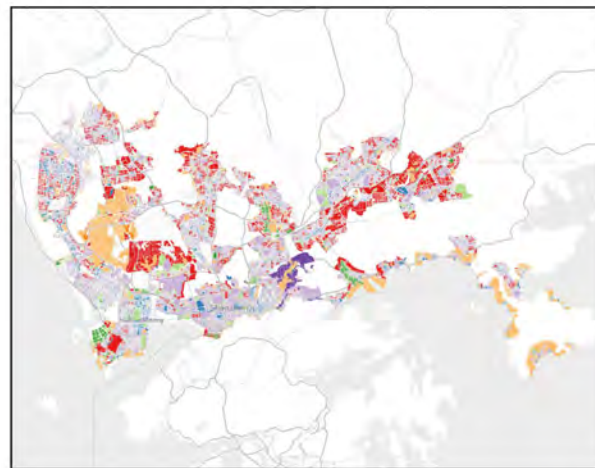
ⁱⁱⁱ<http://soufun.com/>



(1) Beijing



(2) Guangzhou



(3) Shenzhen

Supplementary Figure S2: The land use data in 30m*30m of Beijing, Shenzhen and Guangzhou respectively

Supplementary Table S2: The number of buildings obtained in the 50 Chinese cities

City	Building number	City	Building number
Beijing	656563	Baoding	226190
Shanghai	1429994	Fuzhou	126408
Chongqing	346058	Wenzhou	406072
Chengdu	351348	Nantong	284200
Tianjin	320138	Kunming	102206
Suzhou	775966	Nanning	208792
Guangzhou	1003833	Nanchang	150240
Wuhan	388386	Taiyuan	81442
Zhengzhou	679024	Xiamen	99567
Hangzhou	671362	Quanzhou	113520
Shenzhen	670417	Guiyang	66603
Nanjing	328998	Hohhot	55520
Shenyang	201590	Changsha	183694
Shijiazhuang	271006	Tangshan	214117
Qingdao	212370	Yinchuan	40061
Dalian	167651	Linyi	65962
Xi'an	296294	Luoyang	319006
Foshan	651965	Lanzhou	42709
Hefei	238772	Urumqi	45501
Changchun	155325	Xining	31209
Jinan	125991	Haikou	54800
Weifang	74830	Handan	17059
Wuxi	512096	Nanyang	37912
Ha'erbin	96139	Lhasa	30774
Ningbo	373606	Zhoukou	20990

1.3 Point of Interest (POI) data

The POI data with 17 different types (as listed in Table S3) are obtained from Amap (the largest mobile map platform with 370 million users in China ^{iv}). Totally of 22,864,345 POIs in the 50 Chinese cities are used in this study. Table S4 illustrates the number of POIs in each city.

Supplementary Table S3: The POI data in 17 categories

Amap POI code	Category	Amap POI code	Category
01	Auto Service	11	Tourist Attraction
02	Auto Dealers	12	Commercial House
03	Auto Repair	13	Governmental Organization
05	Food & Beverages	14	Science & Education Service
06	Shopping	15	Transportation Service
07	Daily Life Service	16	Finance & Insurance Service
08	Sports & Recreation	17	Enterprises
09	Medical Service	20	Public Facility
10	Accommodation Service		

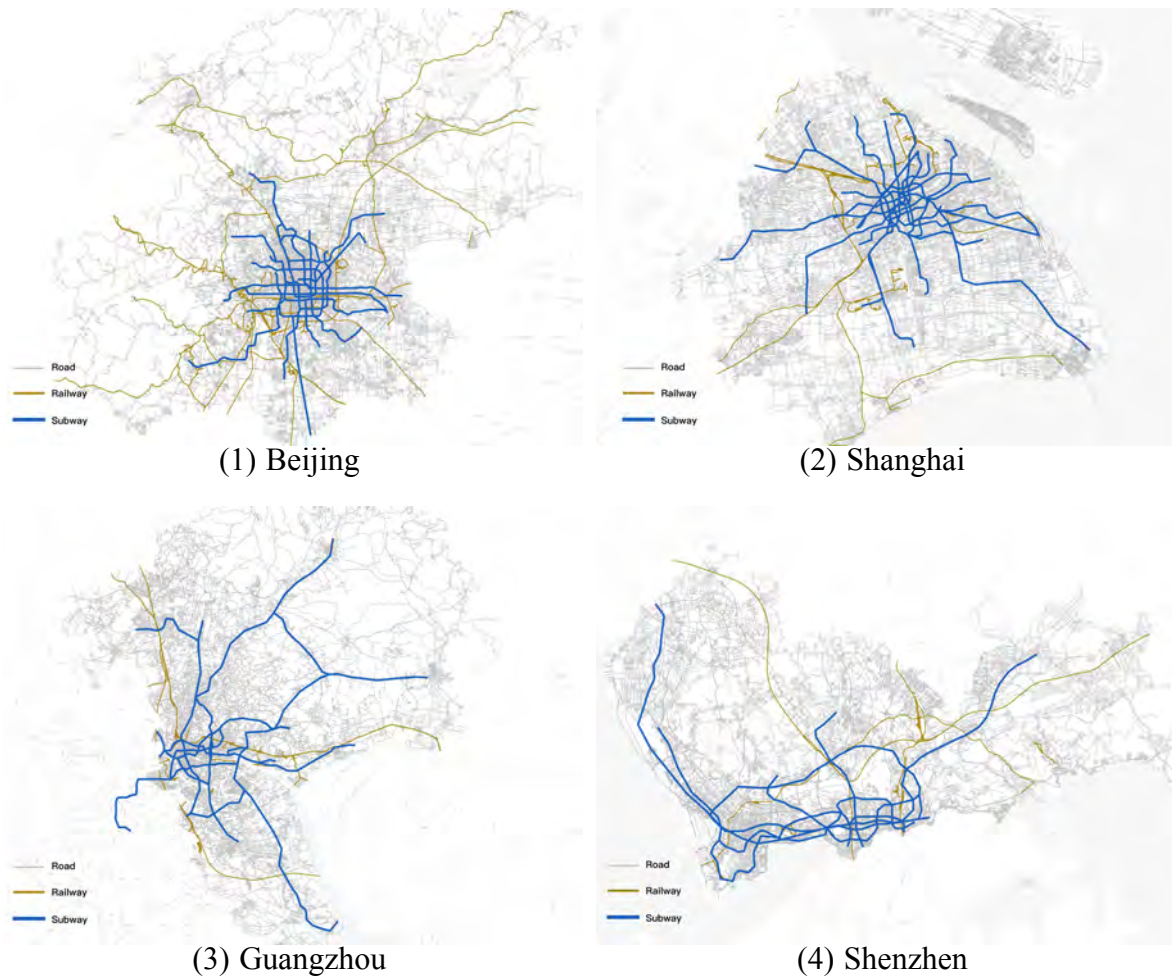
^{iv}<https://www.amap.com/>

Supplementary Table S4: The number of POIs in the 50 Chinese cities

City	POI number	City	POI number
Beijing	1186978	Baoding	650135
Shanghai	1354293	Fuzhou	401366
Chongqing	762841	Wenzhou	500892
Chengdu	1157105	Nantong	604898
Tianjin	668240	Kunming	427367
Suzhou	1808566	Nanning	437742
Guangzhou	1416490	Nanchang	240983
Wuhan	736129	Taiyuan	244973
Zhengzhou	595075	Xiamen	276569
Hangzhou	1044473	Quanzhou	509135
Shenzhen	1042285	Guiyang	244624
Nanjing	542204	Hohhot	103997
Shenyang	331505	Changsha	579445
Shijiazhuang	417468	Tangshan	103278
Qingdao	511709	Yinchuan	111906
Dalian	278813	Linyi	133785
Xi'an	530703	Luoyang	165084
Foshan	1153211	Lanzhou	103279
Hefei	441435	Urumqi	98478
Changchun	214904	Xining	59037
Jinan	674931	Haikou	116020
Weifang	440078	Handan	65166
Wuxi	828394	Nanyang	66601
Ha'erbin	236657	Lhasa	27718
Ningbo	476368	Zhoukou	310615

1.4 Transportation infrastructure footprint data

Transportation footprint data (road, railway and subway) include geometries and features such as road length, road classification, railway length, subway line length, and station name. Road data of the 50 Chinese cities are collected from OpenStreetMap ^v through OSMnx[2]. Railway data and subway data are obtained from Amap. Figure S3 illustrates the road, railway and subway distribution in Beijing, Shanghai, Shenzhen and Guangzhou respectively. Table S5 shows the length statistics of road, railway and subway in the 50 Chinese cities.



Supplementary Figure S3: Road, railway and subway maps in Beijing, Shanghai, Shenzhen and Guangzhou respectively

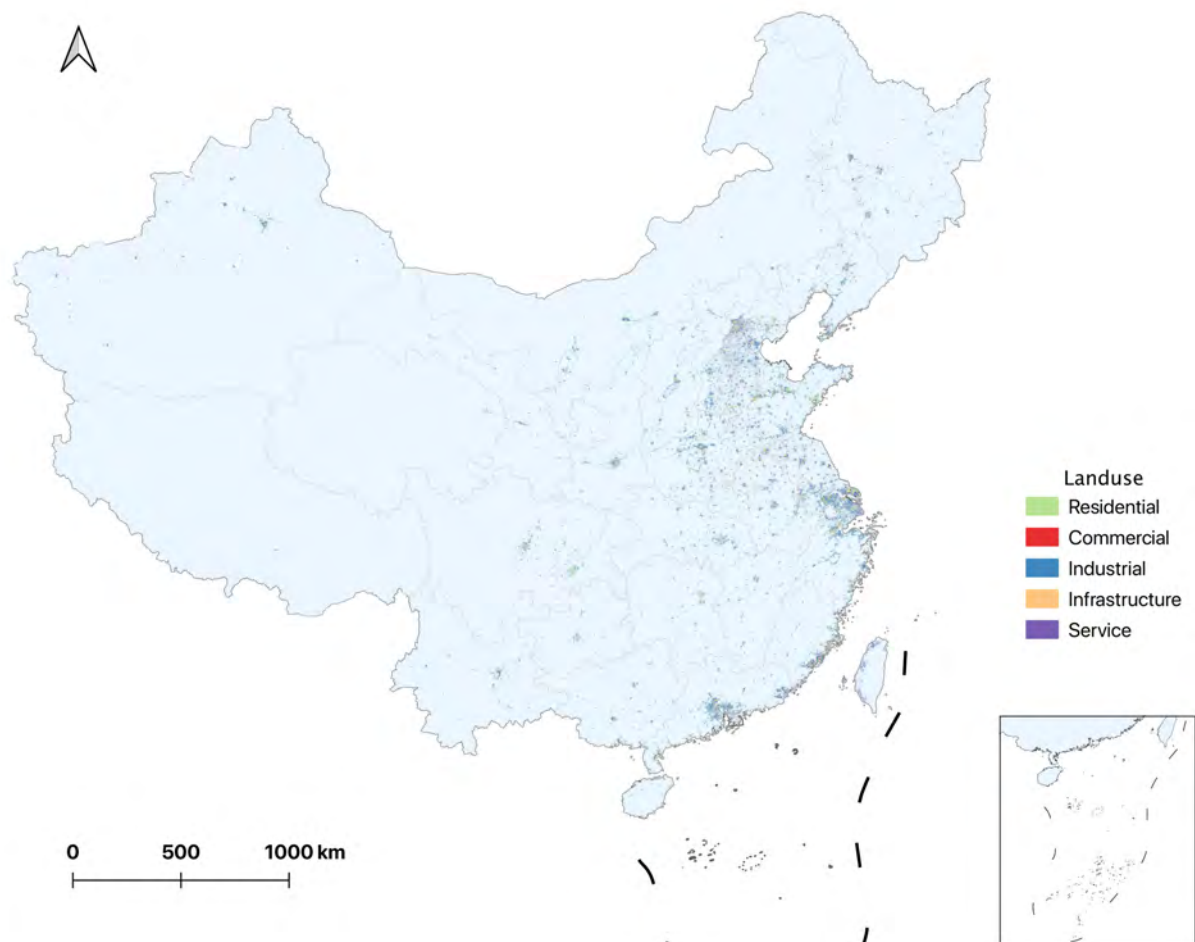
^v<https://www.openstreetmap.org>

Supplementary Table S5: The length of road, railway and subway in the 50 Chinese cities

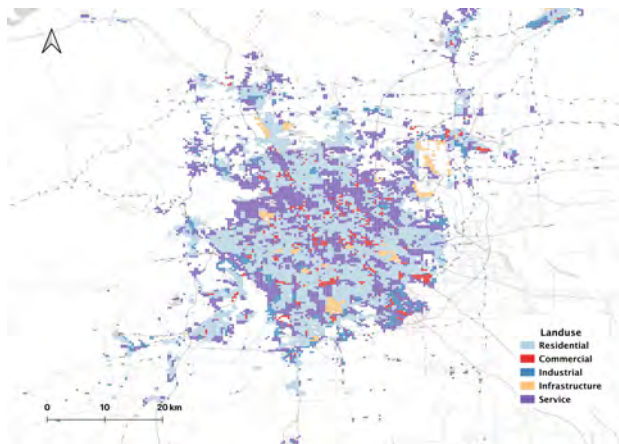
City	Road(m)	Railway(m)	Subway(m)	City	Road(m)	Railway(m)	Subway(m)
Beijing	46292029	3162823	832710	Baoding	23962109	1051526	0
Shanghai	35401307	1719238	907760	Fuzhou	25794196	572296	57537
Chongqing	65422862	3085468	345796	Wenzhou	17063999	316850	55663
Chengdu	31159496	1123701	399790	Nantong	23414947	423831	0
Tianjin	32975941	2604596	276697	Kunming	17265702	1375947	113080
Suzhou	26129071	516179	182420	Nanning	9551557	1004532	83155
Guangzhou	24641109	966570	521495	Nanchang	13613163	1417490	64993
Wuhan	18573628	1683839	369916	Taiyuan	7511178	747577	0
Zhengzhou	23391261	1320053	167740	Xiamen	6262197	169661	73840
Hangzhou	32463282	650281	280497	Quanzhou	12038460	382177	0
Shenzhen	13857923	359437	307455	Guiyang	8214245	1024376	36067
Nanjing	16610641	1455362	408775	Huhehaote	11504025	891950	30046
Shenyang	15785976	1465524	147990	Changsha	15102682	609274	106589
Shijiazhuang	32986283	1247340	54285	Tangshan	19949211	1849998	0
Qingdao	26938086	668977	200912	Yinchuan	7366517	555509	0
Dalian	18177355	1941154	269129	Linyi	32344240	1097260	0
Xi'an	20730270	1315007	178653	Luoyang	10518446	677974	0
Foshan	17232527	425833	39959	Lanzhou	12537191	1726581	30674
Hefei	17545867	998484	101390	Wulumuqi	10609277	1125309	35866
Changchun	17815313	1494665	132085	Xining	4595460	429910	0
Jinan	19026566	1352383	54117	Haikou	4096607	157819	0
Weifang	27654547	1019220	0	Handan	27103545	910301	0
Wuxi	12077650	487462	65841	Nanyang	11117904	795798	0
Ha'erbin	28436904	2141476	40859	Lasa	5809120	458375	0
Ningbo	21351985	388880	104197	Zhoukou	10584974	357477	0

1.5 National land use data

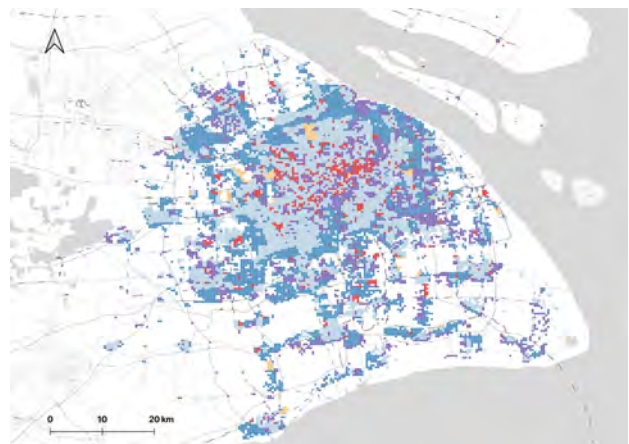
To calculate material stock values of buildings in Beijing, Guangzhou and Shenzhen, the 30m fine-grained land use map with 12 types (as described in Section 1.2) is used for assigning the typology attribute of individual buildings. However, land use information is not accessible in the other 47 cities. After the 500m grid-based material stocks results are calculated, we utilize another national coarse-grained land use data Essential Urban Land Use Categories in China (EULUC-China)[3] for identifying grid typology. EULUC-China is at a relatively coarse resolution and based on variable-size parcels divided by the road network. It classifies essential urban land use into 5 categories (residential, commercial, infrastructure, industrial and service). To identify the grid's typology, the land use category that accounts the biggest portion in grid is applied. Figure S4 illustrates the visualized map of EULUC-China, and Figure S5 shows the 500m grid based land use maps in Beijing, Shanghai, Guangzhou and Shenzhen respectively.



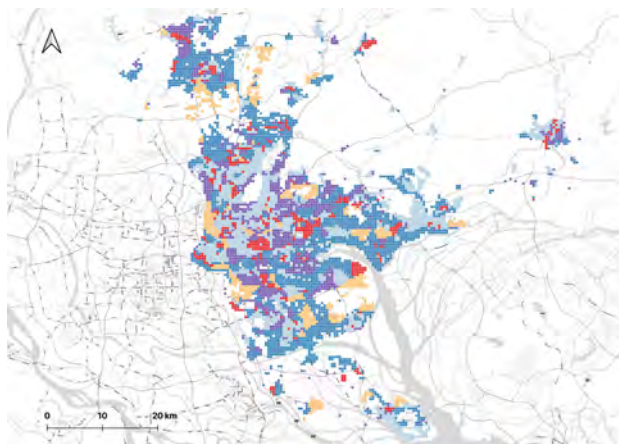
Supplementary Figure S4: The visualized map of EULUC-China in 2018



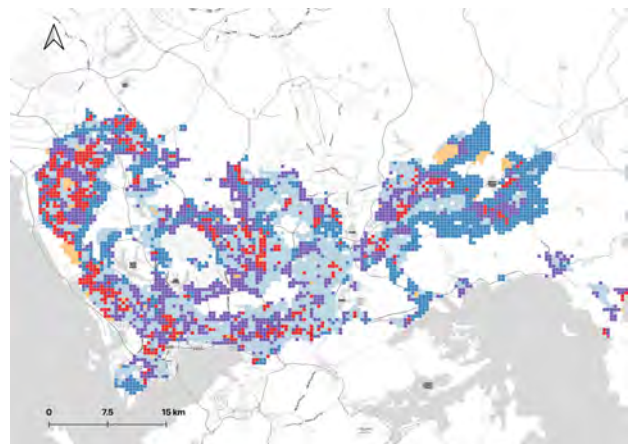
(1) Beijing



(2) Shanghai



(3) Guangzhou

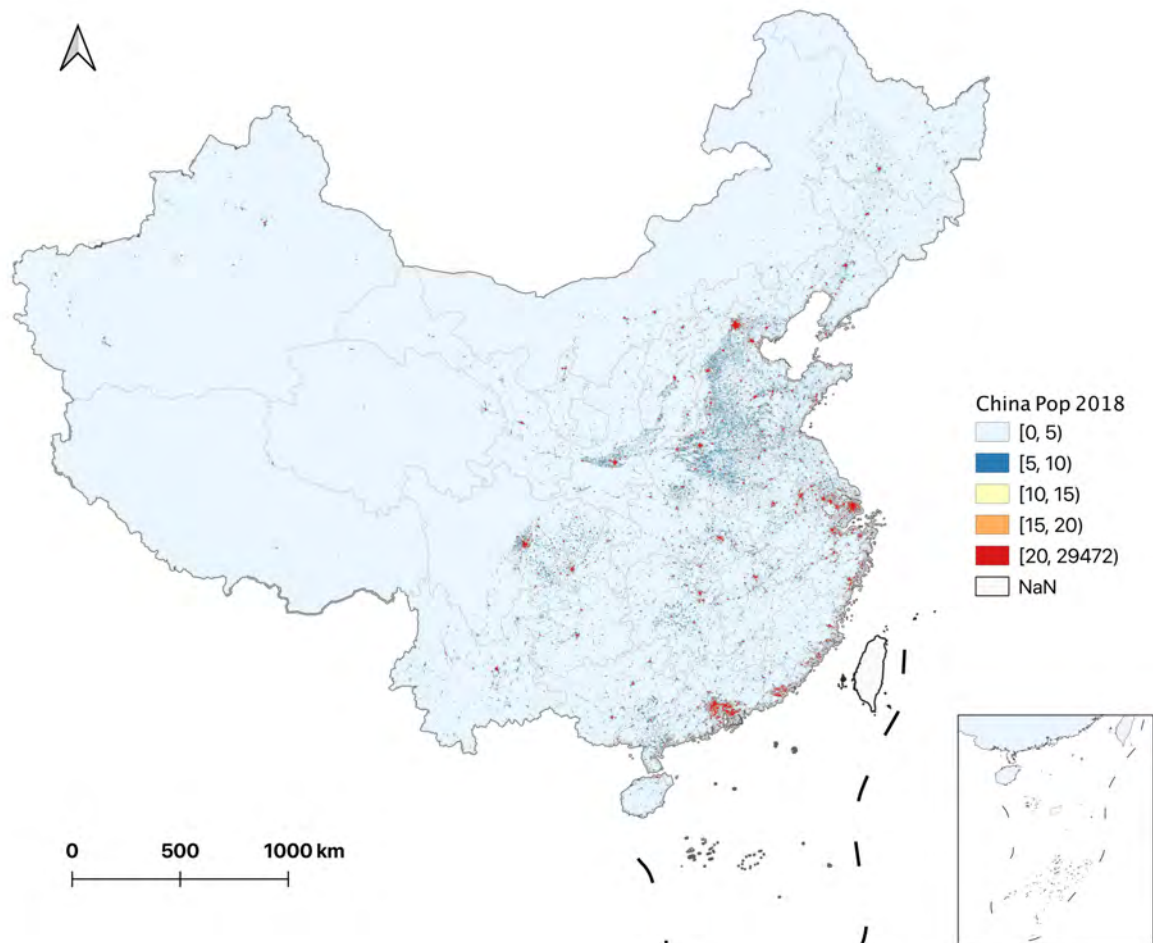


(4) Shenzhen

Supplementary Figure S5: The grid typology in 500 m × 500 m resolution in Beijing, Shanghai, Guangzhou and Shenzhen respectively

1.6 Spatial distribution of population data

Population density and population data (at a 100m resolution) in 2018 China are retrieved from WorldPop Mainland China dataset ^{vi}.



Supplementary Figure S6: The population map in 2018 China acquired from WorldPop

^{vi}<https://www.worldpop.org/>

1.7 Material Composition Indicators (MCIs) of building, road, railway and subway in China

In this study, the time and labor intensive data compiling of building MCIs are conducted from various sources. Firstly, the building construction bill of quantities are provided from several construction and real estate companies in China (e.g. Vanke, Sunac, China Fortune Land Development, Country Garden, China Construction Seventh Engineering Division). Then, considerable building samples are retrieved from handbooks (Construction project investment estimation handbook[4], and Building cost estimation handbook[5, 6]), building cost estimation websites^{vii}, and associations (China Cost Engineering Association^{viii}, Project Management Professional Committee of China engineering construction standard^{ix}). During on-site investigation, MCIs of agricultural buildings are collected. The material inventories of over 1,800 building samples constructed between 1963 and 2017 are compiled. Supplementary data of Chinese building MCIs from literatures[7, 8] are then retrieved. These building samples are further classified into 12 building typologies in accordance with the building design codes in China, and 45 temperature zones (cold zone and hot-summer warm winter zone are used for material stocks estimation in Beijing, Guangzhou and Shenzhen respectively). The detailed building MCIs used in this study are listed in Table S6-S11.

The road and subway MCIs are collected from construction bill of quantities provided from colleges in several construction companies in China (e.g. China Tiesiju Civil Engineering Group Co.,Ltd, China Communications Construction Company Fourth Highway Engineering Co.,Ltd). The road MCIs cover five different levels, namely expressway, first-class road, second-class road, third-class road and fourth-class road. Composition of 6 main materials are retrieved and integrated from road construction bill of quantities. Similarly, the subway MCIs in 2 components (tunnel and station, subway station MCIs include the construction of station, ancillary road, entrances and exits, and ventilation system) are compiled from over 300 material consumption processes in subway construction bill of quantities. The railway MCIs data are extracted from a Chinese case study of the material stock in high-speed rail[9]. The detailed MCIs of road, railway and subway used in this study are listed in Table S12-S14.

^{vii}<http://www.gldzb.com>

^{viii}<http://www.ccea.pro>

^{ix}<http://www.cccsem.org>

Supplementary Table S6: Detailed MCIs for buildings constructed before 1980 in cold zone.

Before 1980 (kg/m²)	Cement	Steel	Timber	Brick	Gravel	Sand	Asphalt	Lime	Glass	Ceramic	Total
Agricultural	16.67	0	0.43	498.67	25	50	0	0	0	0	590.77
Commercial	399.92	68.62	10.28	443.63	800.6	811.78	4.51	43.69	1.71	0	2584.74
Educational	187.68	25.44	14.79	854.28	543.95	604.44	2.59	55.45	2.68	0	2291.3
Historical	27	1	88	52	269	10	0	4	1	18	470
Industrial	218.43	50.65	2.08	595.08	275.2	272.68	2.52	9.48	2.77	0	1428.89
Mixed	404.08	93.51	6.93	289.65	680.95	566.74	1.72	49.98	1.07	0	2094.63
Municipal	222	35.75	28.44	663.92	557.71	528.61	2.35	39.39	2.3	0	2080.47
Parking	87.5	8.25	1.05	416.5	0	0	0	0	0	0	513.3
Public	274.88	54.92	11.63	728.95	503.72	619.33	2.67	30.81	2.06	0	2228.97
Residential	20	0	7	850	0	256	0	0	0	0	1133
Sport	209.68	40.35	52.57	612.28	889.34	717.15	5.24	42.39	2.77	0	2571.77
Storage	1.88	0	0	229.5	0	0	0	0	0	0	231.38

Supplementary Table S7: Detailed MCIs for buildings constructed from 1981 to 2000 in cold zone.

1981-2000 (kg/m²)	Cement	Steel	Timber	Brick	Gravel	Sand	Asphalt	Lime	Glass	Ceramic	Total
Commercial	333.27	57.18	8.57	369.69	667.16	676.49	3.76	36.41	1.43	0	2153.96
Municipal	185	29.79	23.7	553.27	464.76	440.51	1.96	32.83	1.92	0	1733.74
Storage	14.59	0.94	0.12	376.99	6.41	120.12	0	0	0	0	519.17
Mixed	400.08	92.58	6.86	286.78	674.21	561.13	1.7	49.49	1.06	0	2073.89
Industrial	214.15	49.65	2.04	583.41	269.81	267.33	2.47	9.3	2.72	0	1400.88
Public	249.89	49.92	10.57	662.69	457.93	563.03	2.43	28	1.87	0	2026.33
Educational	170.62	23.12	13.45	776.62	494.5	549.49	2.36	50.41	2.44	0	2083.01
Residential	114.3	16.64	6.22	536	226.15	262.58	0.68	11.05	1.15	1.82	1176.59
Sport	220.72	42.47	55.33	644.5	936.15	754.89	5.52	44.62	2.91	0	2707.11
Parking	175	16.5	2.1	833	0	0	0	0	0	0	1026.6
Agricultural	28.57	0	0	1092.86	71.43	178.57	0	0	0	0	1371.43

Supplementary Table S8: Detailed MCIs for buildings constructed from 2001 to 2018 in cold zone.

2001-2018 (kg/m²)	Cement	Steel	Timber	Brick	Gravel	Sand	Asphalt	Lime	Glass	Ceramic	Total
Agricultural	37.38	0	0.53	842.31	11.07	14.05	0	0	0	0	905.34
Commercial	206.68	133.23	2.38	88.64	500.49	329.09	0	0	0	3.4	1263.91
Educational	215.99	50.64	0	0	636.63	614.64	0.1	0	0	0	1518
Industrial	154.73	50.48	6.05	188.26	216.67	144.4	0.24	0	0	0	760.83
Mixed	146.95	71.11	1.28	263.5	0.13	23.06	0	0	0	0	506.03
Municipal	138.48	70.72	0	0	370.09	421	0.13	0	0	0	1000.42
Parking	367.46	95.63	0.26	118.58	1438.81	887.8	1.41	0	0	0	2909.95
Public	183.86	92.44	1.96	373.29	456.8	301.67	0.09	0	0	2.05	1412.16
Residential	84.66	25.85	9.27	319.47	192.3	214.52	0.02	0	0.05	0.45	846.59
Sport	241.48	80.63	2.08	177.46	536.42	315.5	0.36	0	0.07	1.19	1355.19
Storage	45.45	0	0	185.45	65.91	349.09	0	0	0	0	645.9

Supplementary Table S9: Detailed MCIs for buildings constructed before 1980 in hot summer warm winter zone.

Before 1980 (kg/m²)	Cement	Steel	Timber	Brick	Gravel	Sand	Asphalt	Lime	Glass	Ceramic	Total
Agricultural	75.93	0	0.24	873.25	162.83	138.17	0	0	0	0	1250.42
Commercial	1109.03	87.19	8.81	252.97	637.42	502.05	2.33	23.87	1.45	0	2625.12
Educational	600.79	52.33	8.97	334.92	578.42	438.8	0.73	12.12	1.27	1.47	2029.82
Historical	27	1	88	52	269	10	0	4	1	18	470
Industrial	237.01	54.65	1.2	335.56	430.88	278.97	1.04	3.82	0.81	0	1343.95
Mixed	293.02	73.87	3.67	248.31	429.9	314.87	0.77	22.33	0.48	0	1387.21
Municipal	619.19	67.29	4.61	175.92	645.17	487.68	0.46	8.37	1.12	0.71	2010.51
Parking	290.96	50.6	1.06	429.4	774.86	451.87	0.64	0	0	0	1999.39
Public	703.91	97.13	2.62	201.94	911.43	587.68	1.43	6.61	1.13	0.27	2514.13
Residential	585.31	42.57	5.83	236.23	540.92	423.86	0.46	8.67	0.71	1.26	1845.82
Sport	310.57	47.77	26.77	304.35	1053.26	635.43	3.76	25.53	1.28	0	2408.72
Storage	73.26	0.42	0.05	253.8	158.24	262.98	0	0	0	0	748.76

Supplementary Table S10: Detailed MCIs for buildings constructed from 1981 to 2000 in hot summer warm winter zone.

1981-2000 (kg/m²)	Cement	Steel	Timber	Brick	Gravel	Sand	Asphalt	Lime	Glass	Ceramic	Total
Agricultural	79.93	0	0.25	919.21	171.4	145.45	0	0	0	0	1316.23
Commercial	1167.4	91.78	9.27	266.28	670.96	528.48	2.46	25.13	1.53	0	2763.29
Educational	632.41	55.08	9.44	352.55	608.87	461.9	0.76	12.76	1.33	1.54	2136.65
Industrial	249.48	57.52	1.27	353.22	453.56	293.65	1.09	4.03	0.86	0	1414.68
Mixed	308.44	77.75	3.87	261.38	452.52	331.44	0.81	23.51	0.5	0	1460.23
Municipal	651.78	70.84	4.85	185.18	679.13	513.34	0.48	8.81	1.18	0.74	2116.32
Parking	306.27	53.26	1.12	452	815.65	475.66	0.67	0	0	0	2104.63
Public	740.95	102.24	2.76	212.56	959.4	618.61	1.5	6.95	1.19	0.29	2646.46
Residential	616.12	44.81	6.14	248.67	569.39	446.17	0.48	9.13	0.74	1.33	1942.96
Sport	326.91	50.29	28.17	320.37	1108.7	668.87	3.96	26.87	1.34	0	2535.49
Storage	77.12	0.45	0.06	267.16	166.56	276.83	0	0	0	0	788.17

Supplementary Table S11: Detailed MCIs for buildings constructed from 2001 to 2018 in hot summer warm winter zone

2001-2018 (kg/m²)	Cement	Steel	Timber	Brick	Gravel	Sand	Asphalt	Lime	Glass	Ceramic	Total
Agricultural	84.14	0	0.27	967.59	180.42	153.1	0	0	0	0	1385.51
Commercial	1228.84	96.61	9.76	280.29	706.28	556.29	2.59	26.45	1.61	0	2908.72
Educational	665.7	57.98	9.94	371.1	640.91	486.21	0.8	13.43	1.4	1.63	2249.11
Industrial	262.61	60.55	1.34	371.81	477.43	309.11	1.15	4.24	0.9	0	1489.14
Mixed	324.68	81.85	4.07	275.14	476.34	348.89	0.85	24.75	0.53	0	1537.08
Municipal	686.08	74.56	5.1	194.92	714.87	540.36	0.51	9.28	1.24	0.78	2227.71
Parking	322.39	56.07	1.18	475.79	858.58	500.69	0.71	0	0	0	2215.4
Public	779.95	107.62	2.9	223.75	1009.9	651.17	1.58	7.32	1.25	0.3	2785.74
Residential	648.54	47.17	6.46	261.75	599.35	469.65	0.51	9.61	0.78	1.4	2045.23
Sport	344.12	52.93	29.66	337.23	1167.05	704.08	4.17	28.29	1.41	0	2668.94
Storage	81.18	0.47	0.06	281.22	175.33	291.4	0	0	0	0	829.66

Supplementary Table S12: The road MCIs in China

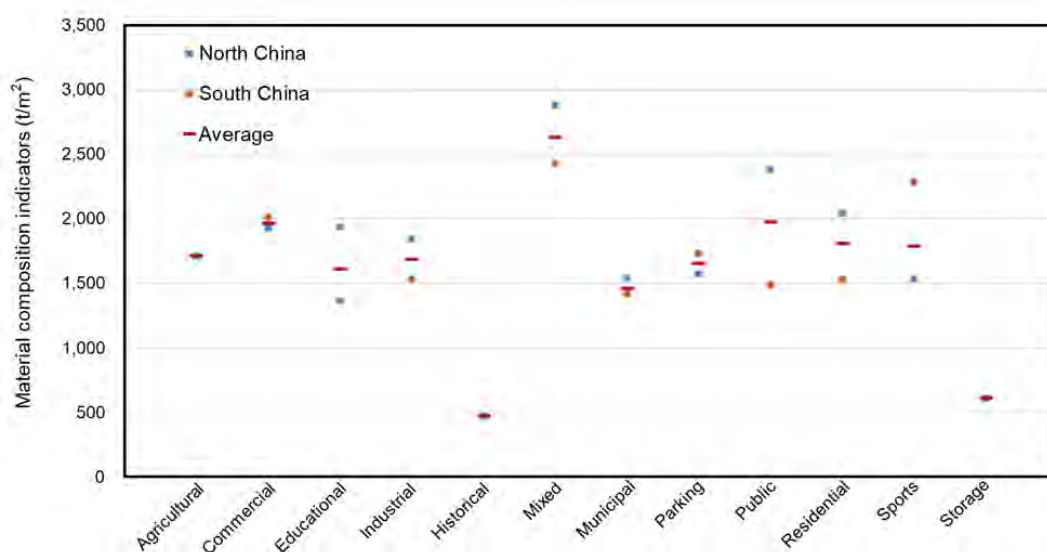
Road (ton/km)	Cement	Steel	Gravel	Sand	Asphalt	Mineral Powder	Total
Expressway	1102.35	0	73046.9	3625.08	1250.26	1184.64	80209.24
First	826.76	0	54785.18	2718.81	937.7	888.48	60156.93
Second	661.41	0	43828.14	2175.05	750.16	710.79	48125.54
Third	2685.26	41.73	23234.5	2615.71	2.74	0	28579.94
Fourth	1195.84	18.58	10347.1	1164.86	1.22	0	12727.6

Supplementary Table S13: The railway MCIs in China

Railway (ton/km)	Cement	Steel	Gravel	Sand	Lime	Fly ash	Copper	Aluminum	Total
Total	4040	350	13950	6530	1525	259	13	12	26679

Supplementary Table S14: The subway MCIs in China

Subway	Cement	Steel	Gravel	Sand	Asphalt	Copper	Total
Lines (ton/km)	18384.99	114	0	0	0	0	18499
Station (ton)	210554.7	16278.17	678.9	4366	3037.44	4.54	218642


Supplementary Figure S7: The difference between mci in the South and North

2 Material stocks calculation and prediction

2.1 Building material stocks estimation in the remaining 47 cities

This method uses contextual information such as building height, floor areas, and surrounding environment of the buildings, and applies machine learning to generalize building stocks to grid level for prediction. The algorithm uses Random Forest to integrate building features and point of interest features as the input vector for predicting building material stocks.

Algorithm 1: Random Forest method for predicting grid material stocks

Input: S : Train set $S = \{(v_i, ms_i), i = 1, 2, 3 \dots, n\}$ (V, MS) $\in R^d \times R$; v_i is the vector and ms_i is the true material stocks of grid i in train set;
 $v_t \in R^d$: Vector of grid t to be predicted

Output: Material Stocks of v_t

1 **for** $i = 1, 2, 3 \dots, N_{tree}$ **do**

- (1). The training set S_i is generated by Bootstrap sampling from the original training set S ;
- (2). Using S_i to generate a Decision Tree h_i ;
 - (a). D_{select} features are randomly selected from d-dimensional features
 - (b). Select the best feature from D_{select} features at each node according to the Gini index
 - (c). Split until the Decision Tree finishes

2 **end**

3 **Return** $ms_t = \frac{1}{N_{tree}} \sum_{i=1}^{N_{tree}} h_i(v_t)$

2.2 Building material stocks model validation

The proposed model predicts material stock on grids for any city. Four cross-validation methods are tested using data from three cities (Beijing, Guangzhou, and Shenzhen) and three algorithms (Linear Regression, XGBoost, and Random Forest). The best results are achieved with Random Forest in all three evaluation indicators (RMSE, MAE, and MAPE).

The cross-validation methods are: using one city for training and another for validation, using two cities for training and the rest for validation, randomly selecting 80% of grids within one city for training and the remaining 20% for validation, and mixing the grids of multiple cities and randomly selecting 80% for training and 20% for validation.

$$\text{MAE}(y, \hat{y}) = \frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i| \quad (1)$$

$$\text{RMSE}(y, \hat{y}) = \sqrt{\frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i|^2} \quad (2)$$

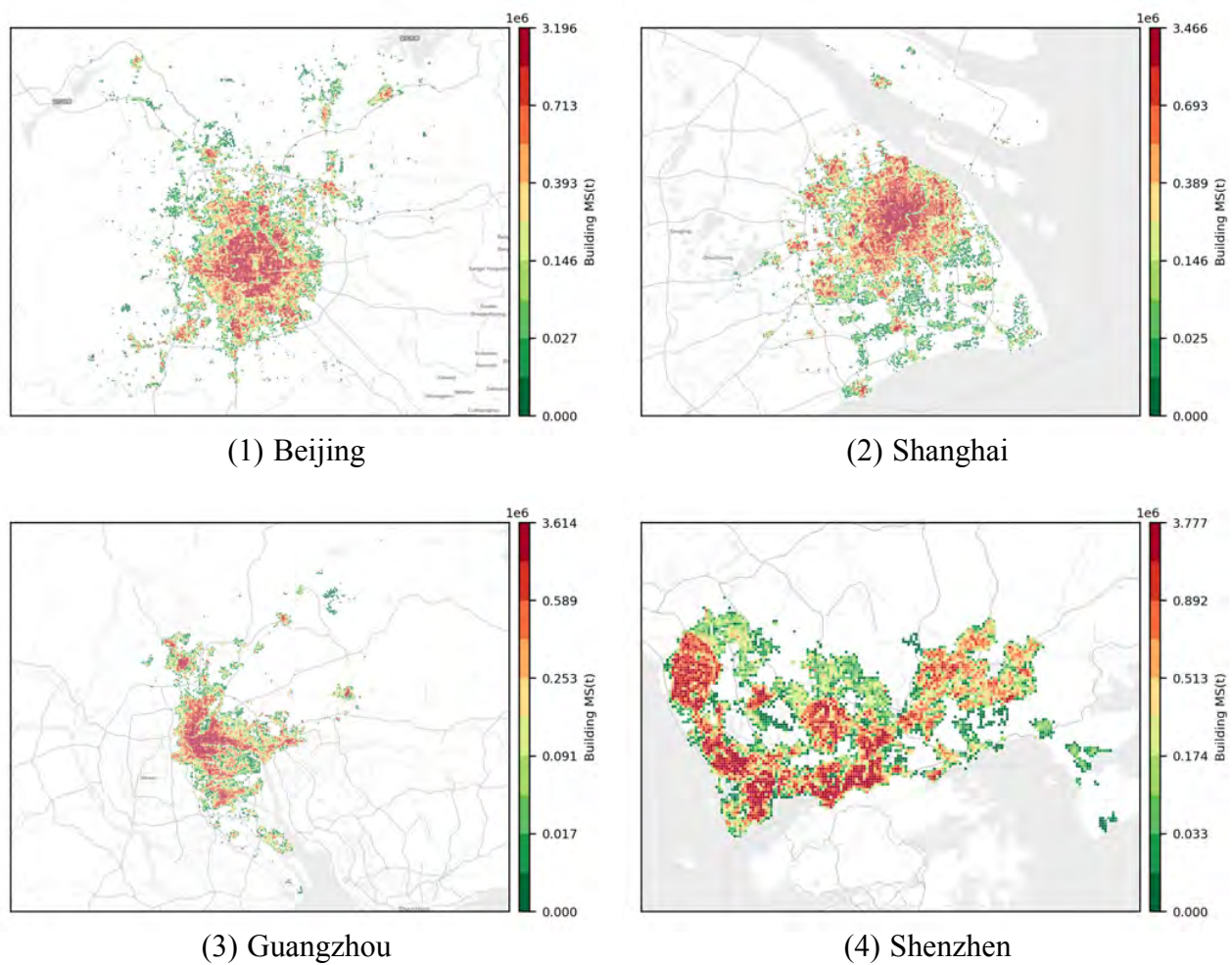
$$\text{MAPE}(y, \hat{y}) = \frac{1}{n} \sum_{i=1}^n \frac{|y_i - \hat{y}_i|}{|y_i|} \quad (3)$$

Supplementary Table S15: Comparison of Linear Regression, XGBoost and Random Forest prediction

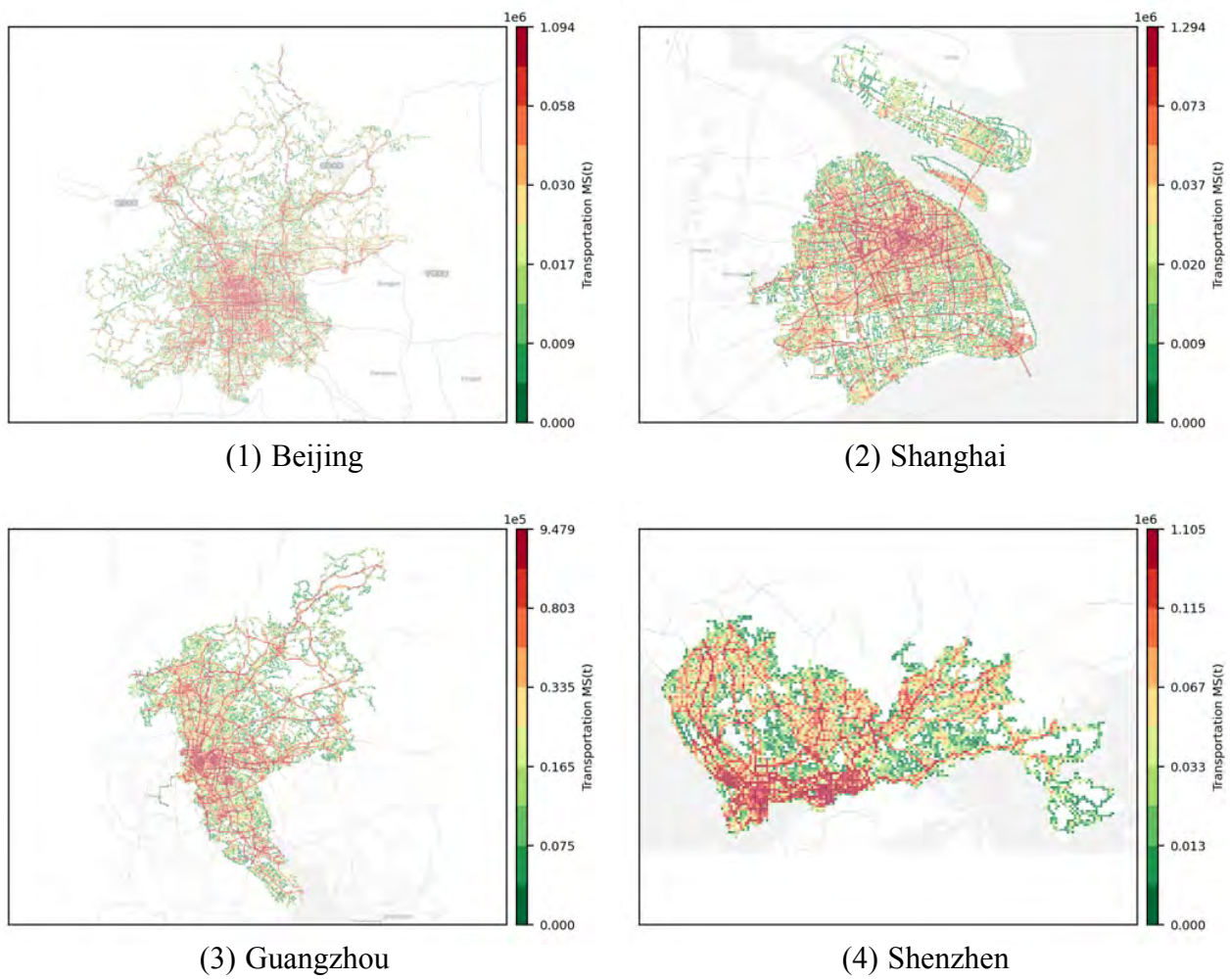
		RMSE	MAE	MAPE			RMSE	MAE	MAPE
	Linear	99444	58111	71.5891		Linear	97653	60597	26.8986
(1)	XGBoost	106513	58309	0.3318	(2)	XGBoost	107919	62693	0.2538
	Random Forest	98869	50531	0.3027		Random Forest	98900	55811	0.2251
		RMSE	MAE	MAPE			RMSE	MAE	MAPE
	Linear	78679	50340	8.5788		Linear	91230	53440	3006.78
(3)	XGBoost	84170	48990	0.1514	(4)	XGBoost	88685	49804	4.6270
	Random Forest	79213	47595	0.1524		Random Forest	88408	49047	0.4682

2.3 The urban built environment stocks in the 50 Chinese cities

Table S16 demonstrates the aggregate building material stocks of 50 cities, and Figure S8 shows the spatial distribution of building material stocks at a 500m*500m grid scale in Beijing, Shanghai, Guangzhou and Shenzhen respectively. The spatial distribution of building material stocks in the 50 Chinese cities are shown in Appendix A.2. The 500m spatial maps of transportation material stocks in Beijing, Shanghai, Guangzhou and Shenzhen are shown in Figure S9 (Appendix A.3 illustrates the distribution of transportation in the 50 Chinese cities).



Supplementary Figure S8: The spatial maps of building material stocks in 500m*500m grid in Beijing, Shanghai, Guangzhou and Shenzhen respectively



Supplementary Figure S9: The spatial maps of transportation material stocks in 500m*500m grid in Beijing, Shanghai, Guangzhou and Shenzhen respectively

Supplementary Table S16: The material composition of buildings in the 50 Chinese cities

City Stocks(Mt)	Cement	Steel	Timber	Brick	Gravel	Sand	Asphalt	Lime	Glass	Ceramic	Total
Beijing	1758.2485	121.0840	54.6134	904.9851	1121.3274	931.0633	4.5312	34.5480	3.3821	4.8627	4929.3834
Shanghai	1600.6439	121.2878	38.7239	812.3306	1191.9531	951.9587	3.7178	28.9175	2.9446	3.9704	4748.2243
Chongqing	857.4538	66.0436	18.2699	416.3391	682.1279	534.0772	1.8516	15.2269	1.5102	2.3180	2587.3129
Chengdu	1014.6834	74.4903	25.6988	517.6040	721.6352	575.8576	2.4729	18.7705	1.8489	2.7360	2953.5416
Tianjin	951.6486	69.5699	28.3206	518.8730	652.7814	533.0565	2.4446	18.2150	1.8018	2.6158	2772.6580
Suzhou	979.5417	76.0484	26.1531	520.6738	728.8278	579.6333	2.4421	18.3602	1.8940	2.8282	2935.1329
Guangzhou	752.4139	63.2904	15.6204	408.0448	688.9786	524.8832	1.3764	12.8870	1.2819	2.3804	2466.6082
Wuhan	854.4506	63.2917	22.7248	439.3692	609.6643	493.1745	2.0294	15.9936	1.5408	2.1908	2510.2015
Zhengzhou	809.6437	60.6686	19.4173	414.2551	613.3690	487.7789	1.8654	14.9010	1.5077	2.2483	2418.5373
Hangzhou	722.2827	53.9947	18.5998	364.4257	535.4931	425.3489	1.7007	13.2072	1.2972	2.0178	2134.6939
Shenzhen	821.5570	70.8517	11.1907	370.4786	753.6706	577.7579	1.3331	13.3883	1.2738	1.7089	2618.9959
Nanjing	756.3023	56.0827	20.3669	386.3933	551.3641	441.2907	1.8206	13.9574	1.3872	2.1398	2227.8594
Shenyang	827.8339	60.3448	22.5798	419.7614	564.2729	459.8693	2.0210	15.6566	1.4923	2.1532	2384.8694
Shijiazhuang	512.9953	38.3407	12.6715	270.3643	383.0593	304.6135	1.2273	9.4265	0.9723	1.4498	1534.7166
Qingdao	509.7379	37.4202	13.6438	266.3628	359.3305	287.4834	1.2103	9.4975	0.8956	1.3462	1488.2421
Dalian	559.3120	41.5073	14.7474	292.8505	399.2616	322.3785	1.3776	10.4413	1.0466	1.5007	1643.4492
Xi'an	601.0041	44.1145	16.0097	299.8059	421.3030	339.1554	1.4593	11.2710	1.0882	1.6130	1738.4226
Foshan	515.5225	45.2974	13.6893	299.7640	451.2496	344.7571	1.1943	9.2575	1.0385	1.9330	1668.0754
Hefei	441.1822	32.7215	10.8757	225.2856	316.0614	254.0397	1.0369	8.1364	0.7761	1.0796	1294.7239
Changchun	574.0054	41.2117	16.4715	298.0747	385.6073	316.0036	1.4960	11.1123	1.0725	1.5285	1646.8938

Continuation of Supplementary Table S16

City	Stocks(Mt)	Cement	Steel	Timber	Brick	Gravel	Sand	Asphalt	Lime	Glass	Ceramic	Total
Jinan		493.1010	35.3305	14.4618	257.0914	328.0123	270.8487	1.2546	9.6357	0.9008	1.2966	1415.2733
Weifang		280.7890	21.1067	7.6342	151.9471	203.8902	161.4724	0.6724	5.2650	0.4981	0.7753	830.4859
Wuxi		476.0545	36.2519	12.3013	255.8386	358.7024	284.6126	1.1045	8.5223	0.8813	1.3146	1437.1404
Ha'erbin		536.9279	39.8719	15.9086	275.3594	359.9333	296.4464	1.5131	10.6743	1.0835	1.6330	1540.9887
Ningbo		358.8517	27.9947	9.3923	192.1886	275.0749	215.6624	0.8543	6.6096	0.6632	1.0465	1087.5539
Baoding		331.2414	24.6253	8.5914	177.4036	244.3904	193.4340	0.8032	6.0483	0.6408	1.0083	991.2172
Fuzhou		345.6742	26.7935	8.8181	173.6099	274.3796	214.2387	0.8047	6.3524	0.6392	1.1833	1049.4306
Wenzhou		387.8801	30.4621	10.3768	200.2948	308.0494	239.3231	0.9459	7.1516	0.7487	1.4081	1185.3421
Nantong		286.3198	21.8105	7.3844	154.6882	217.3321	170.4487	0.6768	5.1485	0.5235	0.8283	866.0628
Kunming		372.8222	28.4671	8.0828	175.8619	286.1600	225.7592	0.8363	6.7680	0.6457	0.9513	1107.2830
Nanning		269.5607	21.5494	5.0689	131.6817	225.4177	174.8083	0.5496	4.6933	0.4829	0.7197	833.4751
Nanchang		219.2289	16.5878	5.6349	113.9163	164.6591	130.6944	0.5253	4.0961	0.3942	0.5999	653.6164
Taiyuan		297.4184	21.6519	8.3005	153.3190	202.8230	166.2682	0.7186	5.6863	0.5249	0.7646	859.5291
Xiamen		273.9399	21.7871	6.0506	130.2687	219.9460	172.1925	0.6118	4.9270	0.4949	0.7702	831.3891
Quanzhou		165.4211	13.6898	4.5325	93.2412	138.0448	105.7679	0.3889	3.0240	0.3115	0.6382	520.1931
Guiyang		203.7088	15.7858	4.5443	99.6607	159.2045	125.1857	0.4777	3.7398	0.3757	0.5669	612.3111
Hohhot		288.4269	20.9718	7.9792	147.8434	193.4492	158.1787	0.8071	5.6323	0.5658	0.7886	827.2159
Changsha		182.9990	13.7687	4.8448	97.9818	134.7588	106.6643	0.4396	3.4610	0.3298	0.5093	542.9844
Tangshan		219.8414	15.8293	6.3154	118.0009	154.1771	124.8317	0.5531	4.0661	0.4424	0.6773	647.1971
Yinchuan		232.3532	17.0580	6.1617	116.7246	157.6754	127.5361	0.6226	4.5255	0.4527	0.6396	665.2394
Linyi		205.3090	15.4638	5.0974	100.2850	142.2748	114.5403	0.5214	3.9950	0.3878	0.5428	590.8719

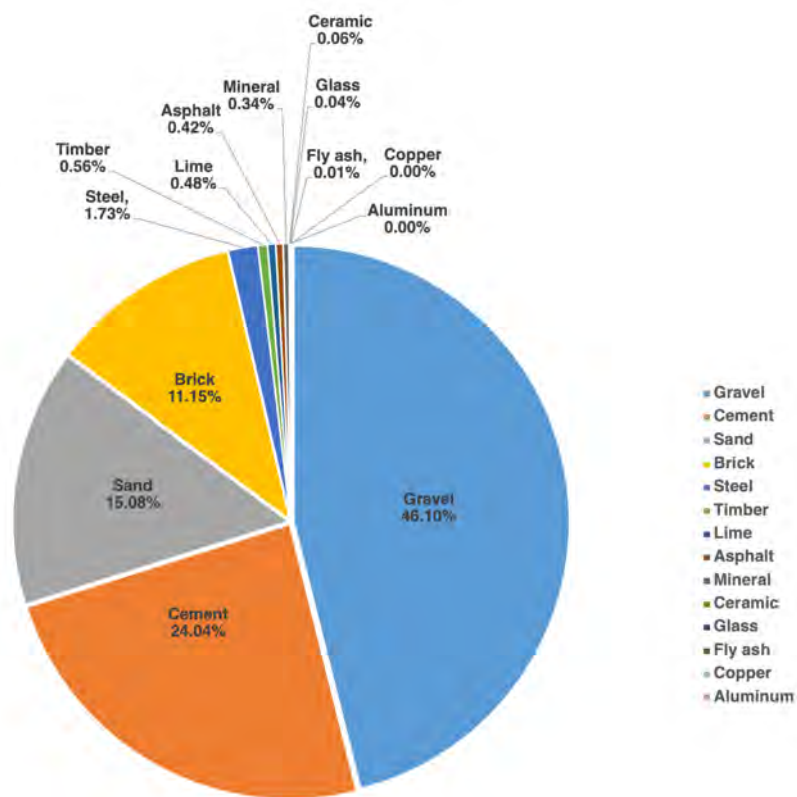
Continuation of Supplementary Table S16

City	Stocks(Mt)	Cement	Steel	Timber	Brick	Gravel	Sand	Asphalt	Lime	Glass	Ceramic	Total
Luoyang		176.8735	13.7810	4.4197	92.9963	142.9643	111.0989	0.3834	3.1486	0.3558	0.6012	543.1400
Lanzhou		163.4912	12.1677	4.3826	82.3150	115.2571	93.3404	0.4172	3.1171	0.3037	0.4234	476.8256
Urumqi		167.8433	11.8188	5.0104	88.2744	107.2804	88.9904	0.4670	3.1912	0.3076	0.4229	476.0511
Xining		174.9219	13.4640	4.5165	85.6396	122.9256	99.0090	0.4858	3.3292	0.3597	0.4980	508.1801
Haikou		135.0153	10.4832	2.6999	64.2755	108.0787	84.7801	0.2847	2.3909	0.2294	0.3292	408.4314
Handan		105.5042	7.5577	2.7661	51.1513	71.1826	57.3632	0.2803	2.0317	0.1964	0.2769	300.1306
Nanyang		31.5127	2.3640	0.8198	16.7862	22.7840	18.1822	0.0733	0.5999	0.0591	0.0750	93.1377
Lhasa		37.1500	2.5852	1.2095	21.3148	25.1117	20.2761	0.1049	0.6835	0.0676	0.1353	108.0761
Zhoukou		15.3208	1.1757	0.4018	8.5322	11.6252	9.2454	0.0348	0.2862	0.0267	0.0388	46.3438

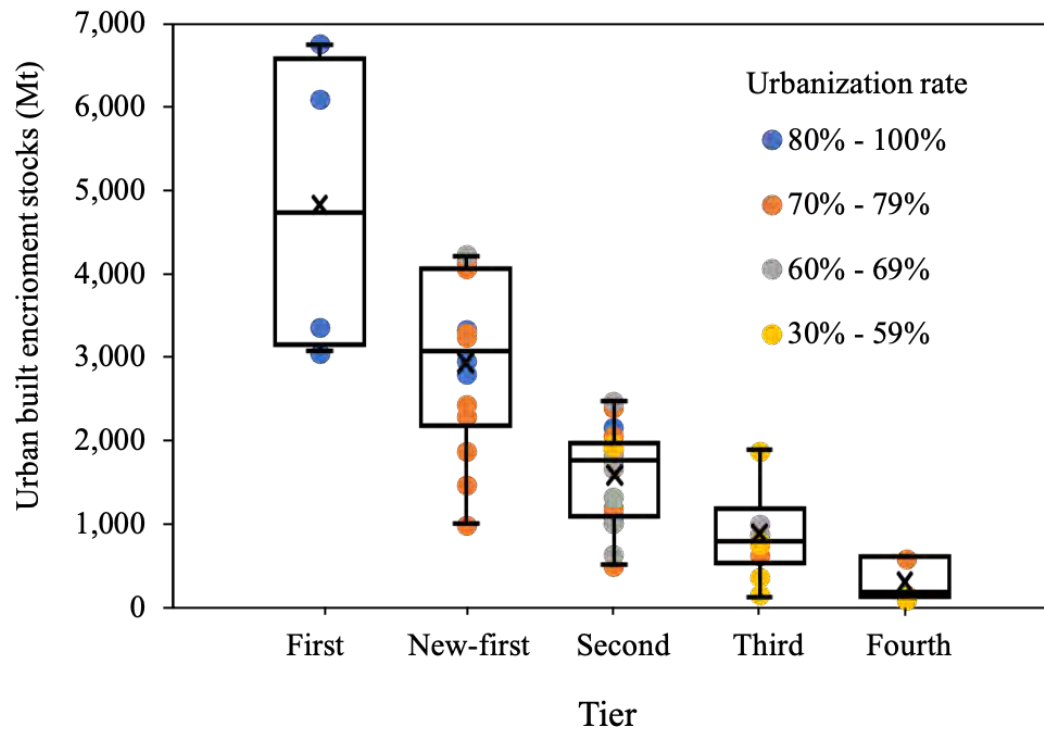
Supplementary Table S17: The t-test results for regression analysis between the socioeconomic factors and urban material stocks in China.

	Population	GDP	Built-up Area
Value	8.483 ***	14.838 ***	10.570 ***
Prob.	0.000	0.000	0.000
R-squared	0.600	0.817	0.699

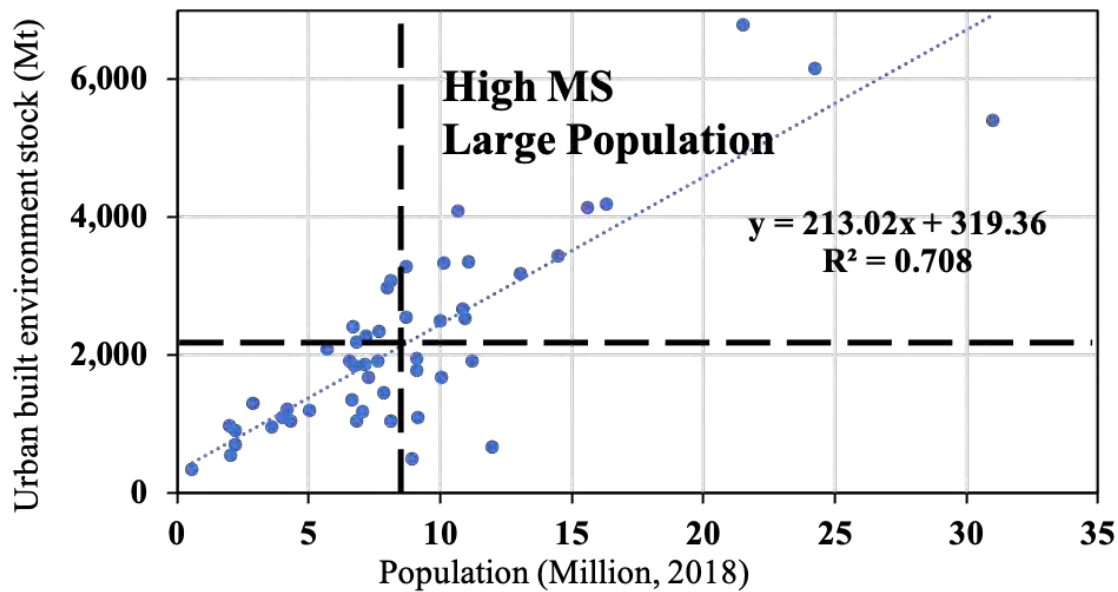
*Note: *** indicate significance at the 1% levels*



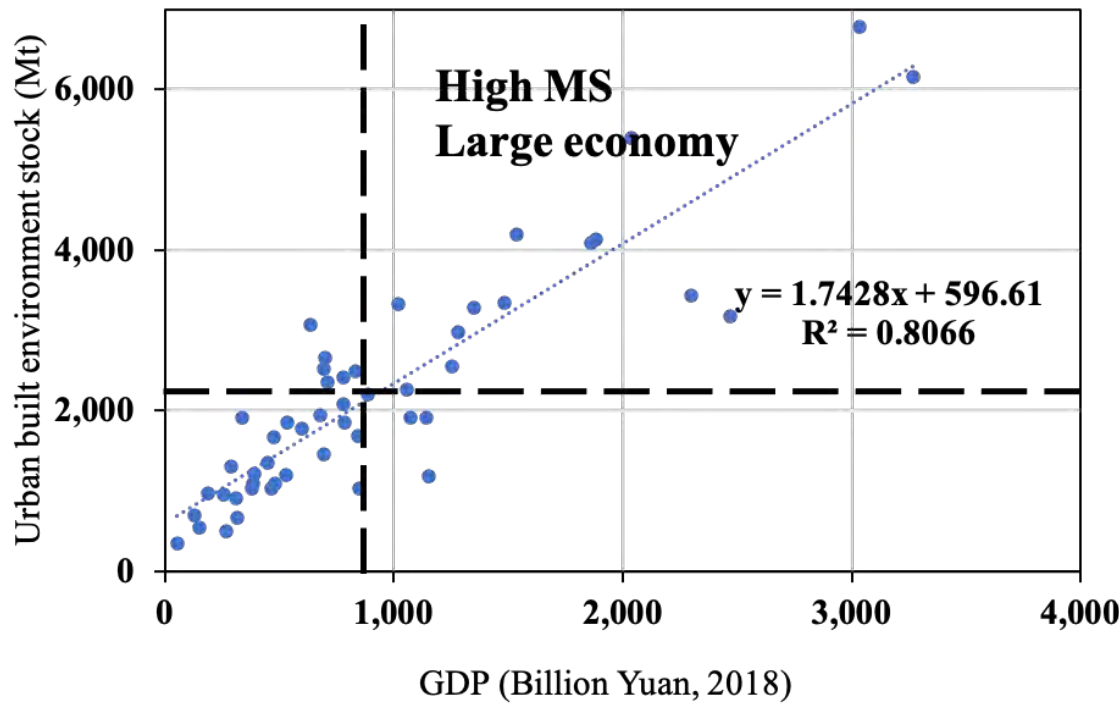
Supplementary Figure S10: The proportion of various materials in the built environment stock of 50 cities



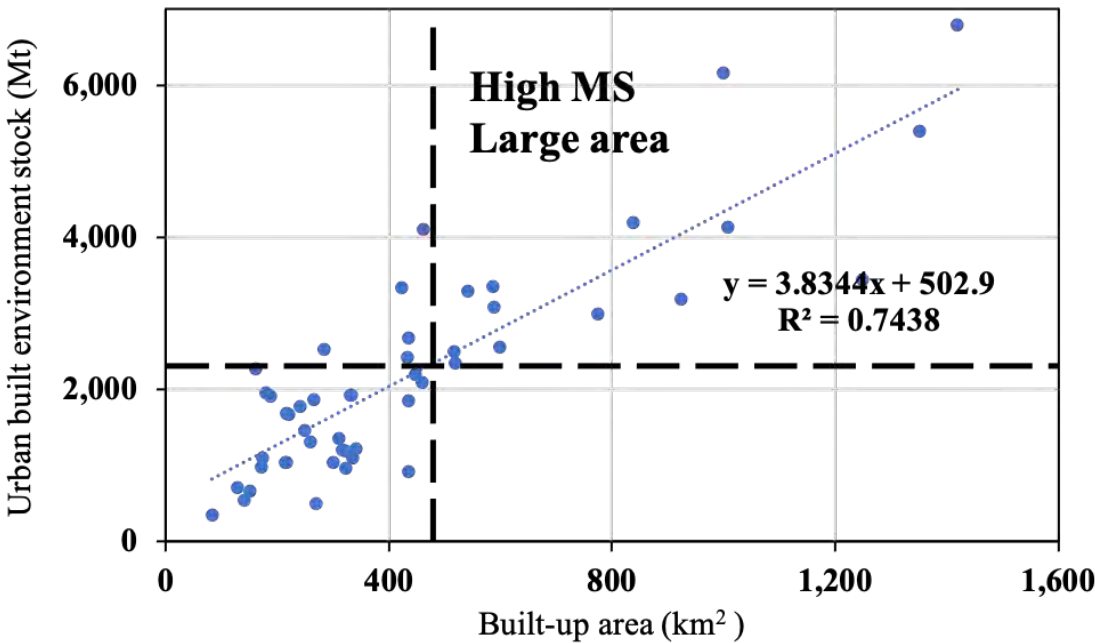
Supplementary Figure S11: The correlation between urban built environment stocks and urbanization rate and city tier



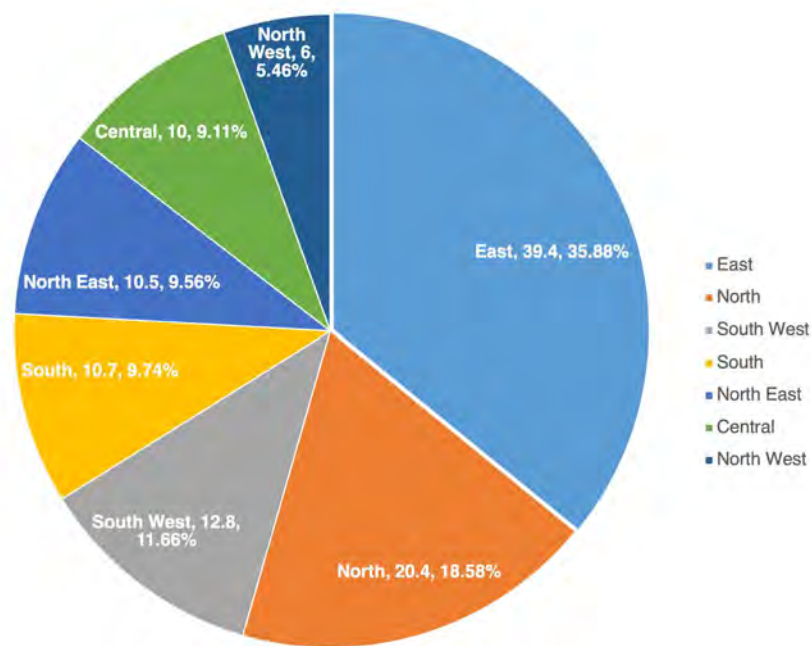
Supplementary Figure S12: The correlation between urban built environment stocks and Population



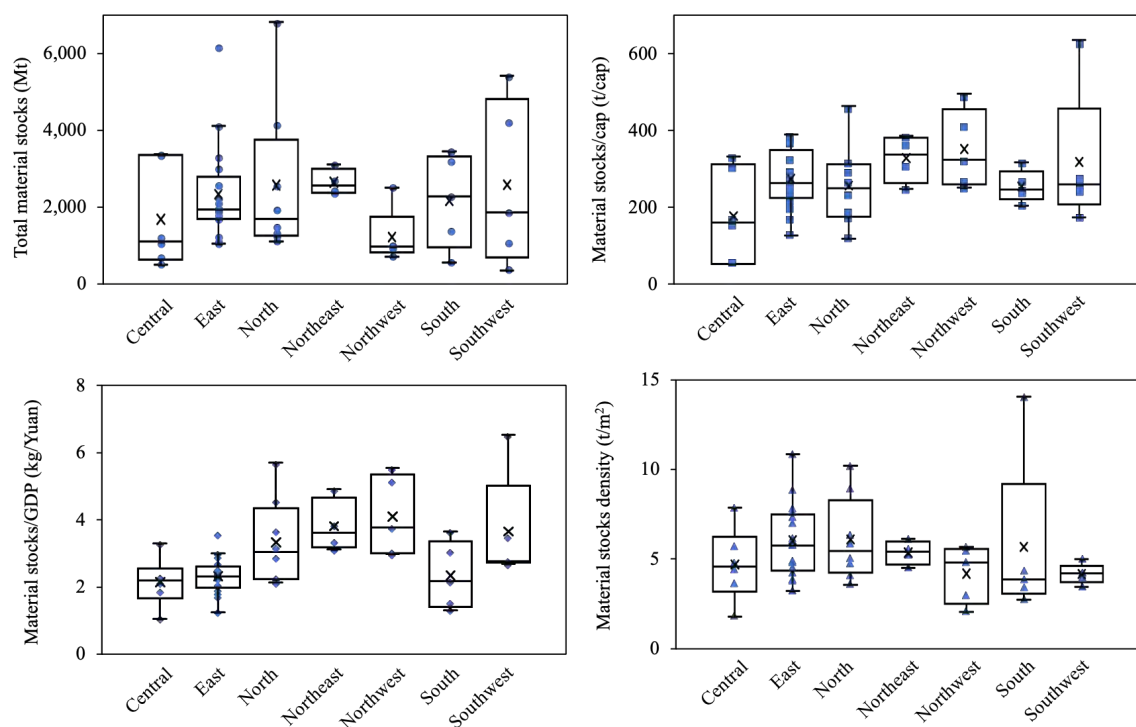
Supplementary Figure S13: The correlation between urban built environment stocks and GDP



Supplementary Figure S14: The correlation between urban built environment stocks and Built-up Area



Supplementary Figure S15: The proportion of different regions in the built environment stock



Supplementary Figure S16: The urban built environment stocks across seven geographical regions in (a) total quantity; (b) per capita, (c) per GDP; and (d) per m^2 levels.

Supplementary Table S18: Comparison of building material stocks among different case cities.

System boundary	Case city	Stocks (Gt)	Year	Reference
Buildings	Chongqing	2.59	2018	Our Study
	Fuzhou	1.05		
	hangzhou	2.14		
	Jinan	1.41		
	Nanjing	2.23		
	Qingdao	1.49		
	Shanghai	4.75		
	Shijiazhuang	1.54		
	Suzhou	2.94		
	Tianjin	2.78		
	Xiamen	0.83		
	Chongqing	3.46		
Buildings	Shanghai	4.16	2018	Song, L., et al.(2021)[10]
	Tianjin	2.18		
	Fuzhou	0.27		
	hangzhou	0.44		
	Jinan	0.41		
	Nanjing	0.44		
	Qingdao	0.31		
	Shanghai	1.66		
	Shijiazhuang	0.27		
	Suzhou	0.5		
	Tianjin	0.58		
	Xiamen	0.34		
Residential buildings	Shanghai	0.53	2010	Han J., et al.(2018)[12]

2.4 The comparison of urban built environment stocks in Chinese cities with cities in the literature

Table S19 presents a comparison between the urban built environment stocks of three major Chinese cities (Beijing, Shanghai, and Chongqing) and the average stock mass of 50 Chinese cities, with those of other global cities (such as Paris, Geneva, Philadelphia, and Vienna). The comparison covers two system boundaries, built environment and building, and three levels: total stock mass, stock per capita, and stock per m^2 .

Supplementary Table S19: Comparisons of urban built environment stocks among different case cities.

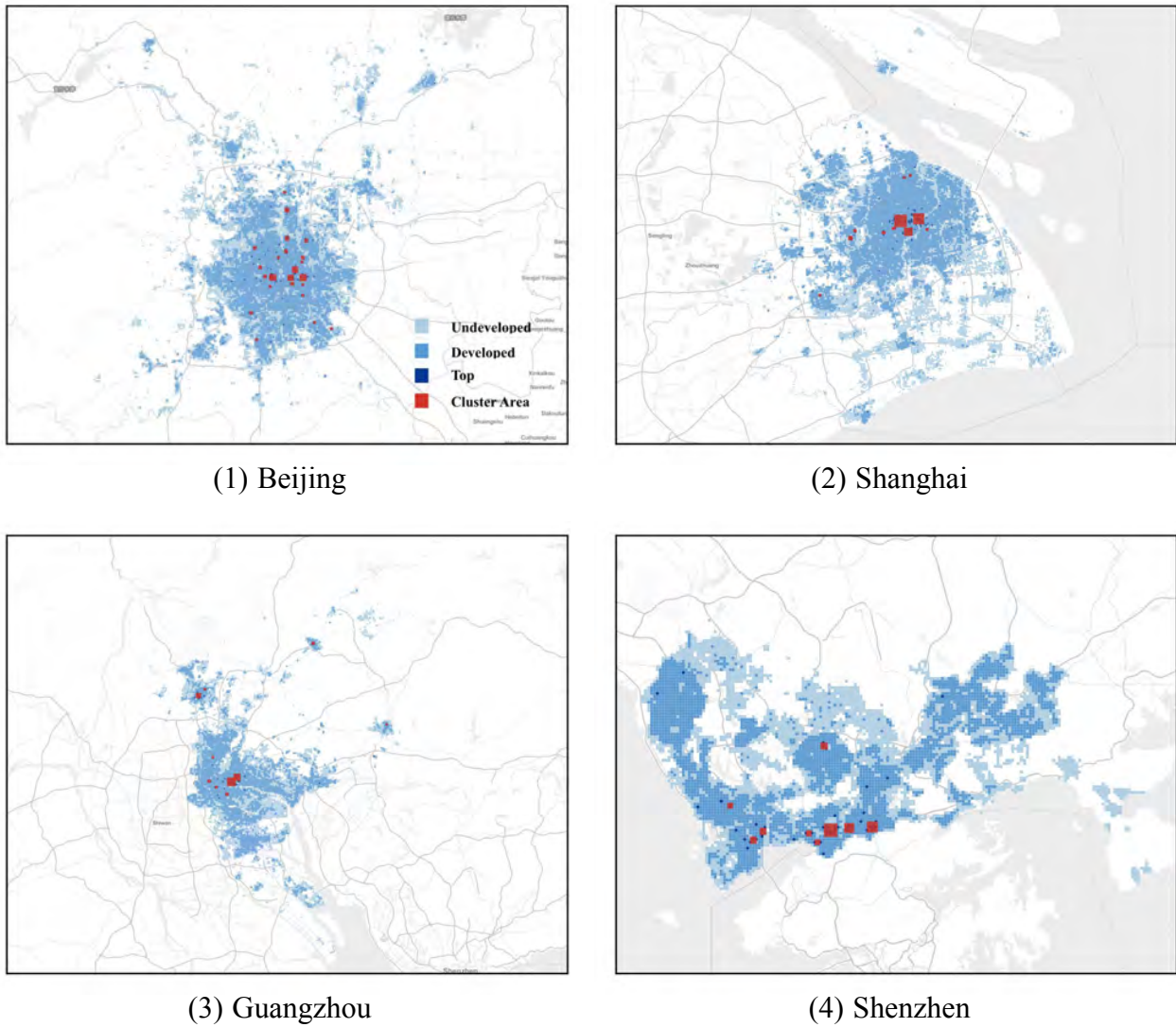
System	Case city	Stock quantity (Mt)	Stock per capita (ton/cap)	Stock density (t/m ²)	Reference
Built environment (including buildings and infrastructures)	Beijing	6,770	315	4.77	Our Study
	Shanghai	6,138	254	6.15	Our Study
	Chongqing	5,385	173	3.98	Our Study
	China average	2,200	261	5.21	Our Study
	Odense	67	329	0.22	Lanau, M., & Liu, G. (2020)[13]
	Paris	/	204	/	Augiseau, V.(2020)[14]
	Geneva	/	165	/	Emmenegger, M. F., et al. (2003)[15]
	Brussels	/	150	/	Environnement Bruxelles. (2015)[16]
	Manchester	NC	111	0.42	Tanikawa, H.,(2009)[17]
	Wakayama	NC	247	1.12	Tanikawa, H., (2009)[17]
Building	United Kingdom	17946	272	/	Streeck, J., (2017)[18]
	Beijing	4,938	229	3.48	Our Study
	Shanghai	4,753	196	4.76	Our Study
	Chongqing	2,594	84	1.92	Our Study
	China average	1,416	169	3.27	Our Study
	Paris	/	146	/	Augiseau, V.(2020)[14]
	Philadelphia	NC	/	1.37	Marcellus., et al.(2016)[19]
	Vienna	380	210	0.96	Kleemann, F., et al. (2017)[20]
	Padua	16	209	0.46	Miatto, A., et al.(2019)[21]
	Melbourne	33	/	0.9	Stephan, A.,(2017)[22]

Note: “/” indicates no result found in literature. “NC” indicates not comparable as these studies estimated the material stocks results in a limited geographical area.

3 Spatial analysis

3.1 Clustering analysis of grids with high building material stocks

Density-based clustering algorithm DBSCAN[23] is introduced to detect spatial distribution categories. The clustering process for top (1% largest grid) building material stocks grids is shown in Algorithm 2. Table S20 shows the clustering numbers of the 50 cities with different ϵ and MinPts. In this study we choose parameter $\epsilon = 1,000\text{m}$ and $\text{MinPts} = 2$, which reveal the most significant spatial patterns across parameters experimented. Figure S17 illustrates the distribution of high building material stocks clusters in Beijing, Shanghai, Guangzhou and Shenzhen respectively. The distribution of high building material stocks in the 50 Chinese cities are shown in Appendix A.4.



Supplementary Figure S17: The spatial maps of high building stocks clusters in Beijing, Shanghai, Guangzhou and Shenzhen respectively

Algorithm 2: Framework of DBSCAN for identifying Top building material stocks grids cluster

Input: S : The set of top 1% building material stocks grids; ϵ : The maximum distance between two samples in a neighborhood; $MinPts$: The number of samples in a neighborhood.

Output: Collection of density-based clusters.

```
1 Mark all objects as unvisited.
2 while no object in unvisited set do
3   Random select an objects  $p$  from unvisited set;
4   Mark  $p$  as visited;
5   if  $p$  has at least  $MinPts$  objects in  $\epsilon - neighborhood$  then
6     Create a new cluster  $C$  and add  $p$  to  $C$ ;
7      $N$  is the set of objects in the  $\epsilon - neighborhood$  of  $p$ ;
8     for  $p' \in N$  do
9       if  $p'$  is unvisited then
10        Mark  $p'$  as visited;
11      end
12      if  $p'$  has at least  $MinPts$  objects in  $\epsilon - neighborhood$  then
13        Add these objects to  $C$ ;
14      end
15      if  $p'$  does not belong to any cluster then
16        Add  $p'$  to  $C$ ;
17      end
18    end
19    Output  $C$ 
20  end
21  else
22    Mark  $p$  as Noise.
23  end
24 end
```

Supplementary Table S20: The number of Clusters numbers across cities with different experimented MinPts and ϵ

MinPts=2				MinPts=3			MinPts=2				MinPts=3		
City	1000	3000	5000	1000	3000	5000	City	1000	3000	5000	1000	3000	5000
Beijing	25	11	7	14	5	6	Baoding	9	5	5	4	3	3
Shanghai	11	7	6	7	5	4	Fuzhou	9	8	6	6	7	6
Chongqing	21	15	15	14	12	12	Wenzhou	13	9	9	8	6	6
Chengdu	12	11	6	6	6	5	Nantong	11	9	9	7	8	9
Tianjin	11	8	7	6	3	4	Kunming	6	3	2	2	3	2
Suzhou	28	17	13	14	11	7	Nanning	6	4	4	2	2	2
Guangzhou	10	5	5	6	5	5	Nanchang	2	1	1	1	1	1
Wuhan	8	9	7	3	3	2	Taiyuan	5	3	1	4	2	1
Zhengzhou	21	10	10	11	8	7	Xiamen	4	2	2	3	1	1
Hangzhou	13	9	6	8	8	5	Quanzhou	8	7	6	3	5	4
Shenzhen	9	4	3	6	4	3	Guiyang	2	1	1	1	1	1
Nanjing	13	8	5	6	6	4	Hohhot	3	1	1	1	1	1
Shenyang	9	4	3	5	3	3	Changsha	2	6	5	1	4	3
Shijiazhuang	14	10	8	3	5	5	Tangshan	4	2	1	0	1	1
Qingdao	10	6	5	5	4	3	Yinchuan	4	4	1	0	1	1
Dalian	6	6	4	5	4	4	Linyi	1	3	2	1	1	1
Xi'an	7	2	1	2	2	1	Luoyang	4	3	1	3	3	1
Foshan	15	6	3	7	5	3	Lanzhou	2	1	1	1	1	1
Hefei	6	4	2	3	2	2	Urumqi	1	1	1	1	1	1
Changchun	8	5	4	5	3	2	Xining	2	1	1	2	1	1
Jinan	5	3	1	3	3	1	Haikou	1	1	1	1	1	1
Weifang	14	5	5	8	5	5	Handan	1	2	1	0	1	1
Wuxi	7	8	7	3	4	4	Nanyang	1	1	1	0	1	1
Ha'erbin	7	7	4	2	5	4	Lhasa	1	1	1	1	1	1
Ningbo	13	6	6	9	6	5	Zhoukou	1	1	1	0	1	1

3.2 Calculation of dispersion index

The aggregation of top building material stocks grids in a city is measured by the average distance from the geometric center. The top building material stocks grids set of the city is formulated as $S = \{p_1, p_2, \dots, p_n\}$ where $p_i = (x_i, y_i)$ represents the location of grid i . The average distance from the geometric center (i.e., $Dist_avg$) is denoted as Equation 4

$$Dist_avg = \frac{\sum_{i=1}^n \sqrt{(x_i - \bar{x})^2 + (y_i - \bar{y})^2}}{n} \quad (4)$$

To eliminate the effect of city size, we propose dispersion index (DI) to accurately depict the high building material stocks grids distribution pattern of each city. DI 's calculation formula is denoted as Equation 5, where $Area_bu$ is the city's urban built-up area. Table S21 shows the DI values for building material stocks in the 50 cities.

$$DI = \frac{Dist_avg}{Area_bu} \quad (5)$$

Cities are further divided into three types based on the number of high material stocks clusters and the dispersion index. The classification rules are as follows:

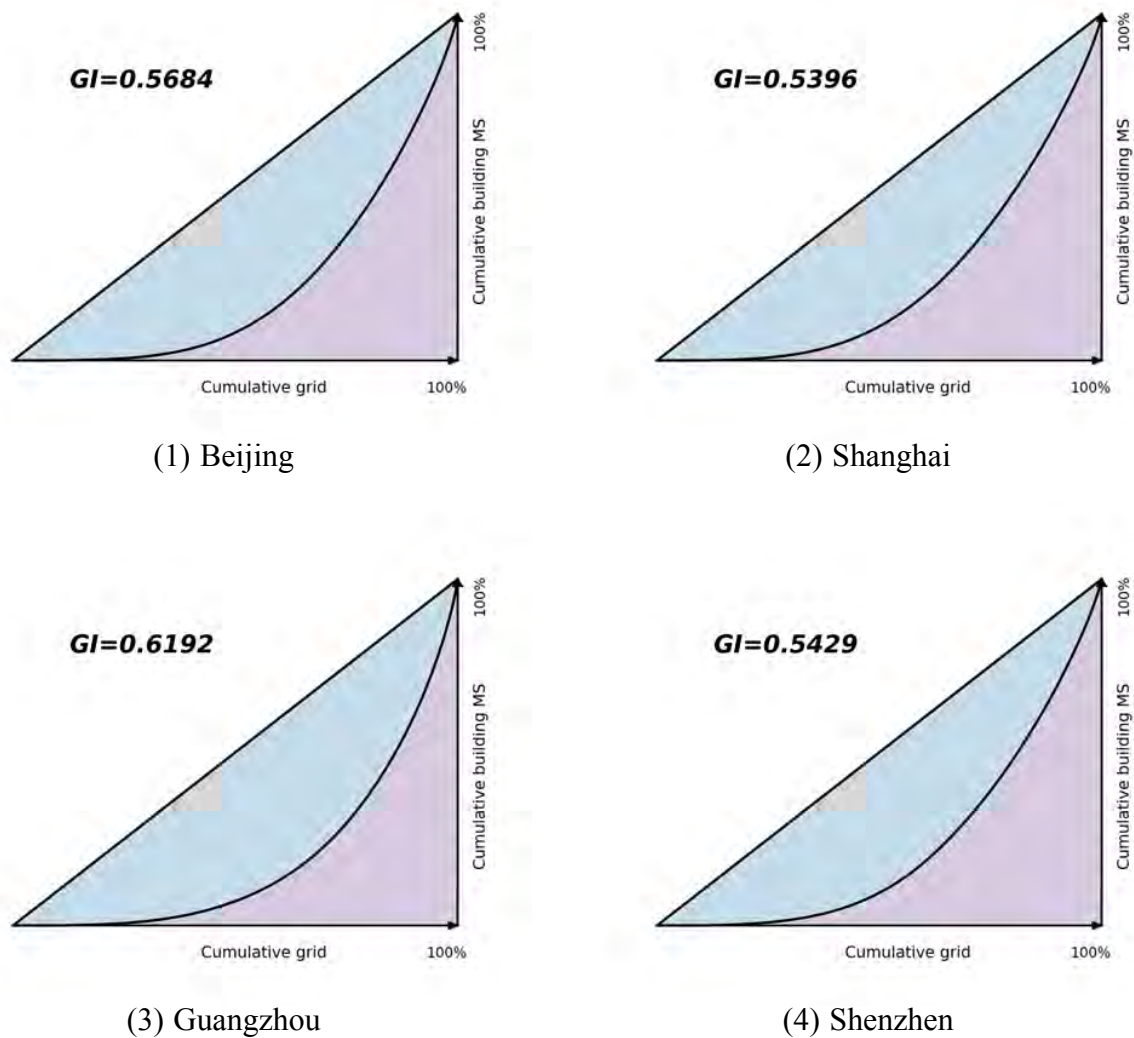
- Monocentric-concentration: The number of clusters is 1, or the clusters is 2 and dispersion index is smaller than 20.
- Multicentric-dispersion: The number of clusters is greater than or equal to 2, and dispersion index is greater than or equal to 20.
- Multicentric-concentration: The number of clusters is greater than 2 and dispersion index is smaller than 20.

Supplementary Table S21: The dispersion index (DI) results of the 50 Chinese cities

City	Built-up Area (km^2)	Dist_avg	DI	City	Built-up Area (km^2)	Dist_avg	DI
Beijing	1419.66	12123.60	8.54	Baoding	187.44	41488.74	221.34
Shanghai	998.75	9705.48	9.72	Fuzhou	265.33	23138.07	87.20
Chongqing	1350.66	47741.72	35.35	Wenzhou	241.4	20212.63	83.73
Chengdu	837.27	14345.45	17.13	Nantong	215.62	40780.90	189.13
Tianjin	1007.91	11973.30	11.88	Kunming	435.81	6954.93	15.96
Suzhou	461.65	25425.26	55.07	Nanning	310.47	13968.42	44.99
Guangzhou	1249.11	17391.33	13.92	Nanchang	317.3	2129.39	6.71
Wuhan	585.61	11416.81	19.50	Taiyuan	340	3812.56	11.21
Zhengzhou	422.35	23913.96	56.62	Xiamen	334.64	5189.38	15.51
Hangzhou	541.38	13611.56	25.14	Quanzhou	214	16742.35	78.24
Shenzhen	923.25	9771.10	10.58	Guiyang	299	1685.02	5.64
Nanjing	773.79	10693.63	13.82	Hohhot	260	4196.33	16.14
Shenyang	588.26	7860.55	13.36	Changsha	322.73	13806.50	42.78
Shijiazhuang	283.72	19460.30	68.59	Tangshan	249	5500.51	22.09
Qingdao	599.32	17567.62	29.31	Yinchuan	170.7	3747.92	21.96
Dalian	433.3	25204.35	58.17	Linyi	219.7	4664.62	21.23
Xi'an	517.74	4642.30	8.97	Luoyang	216.37	4378.67	20.24
Foshan	160.78	12625.47	78.53	Lanzhou	321.75	1717.24	5.34
Hefei	460	7040.15	15.30	Urumqi	436	987.60	2.27
Changchun	519.04	6895.68	13.29	Xining	129	1991.01	15.43
Jinan	447.69	6059.49	13.54	Haikou	140.59	1169.10	8.32
Weifang	179.34	21773.72	121.41	Handan	172.27	2548.73	14.79
Wuxi	332.01	30292.55	91.24	Nanyang	150.14	1303.87	8.68
Ha'erbin	435.81	12794.10	29.36	Lhasa	82.82	831.96	10.05
Ningbo	330.75	23599.00	71.35	Zhoukou	269	1399.71	5.20

3.3 Spatial unbalanced rate of building material stocks distributions

Building material stocks Gini index, based on normalized cumulative material stock on grids, is introduced to describe the unbalanced rate of stock distributions. Lorenz curve indicates the proportion of accumulated stocks assumed by the bottom x% of the grids. Table S22 and Figure S18 displays the statistical results of Gini index in the 50 cities and Lorenz curves for building stocks in Beijing, Shanghai, Guangzhou and Shenzhen respectively. The Lorenz curves for all the 50 Chinese cities are illustrated in Appendix A.5.



Supplementary Figure S18: The Lorenz curves for building stocks in Beijing, Shanghai, Guangzhou and Shenzhen respectively

Supplementary Table S22: The Gini index across cities

City	Gini	City	Gini
Beijing	0.5684	Baoding	0.7115
Shanghai	0.5396	Fuzhou	0.7098
Chongqing	0.7433	Wenzhou	0.7864
Chengdu	0.5704	Nantong	0.7110
Tianjin	0.5986	Kunming	0.6203
Suzhou	0.6990	Nanning	0.6350
Guangzhou	0.6192	Nanchang	0.7598
Wuhan	0.5765	Taiyuan	0.6394
Zhengzhou	0.6981	Xiamen	0.6132
Hangzhou	0.6464	Quanzhou	0.7469
Shenzhen	0.5429	Guiyang	0.6990
Nanjing	0.5844	Hohhot	0.5988
Shenyang	0.5479	Changsha	0.5163
Shijiazhuang	0.6335	Tangshan	0.4525
Qingdao	0.6785	Yinchuan	0.5843
Dalian	0.5724	Linyi	0.5572
Xi'an	0.6296	Luoyang	0.6518
Foshan	0.5902	Lanzhou	0.6296
Hefei	0.5749	Urumqi	0.3982
Changchun	0.4612	Xining	0.5892
Jinan	0.5799	Haikou	0.6613
Weifang	0.7568	Handan	0.5531
Wuxi	0.5598	Nanyang	0.4352
Ha'erbin	0.5435	Lhasa	0.5066
Ningbo	0.7153	Zhoukou	0.5521

Supplementary Table S23: The number of top building material stocks clusters, desperation index (DI) of clusters, building material stocks GINI index (GI), and the GDP Per Capita(GDP/cap) of 50 cities in three development stages.

Monocentric-concentration						Multicentric-dispersion						Multicentric-concentration					
Cluster=1 or (Cluster=2 and DI <20)						Cluster ≥ 2 and DI ≥ 20						Cluster >2 and DI <20					
City	Clusters	DI	GI	GDP/cap		City	Clusters	DI	GI	GDP/cap		City	Clusters	DI	GI	GDP/cap	
Guiyang	2	6	0.7	87963		Baoding	9	221	0.71	30349		Beijing	25	9	0.57	140945	
Haikou	1	8	0.66	73659		Changsha	2	43	0.52	163736		Changchun	8	13	0.46	92253	
Handan	1	15	0.55	41941		Chongqing	21	35	0.74	65645		Chengdu	12	17	0.57	93950	
Lanzhou	2	5	0.63	71326		Dalian	6	58	0.57	116966		Guangzhou	10	14	0.62	158621	
Lhasa	1	10	0.51	96571		Foshan	15	79	0.59	146732		Hefei	6	15	0.57	137228	
Linyi	1	21	0.56	47311		Fuzhou	9	87	0.71	110337		Hohhot	3	16	0.6	101150	
Nanchang	2	7	0.76	104643		Ha'erbin	7	29	0.54	64475		Jinan	5	14	0.58	130132	
Nanyang	1	9	0.44	26511		Hangzhou	13	25	0.65	155172		Kunming	6	16	0.62	79613	
Urumqi	1	2	0.4	138996		Luoyang	4	20	0.65	68047		Nanjing	13	14	0.58	160250	
Xining	2	15	0.59	58208		Nanning	6	45	0.64	67267		Shanghai	11	10	0.54	134814	
Zhoukou	1	5	0.55	30022		Nantong	11	189	0.71	115755		Shenyang	9	13	0.55	78395	
						Ningbo	13	71	0.72	141196		Shenzhen	9	11	0.54	189493	
						Qingdao	10	29	0.68	144048		Taiyuan	5	11	0.64	92476	
						Quanzhou	8	78	0.75	104145		Tianjin	11	12	0.6	120571	
						Shijiazhuang	14	69	0.63	63589		Wuhan	8	19	0.58	133998	
						Suzhou	28	55	0.7	174129		Xiamen	4	16	0.61	119487	
						Tangshan	4	22	0.45	88712		Xi'an	7	9	0.63	83490	
						Weifang	14	121	0.76	74862							
						Wenzhou	13	84	0.79	65855							
						Wuxi	7	91	0.56	174094							
						Yinchuan	4	22	0.58	95528							
						Zhengzhou	21	57	0.7	100592							
Average	1	9	0.58	70650		Average	11	70	0.65	105965		Average	9	13	0.58	120404	

3.4 Exponential distribution of building material stocks accumulation

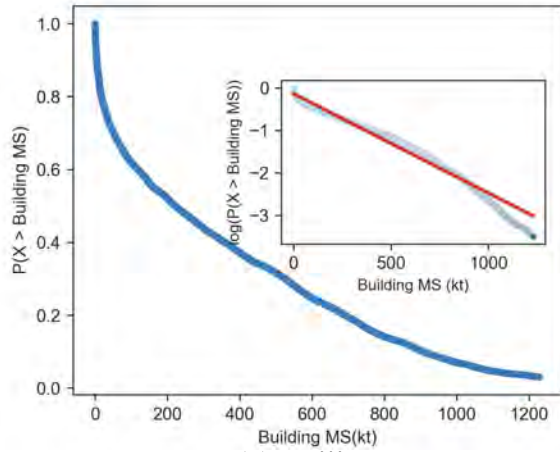
Understanding building stocks spatial distribution is essential for urban planning and development. We find that regardless of the size, development degree and location of the city, the building material stocks conform to a two-parameter exponential distribution on grid level. The formula for the probability density function (pdf) of the stock distribution is shown in Equation 6.

$$pdf(x; \mu, \theta) = \frac{1}{\theta} e^{-\frac{x-\mu}{\theta}} \quad (6)$$

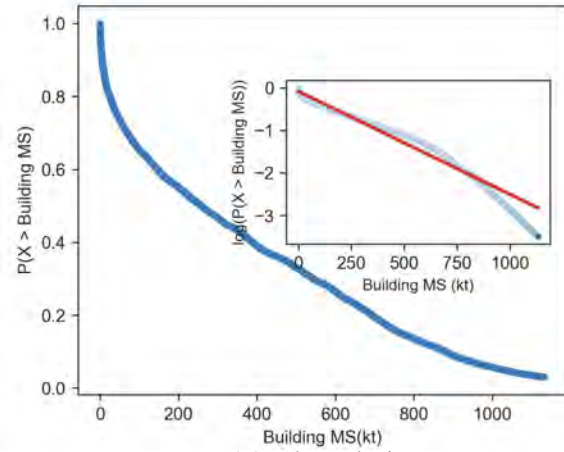
The complementary cumulative distribution function (ccdf) is denoted as Equation 7. On a logarithmic scale, the ccdf in the $x - \ln(ccdf)$ plane is a straight line with slope $-\frac{1}{\theta}$. Before the linear fit, a few outliers with Z-Score greater than 2.5 are removed.

$$\begin{aligned} ccdf(x; \mu, \theta) &= e^{-\frac{x-\mu}{\theta}} \\ \ln ccdf(x; \mu, \theta) &= -\frac{x-\mu}{\theta} \end{aligned} \quad (7)$$

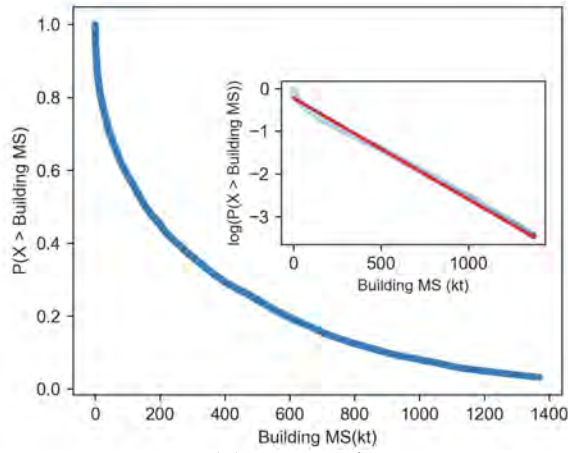
The two-parameter exponential distribution is determined by the location parameter μ and the scale parameter θ . Location parameter μ represents the probability of low building material stocks grids. The greater μ , the more low building material stocks grids in the city. Scale parameter θ indicates the steepness of the ccdf curve, which determines the unevenness of building material stocks distribution. The smaller θ value will lead to more unbalanced the building material stocks distribution and the steeper the curve. On the contrary, the greater the θ value, the more uniform the building material stocks distribution and the less steeper the curve.



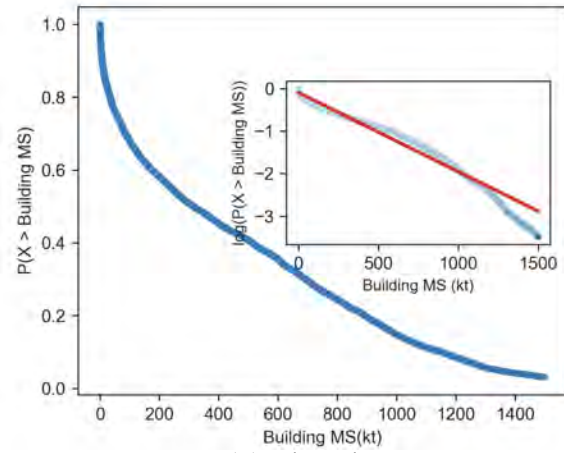
(1) Beijing



(2) Shanghai



(3) Guangzhou



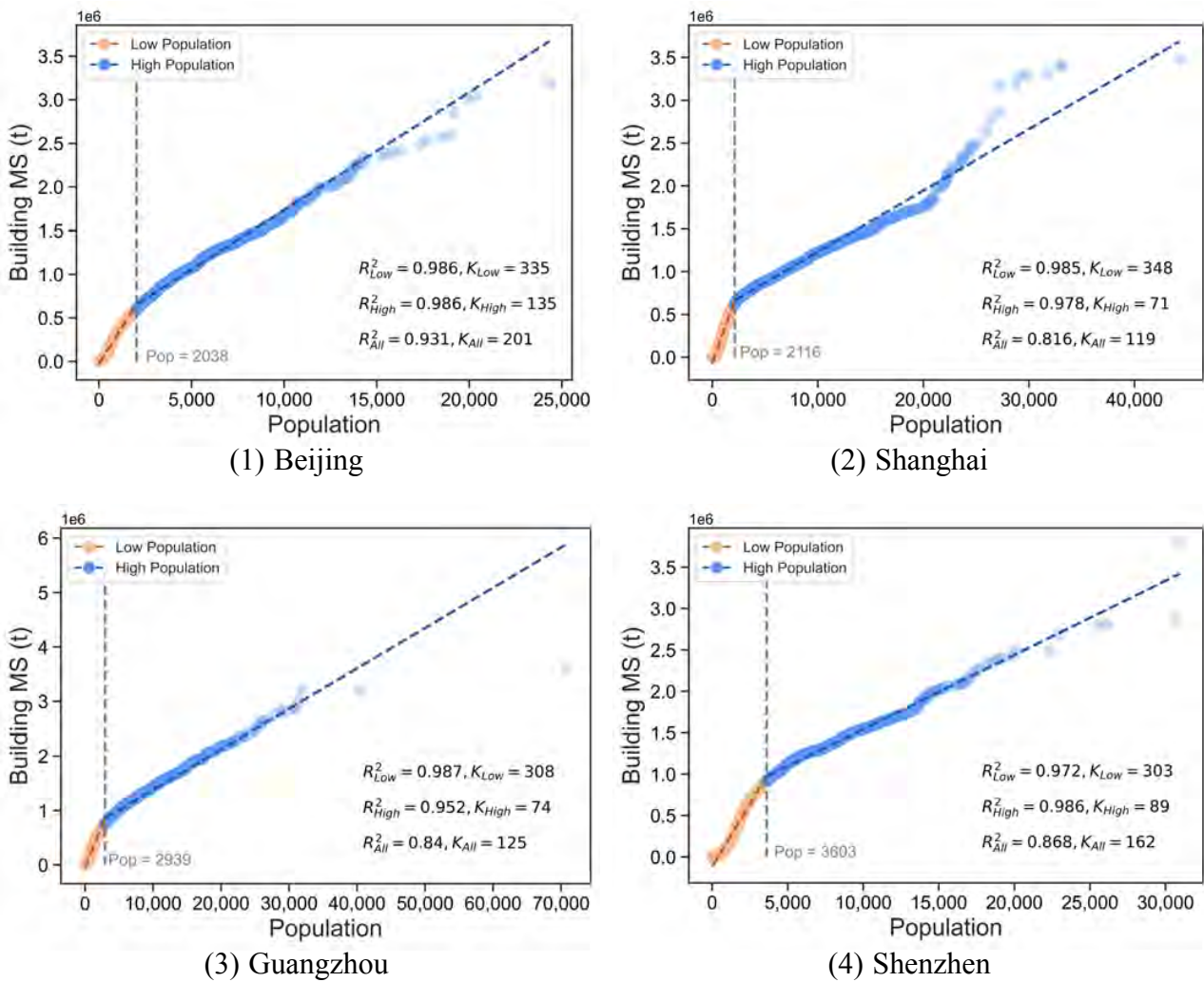
(4) Shenzhen

Supplementary Figure S19: The cdf curves for building stocks at 500m scale in Beijing, Shanghai, Guangzhou and Shenzhen respectively

We also supplement experiments at different spatial resolutions (including 250m, 500m, and 1000m) and find that the stock distribution within cities conforms to the two-parameter exponential distribution at any scale. And the higher the resolution, the more obvious this law, reflected in the higher R^2 value of the fitting curve (See Appendix A.6). This might be because the higher the resolution is, the purer the grid is (i.e., the heterogeneity is less obvious). Moreover, the law has nothing to do with the economic size of the city (developed or undeveloped). In view of this, the two-parameter exponential distribution is a general law for built environment stocks.

3.5 Correlations between population and building stocks

Geolocalized population map is used to estimate the per capita level material stocks. In addition, we plot the two stages (with a break point) of linear correlations between building stocks and population on the 500*500m grid level that are ranked in ascending order respectively. The breakpoint of population, determined from the continuous piecewise linear function algorithm [24], is also detected in the 50 cities. Figure S20 presents the correlations between population and building material stocks at grid level and the breakpoint of population in Beijing, Shanghai, Guangzhou and Shenzhen respectively. The correlations for all the 50 Chinese cities are illustrated in Appendix A.7.



Supplementary Figure S20: The correlations between the population and building stocks at grid level in Beijing, Shanghai, Guangzhou and Shenzhen respectively

3.6 Log-normal distribution of BtR ratio at grid level

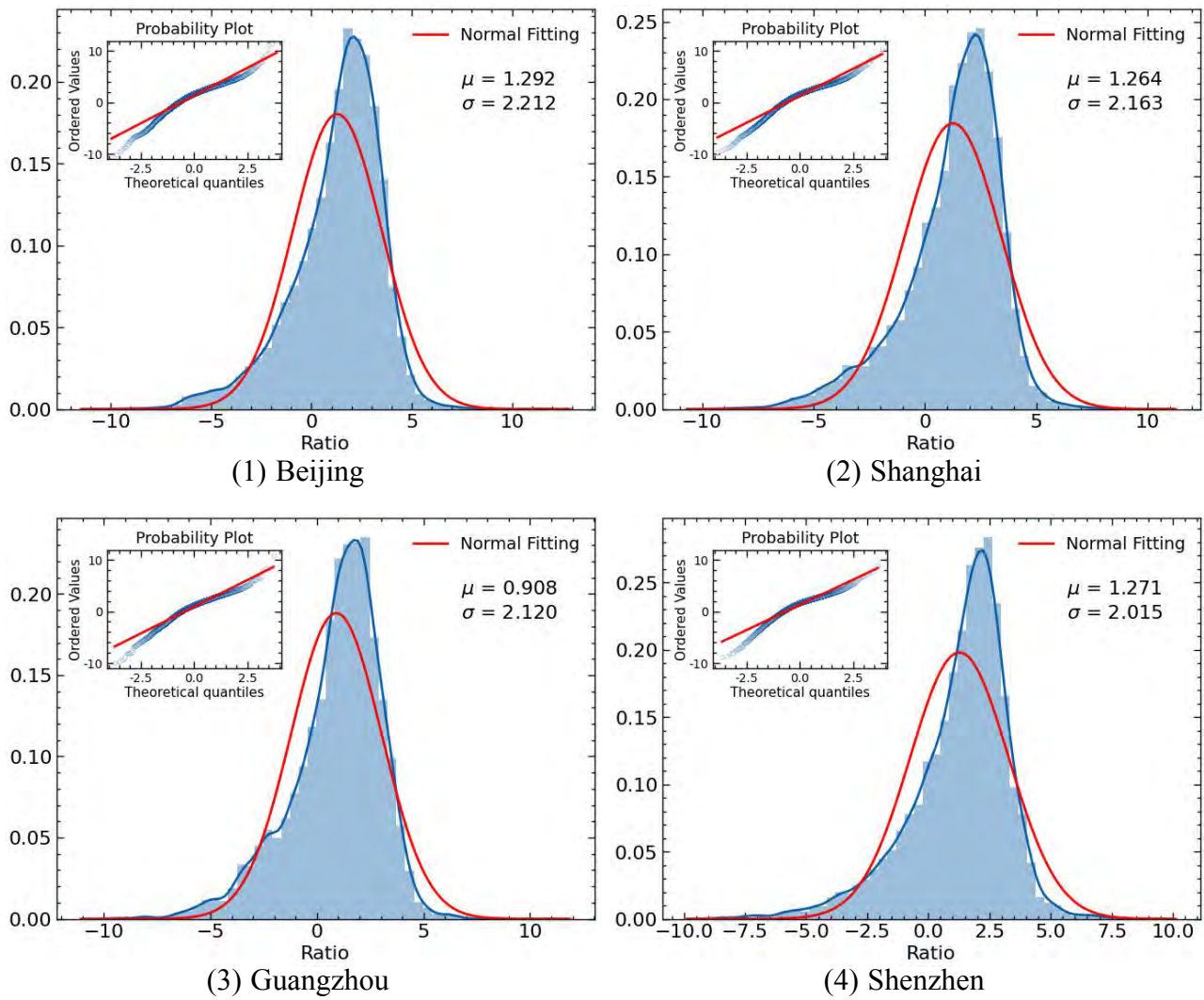
The BtR ratio (ratio of building stock to road stock) is defined as Equation 8, where $MS_{Building} > 0$ and $MS_{Road} > 0$.

$$Ratio = \frac{MS_{Building}}{MS_{Road}} \quad (8)$$

We find that all the 50 cities' BtR ratio approximately conform to a log-normal exponential distribution at 500m grid level. The formula for the probability density function of the BtR ratio is denoted as Equation 9.

$$pdf(x; \mu, \sigma) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left(-\frac{(\ln x - \mu)^2}{2\sigma^2}\right) \quad (9)$$

The Equation 9 can also be defined as $\ln(Ratio) \sim N(\mu, \sigma^2)$, where the μ and σ^2 represent mean and variance of normal distribution, respectively. Figure S21 illustrates the pdf curves and Probability Plot(P-P plot) of Beijing, Guangzhou, Shanghai and Shenzhen respectively. The BtR ratio pdf plot for all the 50 Chinese cities are illustrated in Appendix A.8.



Supplementary Figure S21: The pdf curves and P-P plot for BtR ratio in Beijing, Shanghai, Guangzhou and Shenzhen respectively

4 Carbon replacement value calculation

The carbon replacement value (CRV) of urban built environment stocks are estimated based on greenhouse gas (GHG) emission impact factors and calculated material stocks. GHG emission factors of different construction materials are fetched from local specific Chinese Life Cycle Database (CLCD) in eBalance software. The GHG emission inventory data are provided in kg carbon dioxide equivalent ($CO_2 - eq$) per ton construction material (see in Table S24).

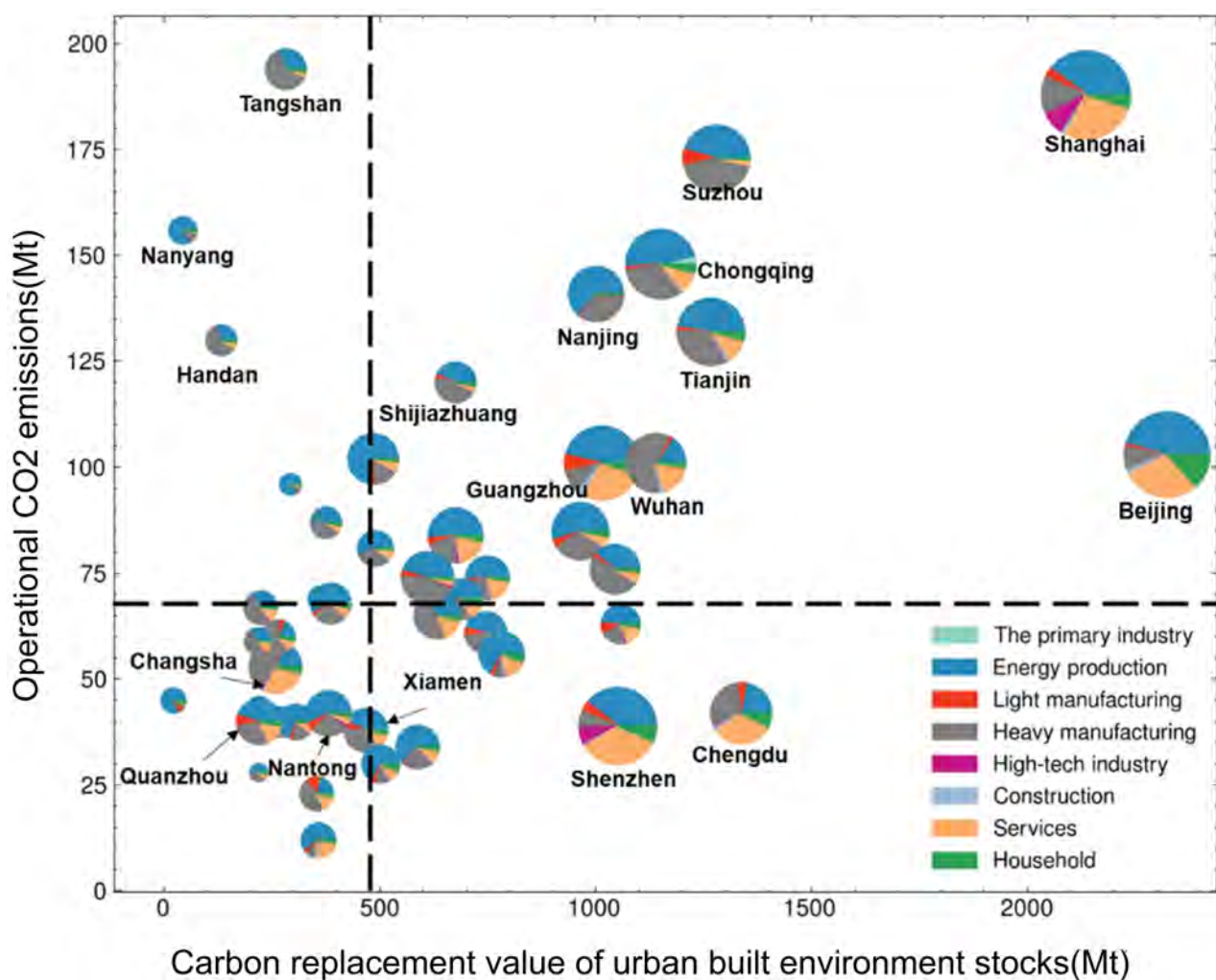
Equation 10 presents the CRV calculation formula, where CRV_m is the carbon replacement value for material m , summed up from building, road, railway and subway; $IF_{m,i}$ is the embodied GHG emission factor of material m in sector i ; and $MS_{m,i}$ is the stock of material m in sector i . The results of total carbon replacement value among 14 different materials in the 50 Chinese cities are illustrated in S25.

$$CRV_m = \sum_{i=1}^4 (IF_{m,i} \times MS_{m,i}) \quad (10)$$

Supplementary Table S24: The GHG emission factors of construction materials

Material	Emission Factor (kg CO2-eq/t)	Material	Emission Factor (kg CO2-eq/t)
Asphalt	221.00	Sand	1.26
Brick	271.00	Steel	2655.00
Cement	843.25	Timber	300.00
Ceramic	857.00	Silica fume	1.35
Glass	1136.00	Fly ash	107.00
Gravel	1.45	Copper	2710.00
Lime	740.00	Aluminum(Al)	1650.00

Figure S22 represents the operational CO2 emissions and carbon replacement value of urban built environment stocks in Chinese cities. The operational CO2 emissions are for the year 2010 and are acquired from literature[25] (Baoding, Foshan, Haikou and Lhasa are not presented due to data gaps); the circle size is proportional to the GDP of each city and the share indicates different sources of operational CO2 emissions. The carbon replacement value emissions are calculated based on our stock results and the method proposed in our earlier studies.



Supplementary Figure S22: The operational CO2 emissions and carbon replacement value of urban built environment stocks in Chinese cities

Supplementary Table S25: The aggregate building material stocks in the 50 Chinese cities

CRV (Mt)	Asphalt	Brick	Cement	Ceramic	Glass	Gravel	Lime	Sand	Steel	Timber	Silica fume	Fly ash	Copper	Al	Total
Baoding	2.35	48.08	311.24	0.86	0.73	1.52	5.66	0.32	67.39	2.58	0.01	0.03	0.04	0.02	440.82
Beijing	4.89	245.25	1638.43	4.17	3.84	3.79	29.13	1.33	344.52	16.38	0.02	0.09	0.12	0.06	2292.03
Changchun	1.80	80.78	530.54	1.31	1.22	1.40	9.91	0.46	115.72	4.94	0.01	0.04	0.05	0.03	748.22
Changsha	1.66	26.55	188.77	0.44	0.37	0.98	3.25	0.18	40.86	1.45	0.01	0.02	0.02	0.01	264.58
Chengdu	3.37	140.27	947.50	2.34	2.10	2.53	15.16	0.82	210.93	7.71	0.02	0.03	0.04	0.02	1332.84
Chongqing	7.49	112.83	848.08	1.99	1.72	4.48	14.75	0.89	189.15	5.48	0.04	0.09	0.11	0.06	1187.15
Dalian	1.90	79.36	523.99	1.29	1.19	1.50	9.92	0.48	117.08	4.42	0.01	0.05	0.07	0.04	741.29
Foshan	1.63	81.24	460.04	1.66	1.18	1.39	7.33	0.48	122.45	4.11	0.01	0.01	0.02	0.01	681.54
Fuzhou	1.75	47.05	333.66	1.01	0.73	1.39	5.35	0.34	74.84	2.65	0.01	0.02	0.02	0.01	468.82
Guangzhou	2.44	110.58	724.51	2.04	1.46	2.12	10.63	0.74	182.05	4.69	0.01	0.03	0.04	0.02	1041.34
Guiyang	1.29	27.01	188.44	0.49	0.43	0.76	3.92	0.19	44.16	1.36	0.01	0.03	0.04	0.02	268.15
Ha'erbin	2.77	74.62	502.70	1.40	1.23	1.92	10.32	0.47	110.49	4.77	0.01	0.06	0.08	0.04	710.88
Haikou	0.34	17.42	119.40	0.28	0.26	0.33	1.95	0.12	28.18	0.81	0.00	0.00	0.01	0.00	169.11
Handan	1.57	13.86	123.49	0.24	0.22	1.09	2.53	0.14	22.20	0.83	0.01	0.03	0.03	0.02	166.27
Hangzhou	2.80	98.76	684.34	1.73	1.47	2.17	10.51	0.63	152.41	5.58	0.01	0.02	0.02	0.01	960.48
Hefei	2.21	61.05	412.28	0.93	0.88	1.43	7.15	0.38	92.01	3.26	0.01	0.03	0.04	0.02	581.68
Hohhot	1.31	40.07	264.30	0.68	0.64	0.88	5.17	0.24	57.89	2.39	0.01	0.02	0.03	0.02	373.65
Jinan	2.12	69.67	448.54	1.11	1.02	1.46	8.66	0.41	96.90	4.34	0.01	0.04	0.05	0.03	634.35
Kunming	1.94	47.66	354.88	0.82	0.73	1.32	6.56	0.35	80.80	2.42	0.01	0.04	0.05	0.03	497.60

Continuation of Supplementary Table S25

CRV (Mt)	Asphalt	Brick	Cement	Ceramic	Glass	Gravel	Lime	Sand	Steel	Timber	Silica fume	Fly ash	Copper	Al	Total
Lanzhou	1.07	22.31	163.29	0.36	0.35	0.75	4.26	0.17	35.35	1.31	0.01	0.05	0.06	0.03	229.36
Lhasa	0.52	5.78	41.24	0.12	0.08	0.34	1.02	0.05	7.62	0.36	0.00	0.01	0.02	0.01	57.16
Linyi	2.38	27.18	216.16	0.47	0.44	1.57	4.19	0.24	43.63	1.53	0.01	0.03	0.04	0.02	297.89
Luoyang	1.38	25.20	163.66	0.52	0.40	0.83	3.10	0.18	37.60	1.33	0.01	0.02	0.02	0.01	234.26
Nanchang	1.30	30.87	216.48	0.51	0.45	0.90	4.63	0.21	48.25	1.69	0.01	0.04	0.05	0.03	305.42
Nanjing	2.19	104.71	699.85	1.83	1.58	1.68	11.97	0.62	158.60	6.11	0.01	0.04	0.05	0.03	989.27
Nanning	1.58	35.69	253.68	0.62	0.55	0.97	4.61	0.26	61.24	1.52	0.01	0.03	0.04	0.02	360.80
Nantong	2.00	41.92	270.90	0.71	0.59	1.35	4.29	0.28	59.37	2.22	0.01	0.01	0.01	0.01	383.67
Nanyang	1.58	4.55	42.15	0.06	0.07	0.76	1.34	0.07	7.39	0.25	0.01	0.02	0.03	0.02	58.29
Ningbo	2.15	52.08	343.40	0.90	0.75	1.43	5.33	0.33	78.64	2.82	0.01	0.01	0.01	0.01	487.88
Qingdao	2.85	72.18	481.49	1.15	1.02	1.84	7.78	0.44	104.82	4.09	0.01	0.02	0.02	0.01	677.74
Quanzhou	1.43	25.27	154.42	0.55	0.35	0.86	2.67	0.17	37.15	1.36	0.01	0.01	0.01	0.01	224.27
Shanghai	3.81	220.14	1499.28	3.40	3.35	3.32	23.34	1.31	346.27	11.62	0.02	0.05	0.07	0.03	2115.99
Shenyang	2.05	113.76	741.80	1.85	1.70	1.66	13.24	0.64	166.29	6.77	0.01	0.04	0.05	0.03	1049.89
Shenzhen	1.55	100.40	754.01	1.46	1.45	1.72	10.31	0.77	198.52	3.36	0.01	0.01	0.02	0.01	1073.59
Shijiazhuang	2.21	73.27	482.05	1.24	1.10	1.78	8.38	0.47	106.07	3.80	0.01	0.03	0.04	0.02	680.50
Suzhou	3.53	141.10	885.68	2.42	2.15	2.49	14.17	0.81	209.32	7.85	0.02	0.01	0.02	0.01	1269.59
Taiyuan	1.14	41.55	261.13	0.66	0.60	0.75	5.05	0.24	58.40	2.49	0.01	0.02	0.03	0.01	372.07
Tangshan	2.02	31.98	214.92	0.58	0.50	1.24	5.10	0.23	44.57	1.89	0.01	0.05	0.07	0.04	303.20
Tianjin	3.64	140.61	883.85	2.24	2.05	2.59	16.42	0.79	195.55	8.50	0.02	0.07	0.09	0.05	1256.47

Continuation of Supplementary Table S25

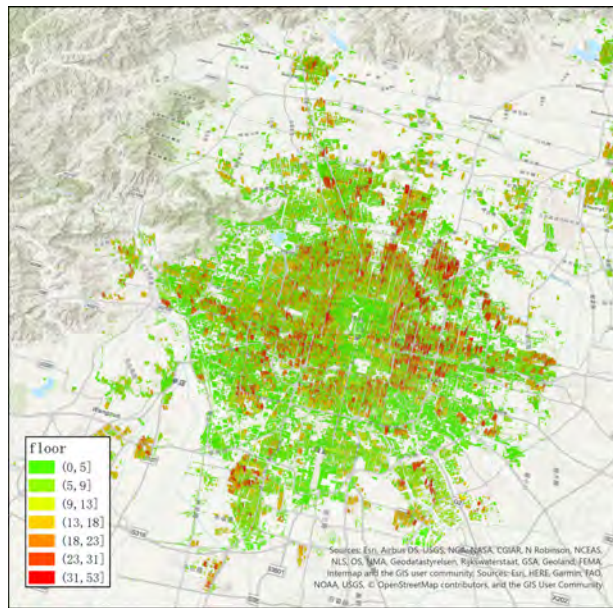
CRV (Mt)	Asphalt	Brick	Cement	Ceramic	Glass	Gravel	Lime	Sand	Steel	Timber	Silica fume	Fly ash	Copper	Al	Total
Urumqi	1.04	23.92	163.51	0.36	0.35	0.69	3.63	0.15	33.87	1.50	0.01	0.03	0.04	0.02	229.14
Weifang	2.74	41.18	275.49	0.66	0.57	1.70	5.05	0.29	58.28	2.29	0.01	0.03	0.04	0.02	388.36
Wenzhou	1.56	54.28	351.67	1.21	0.85	1.19	5.65	0.35	82.70	3.11	0.01	0.01	0.01	0.01	502.60
Wuhan	2.44	119.07	794.95	1.88	1.75	1.86	13.74	0.69	180.37	6.82	0.01	0.05	0.06	0.03	1123.71
Wuxi	1.36	69.33	427.77	1.13	1.00	1.11	6.86	0.40	99.36	3.69	0.01	0.01	0.02	0.01	612.06
Xiamen	0.76	35.30	249.52	0.66	0.56	0.63	3.84	0.24	60.58	1.82	0.00	0.00	0.01	0.00	353.92
Xi'an	1.97	81.25	557.25	1.38	1.24	1.52	9.82	0.49	123.95	4.80	0.01	0.04	0.05	0.03	783.80
Xining	0.56	23.21	154.78	0.43	0.41	0.42	2.95	0.14	36.36	1.35	0.00	0.01	0.02	0.01	220.65
Yinchuan	0.85	31.63	206.84	0.55	0.51	0.61	3.98	0.19	46.13	1.85	0.00	0.02	0.02	0.01	293.19
Zhengzhou	2.39	112.26	736.73	1.93	1.71	1.99	12.52	0.69	167.72	5.83	0.01	0.04	0.05	0.03	1043.88
Zhoukou	1.17	2.31	26.04	0.03	0.03	0.59	0.62	0.05	3.84	0.12	0.01	0.01	0.01	0.01	34.83

References

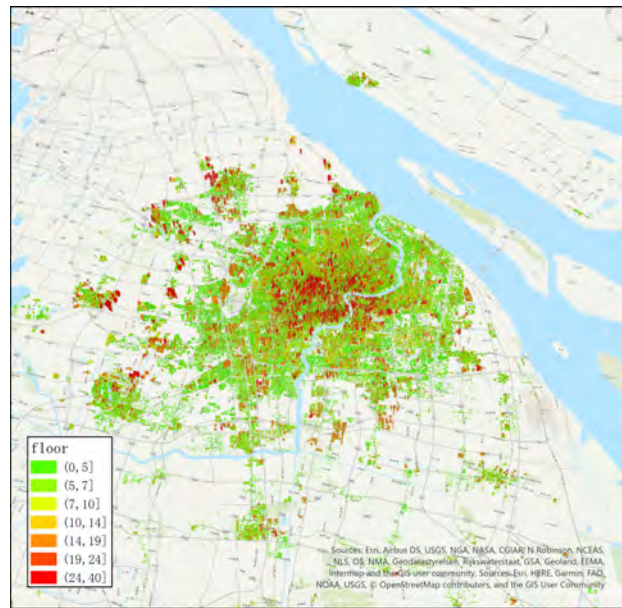
- [1] Ruichang Mao, Yi Bao, Zhou Huang, Qiance Liu, and Gang Liu. High-resolution mapping of the urban built environment stocks in beijing. *Environmental Science & Technology*, 54(9):5345–5355, 2020.
- [2] Geoff Boeing. Osmnx: New methods for acquiring, constructing, analyzing, and visualizing complex street networks. *Computers, Environment and Urban Systems*, 65:126–139, 2017.
- [3] Peng Gong, Bin Chen, Xuecao Li, Han Liu, Jie Wang, Yuqi Bai, Jingming Chen, Xi Chen, Lei Fang, Shuailong Feng, et al. Mapping essential urban land use categories in china (euluc-china): preliminary results for 2018. *Science Bulletin*, 65(3):182–187, 2020.
- [4] H Yu and GJ Li. *Construction project investment estimation handbook*. China Architecture & Building Press, 1999.
- [5] Wang Du. *Building cost estimation handbook*. Beijing. China Architecture & Building Press, 1996.
- [6] Li Ling. *Building cost estimation handbook*. Beijing. China Statistics Press, 2002.
- [7] Beijia Huang, Feng Zhao, Tomer Fishman, Wei-Qiang Chen, Niko Heeren, and Edgar G Hertwich. Building material use and associated environmental impacts in china 2000–2015. *Environmental science & technology*, 52(23):14006–14014, 2018.
- [8] Dong Yang, Jing Guo, Lingwen Sun, Feng Shi, Jingru Liu, and Hiroki Tanikawa. Urban buildings material intensity in china from 1949 to 2015. *Resources, Conservation and Recycling*, 159:104824, 2020.
- [9] Tao Wang, Jun Zhou, Ye Yue, Jie Yang, and Seiji Hashimoto. Weight under steel wheels: Material stock and flow analysis of high-speed rail in china. *Journal of Industrial Ecology*, 20(6):1349–1359, 2016.
- [10] Lulu Song, Ji Han, Nan Li, Yuanyi Huang, Min Hao, Min Dai, and Wei-Qiang Chen. China material stocks and flows account for 1978–2018. *Scientific Data*, 8(1):1–9, 2021.
- [11] Jing Guo, Alessio Miatto, Feng Shi, and Hiroki Tanikawa. Spatially explicit material stock analysis of buildings in eastern china metropolises. *Resources, Conservation and Recycling*, 146:45–54, 2019.
- [12] Ji Han, Wei-Qiang Chen, Lixiao Zhang, and Gang Liu. Uncovering the spatiotemporal dynamics of urban infrastructure development: A high spatial resolution material stock and flow analysis. *Environmental science & technology*, 52(21):12122–12132, 2018.
- [13] Maud Lanau and Gang Liu. Developing an urban resource cadaster for circular economy: A case of odense, denmark. *Environmental science & technology*, 54(7):4675–4685, 2020.

- [14] Vincent Augiseau. Construction materials flows and stocks in paris region: an overview. *Ecocycles*, 6(1):18–22, 2020.
- [15] M Faist Emmenegger, R Frischknecht, L Cornaglia, and S Rubli. Métabolisme des activités économiques du canton de genève—phase 1. *SubStance*, 41(0):106, 2003.
- [16] Bruxelles Environnement. Métabolisme de la région de bruxelles-capitale: Identification des flux, acteurs et activités économiques sur le territoire et pistes de réflexion pour l’optimisation des ressources. *Rapport compilé par Batir, Ecores et ICEDD*, 2015.
- [17] Hiroki Tanikawa and Seiji Hashimoto. Urban stock over time: spatial material stock analysis using 4d-gis. *Building Research & Information*, 37(5-6):483–502, 2009.
- [18] Jan Streeck, Dominik Wiedenhofer, Fridolin Krausmann, and Helmut Haberl. Stock-flow relations in the socio-economic metabolism of the united kingdom 1800–2017. *Resources, Conservation and Recycling*, 161:104960, 2020.
- [19] Kimberlee A Marcellus-Zamora, Patricia M Gallagher, Sabrina Spatari, and Hiroki Tanikawa. Estimating materials stocked by land-use type in historic urban buildings using spatio-temporal analytical tools. *Journal of Industrial Ecology*, 20(5):1025–1037, 2016.
- [20] Fritz Kleemann, Jakob Lederer, Helmut Rechberger, and Johann Fellner. Gis-based analysis of vienna’s material stock in buildings. *Journal of Industrial Ecology*, 21(2):368–380, 2017.
- [21] Alessio Miatto, Heinz Schandl, Luigi Forlin, Fabio Ronzani, Paolo Borin, Andrea Giordano, and Hiroki Tanikawa. A spatial analysis of material stock accumulation and demolition waste potential of buildings: A case study of padua. *Resources, Conservation and Recycling*, 142:245–256, 2019.
- [22] André Stephan and Aristide Athanassiadis. Quantifying and mapping embodied environmental requirements of urban building stocks. *Building and Environment*, 114:187–202, 2017.
- [23] Martin Ester, Hans-Peter Kriegel, Jörg Sander, and Xiaowei Xu. A density-based algorithm for discovering clusters in large spatial databases with noise. In *Proceedings of the Second International Conference on Knowledge Discovery and Data Mining*, KDD’96, page 226–231, 1996.
- [24] Charles F Jekel and Gerhard Venter. pwlf: A python library for fitting 1d continuous piecewise linear functions. URL: https://github.com/cjekel/piecewise_linear_fit_py, 2019.
- [25] Yuli Shan, Jianghua Liu, Zhu Liu, Shuai Shao, and Dabo Guan. An emissions-socioeconomic inventory of chinese cities. *Scientific data*, 6(1):1–10, 2019.

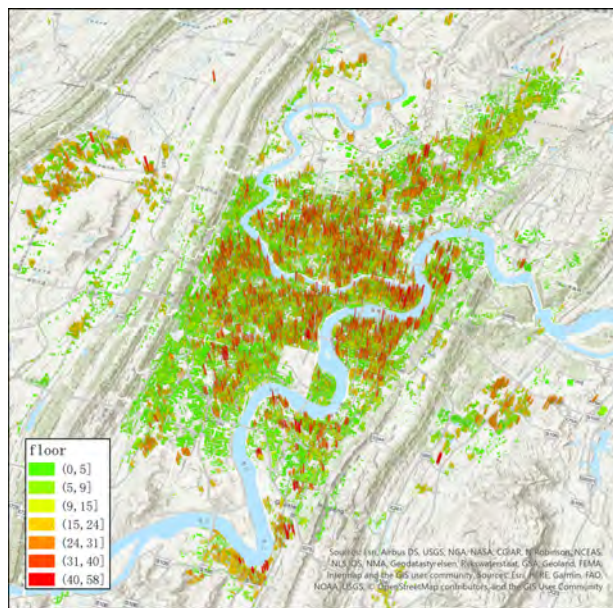
A.1 The building geometries collected in the 50 Chinese cities



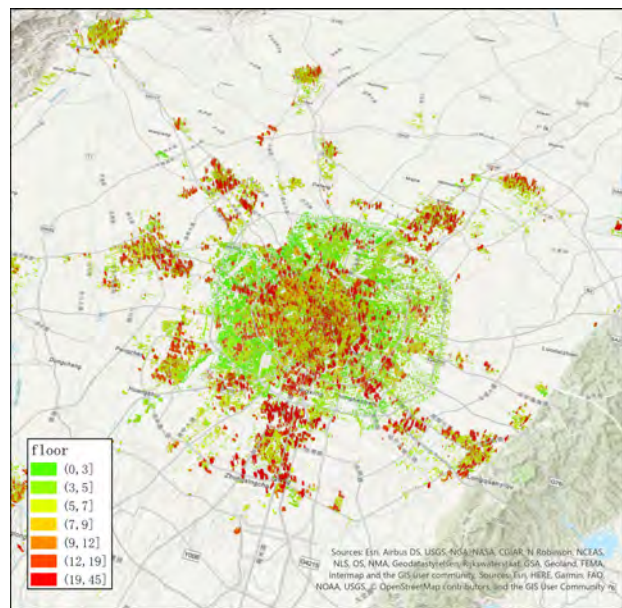
(1) Beijing



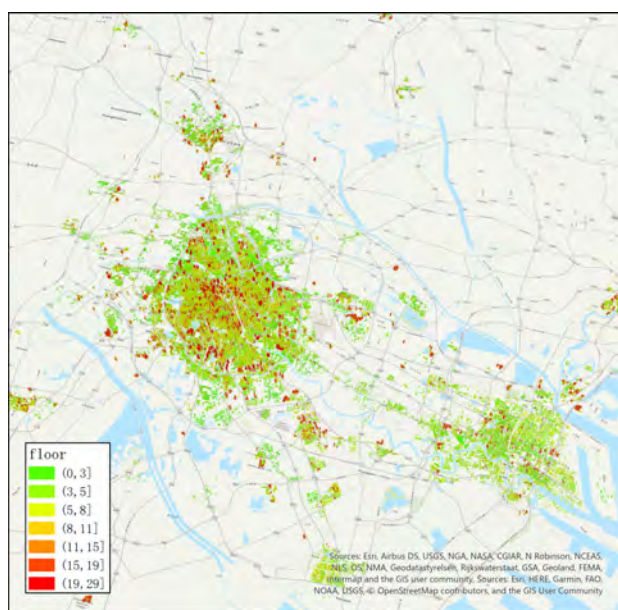
(2) Shanghai



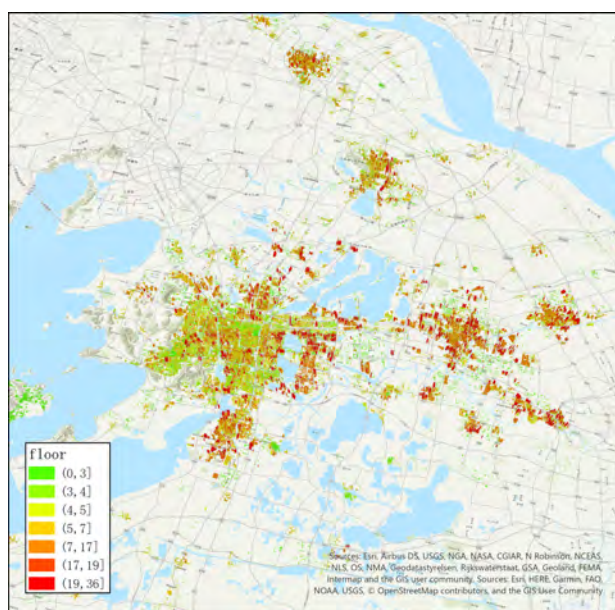
(3) Chongqing



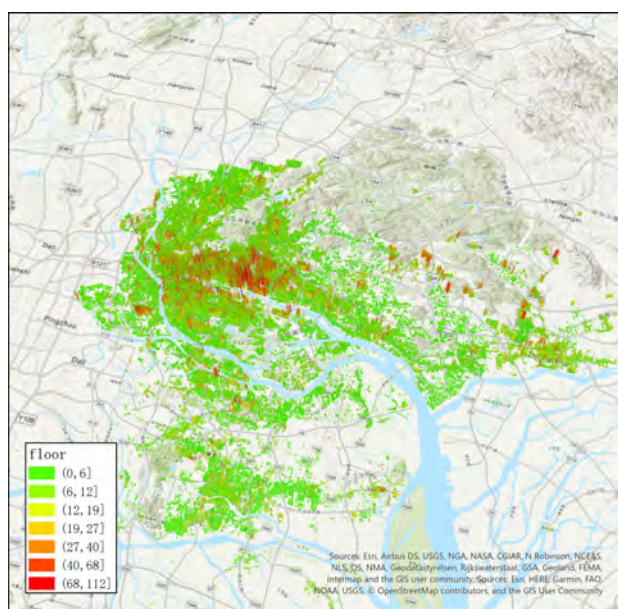
(4) Chengdu



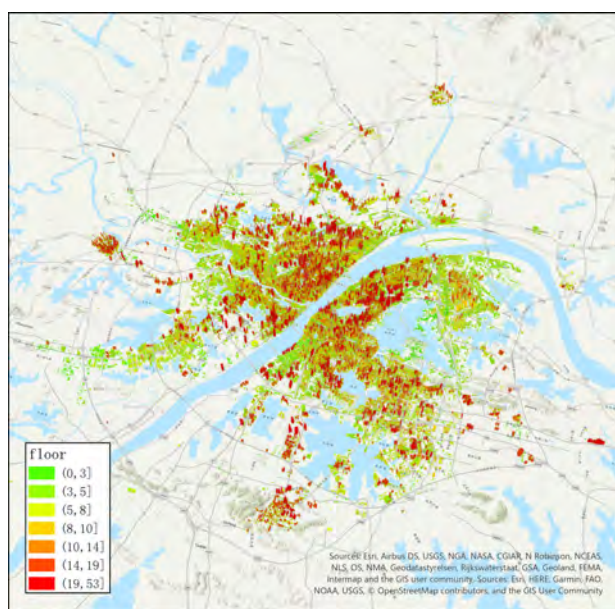
(5) Tianjin



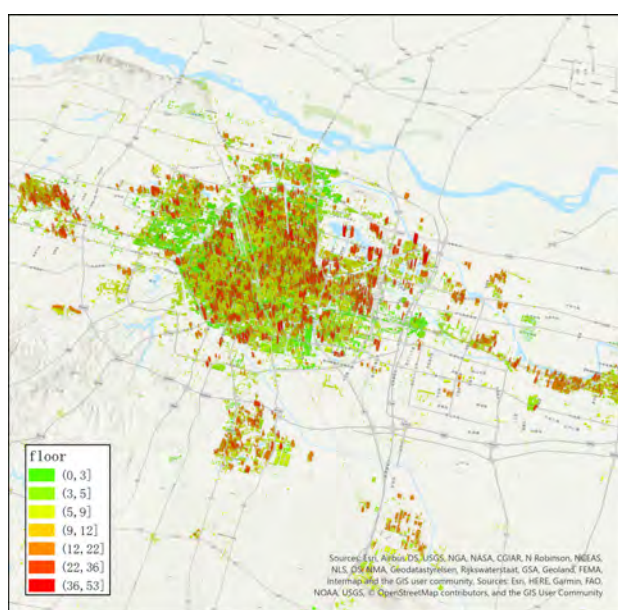
(6) Suzhou



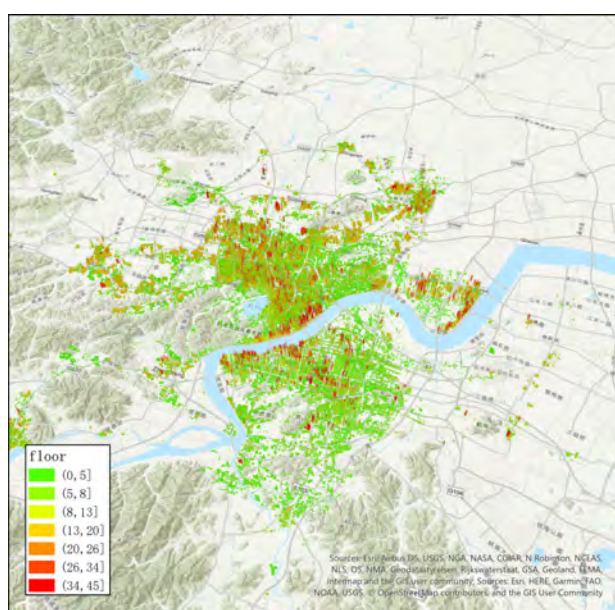
(7) Guangzhou



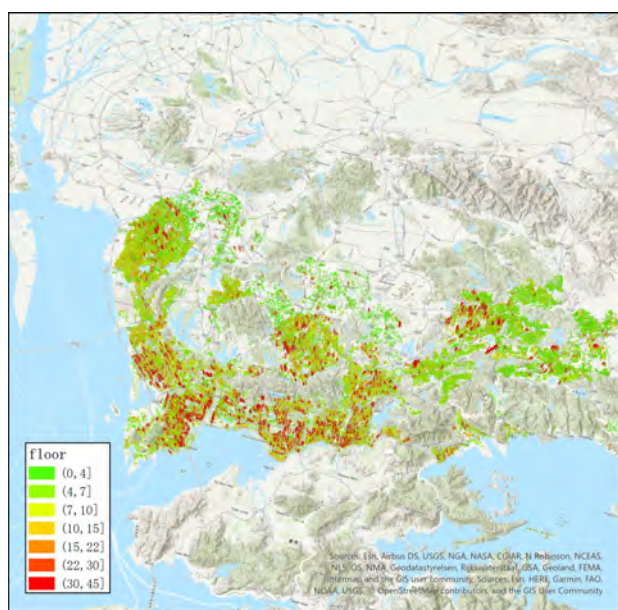
(8) Wuhan



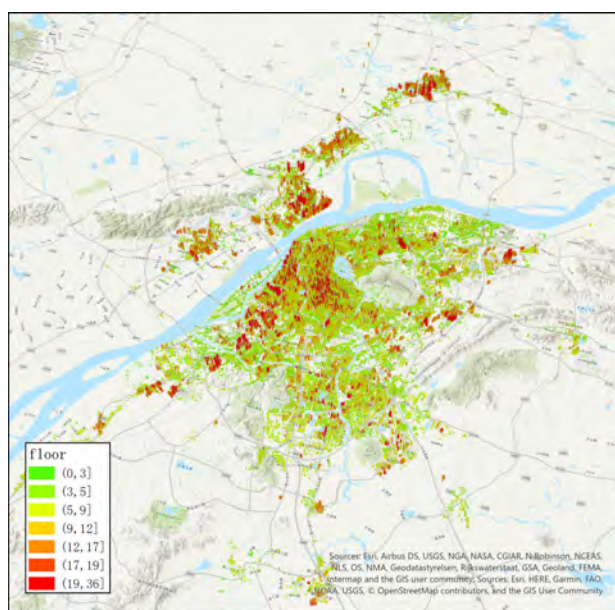
(9) Zhengzhou



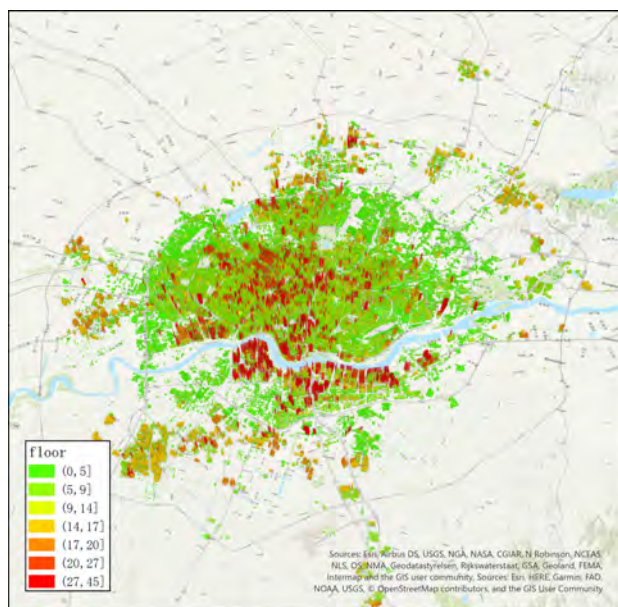
(10) Hangzhou



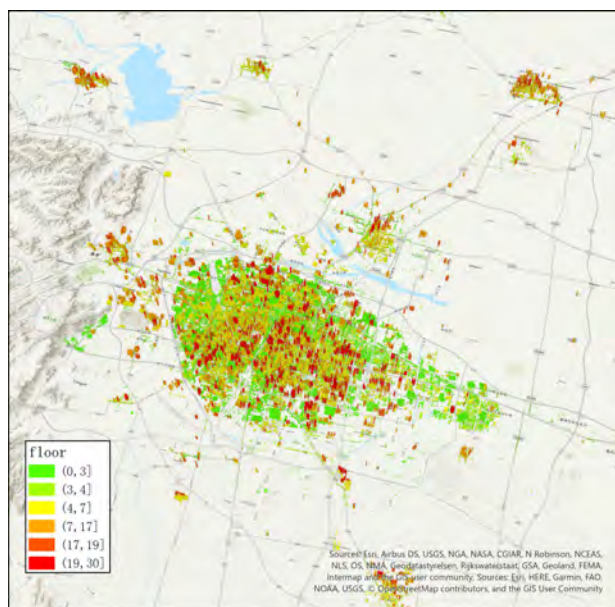
(11) Shenzhen



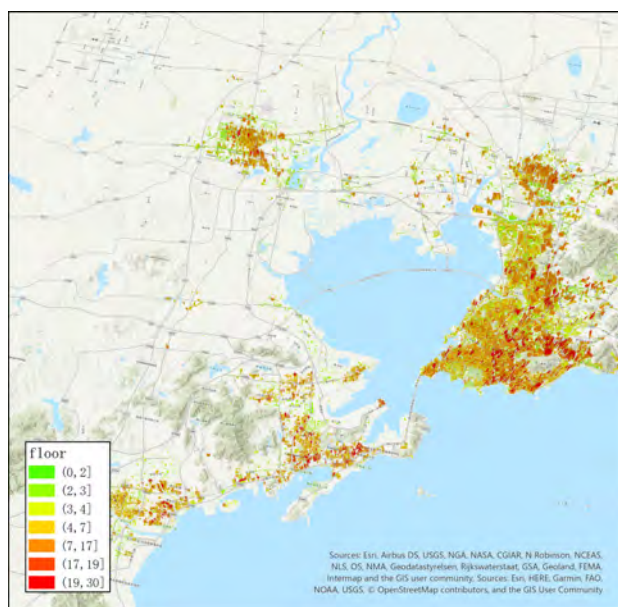
(12) Nanjing



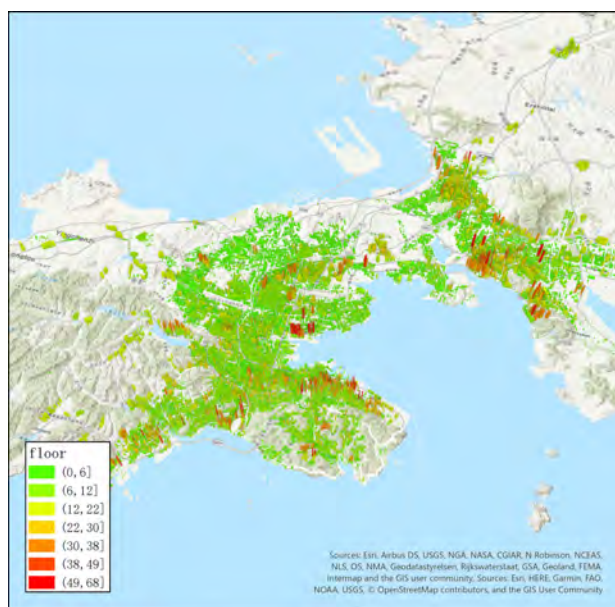
(13) Shenyang



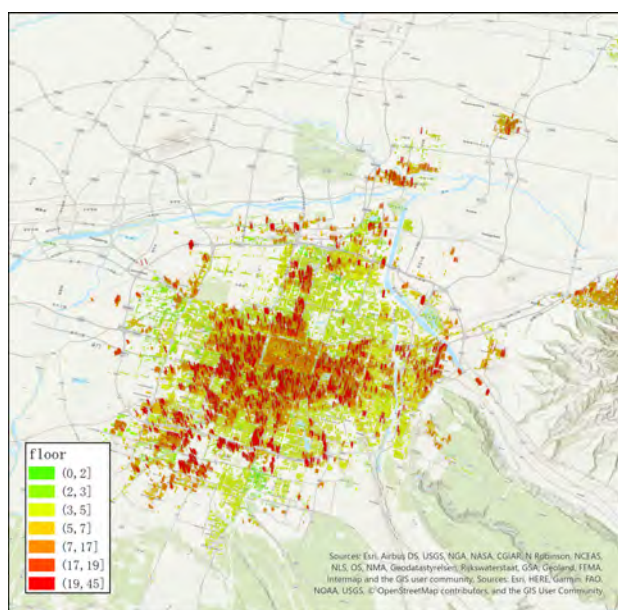
(14) Shijiazhuang



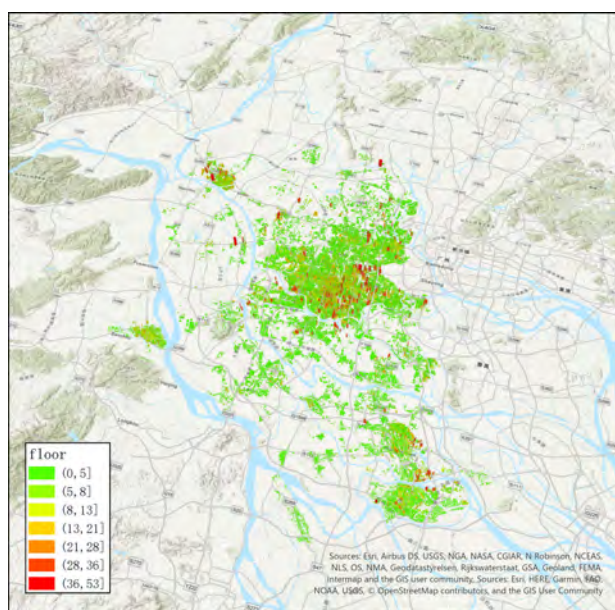
(15) Qingdao



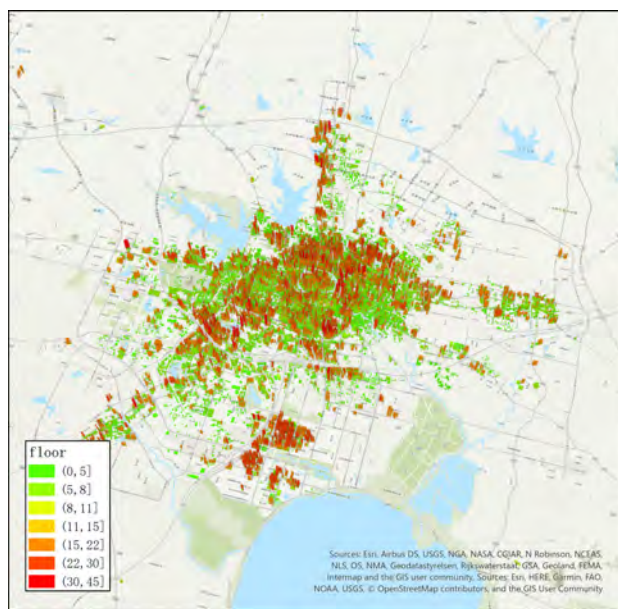
(16) Dalian



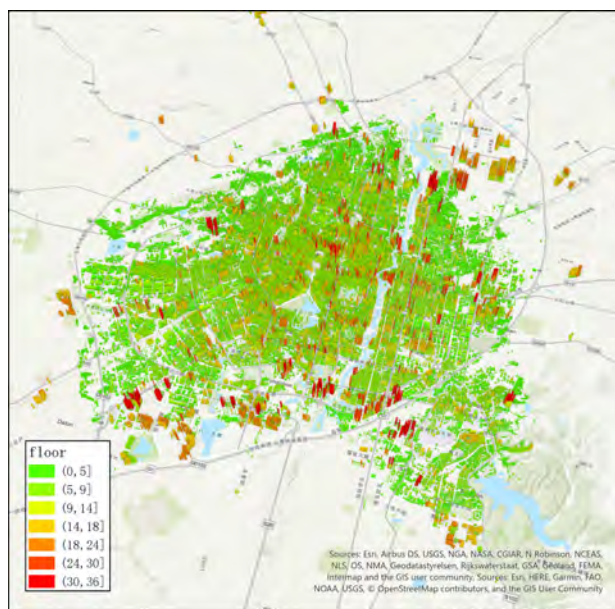
(17) Xi'an



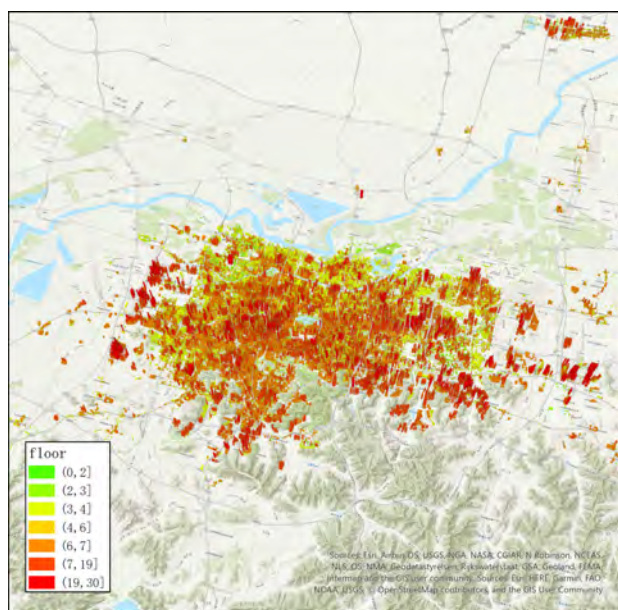
(18) Foshan



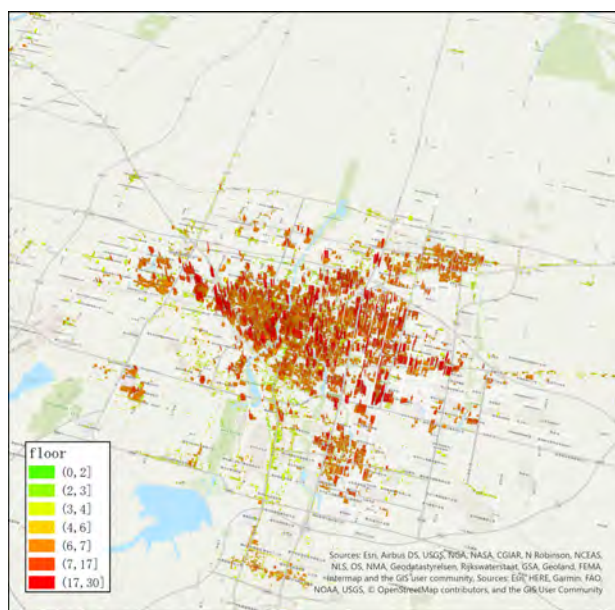
(19) Hefei



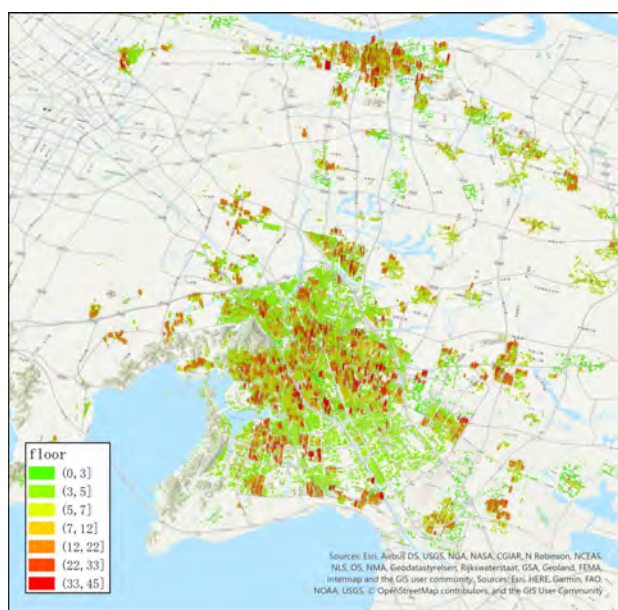
(20) Changchun



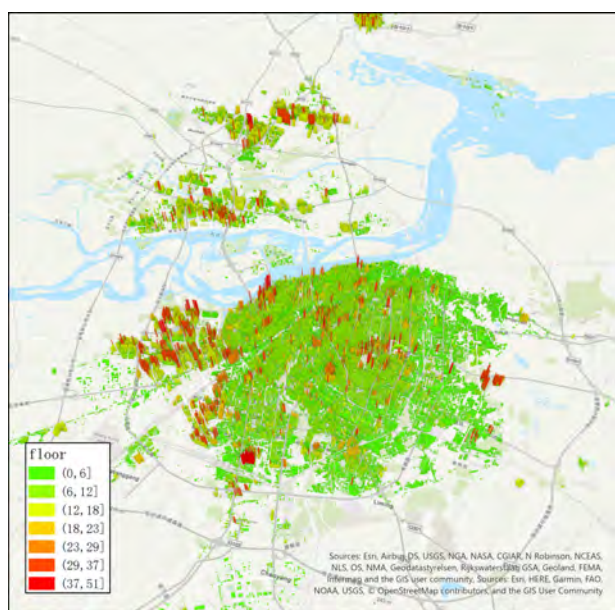
(21) Jinan



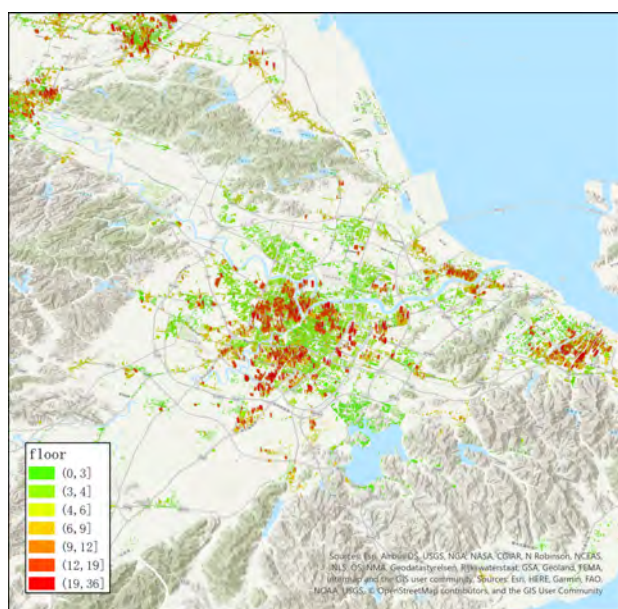
(22) Weifang



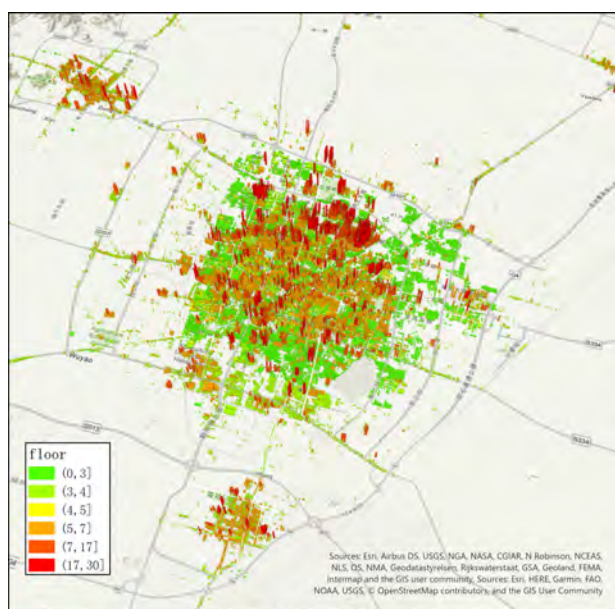
(23) Wuxi



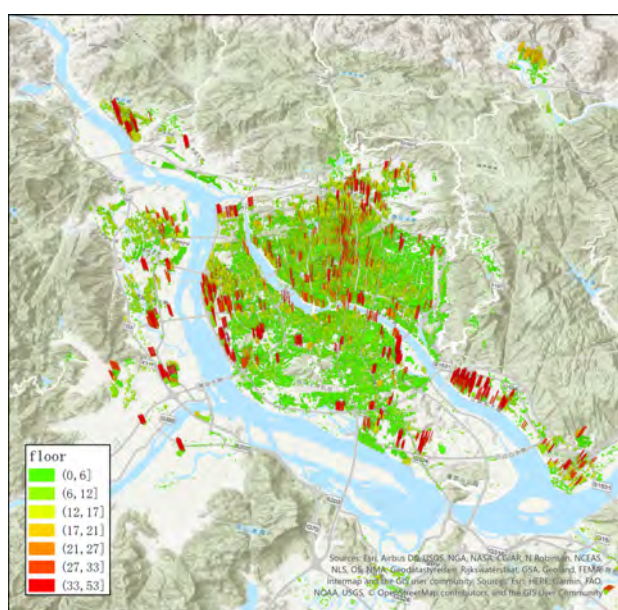
(24) Ha'erbin



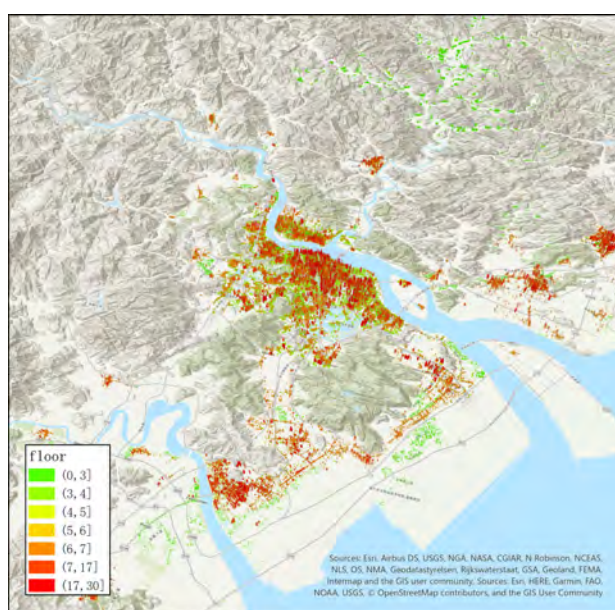
(25) Ningbo



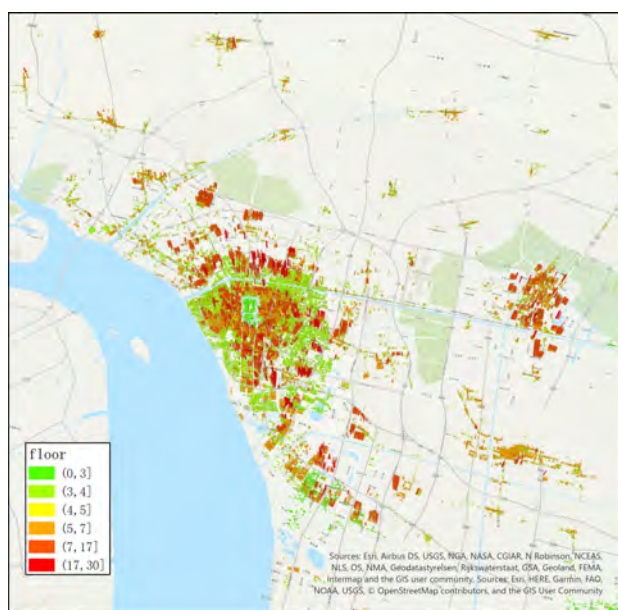
(26) Baoding



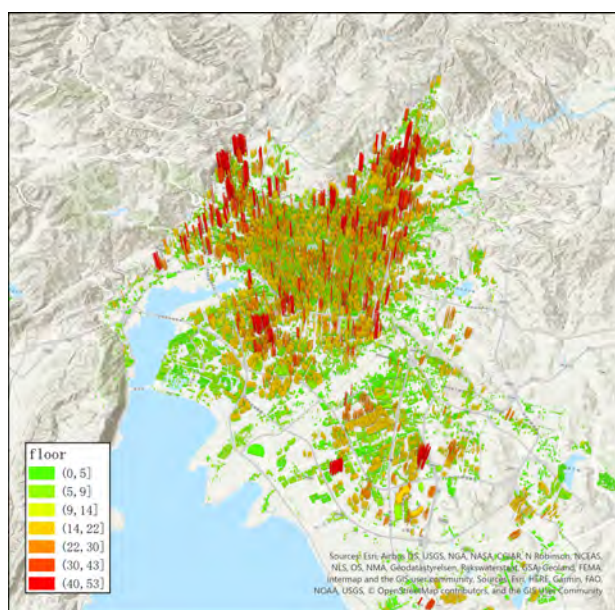
(27) Fuzhou



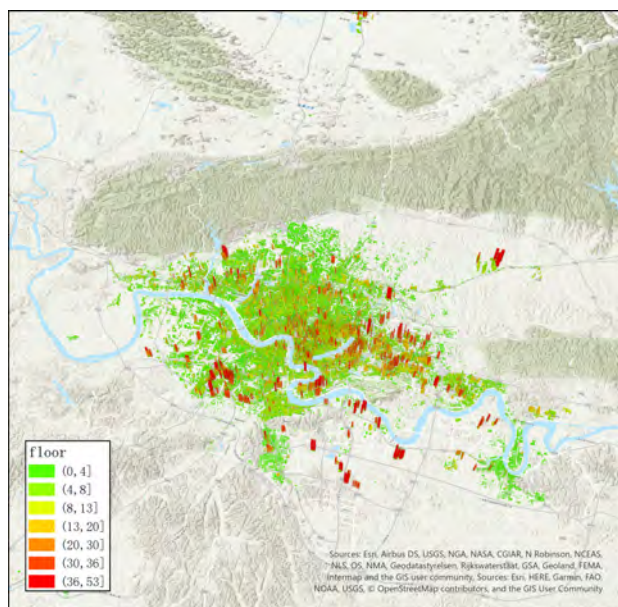
(28) Wenzhou



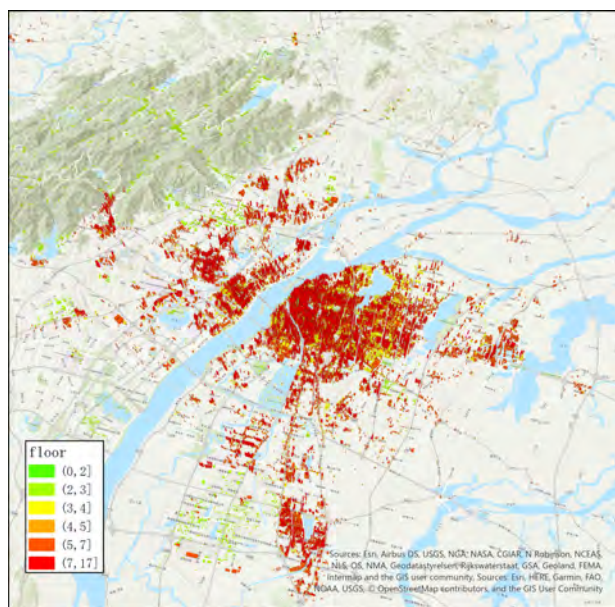
(29) Nantong



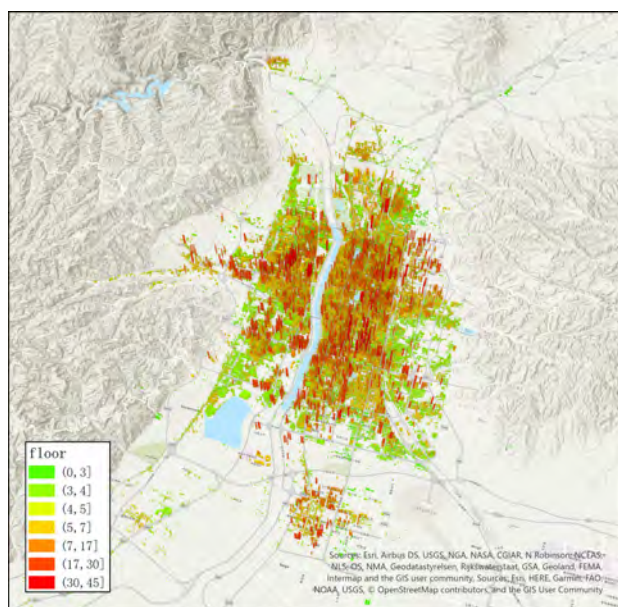
(30) Kunming



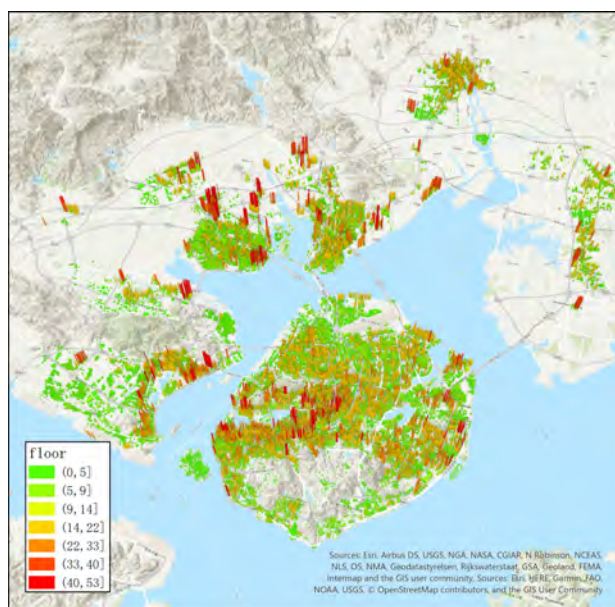
(31) Nanning



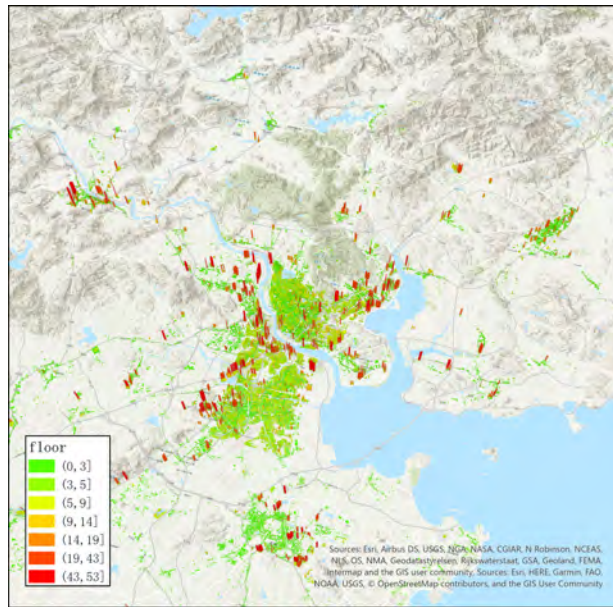
(32) Nanchang



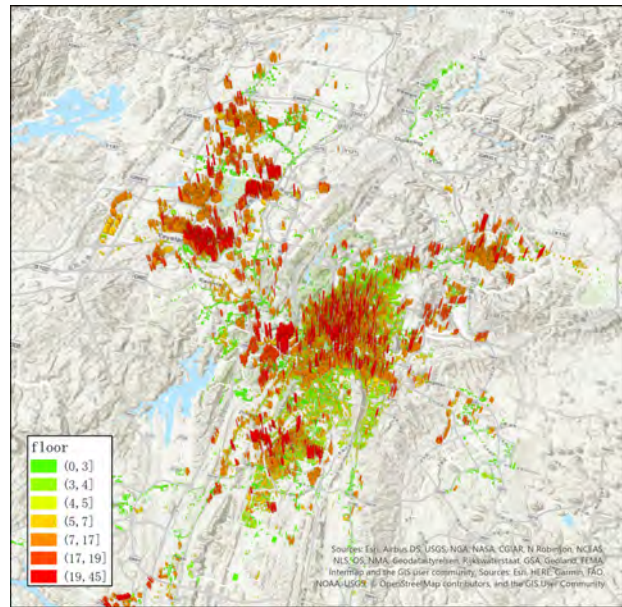
(33) Taiyuan



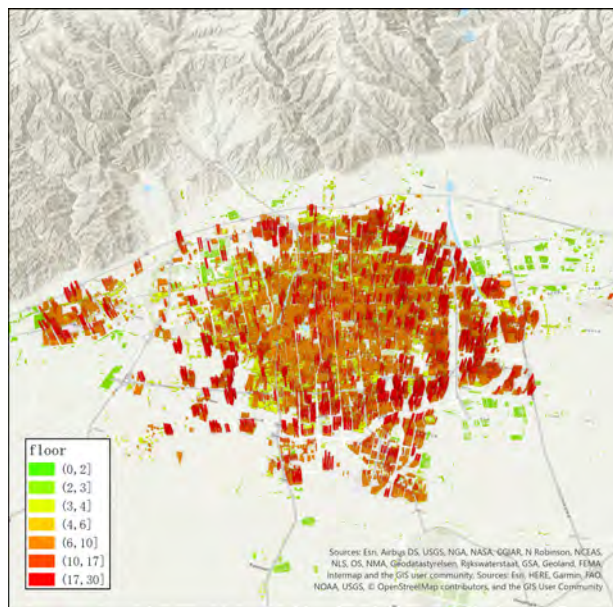
(34) Xiamen



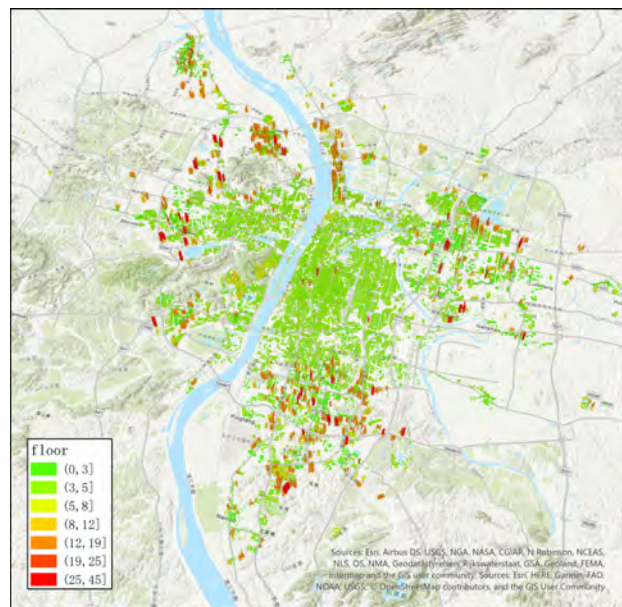
(35) Quanzhou



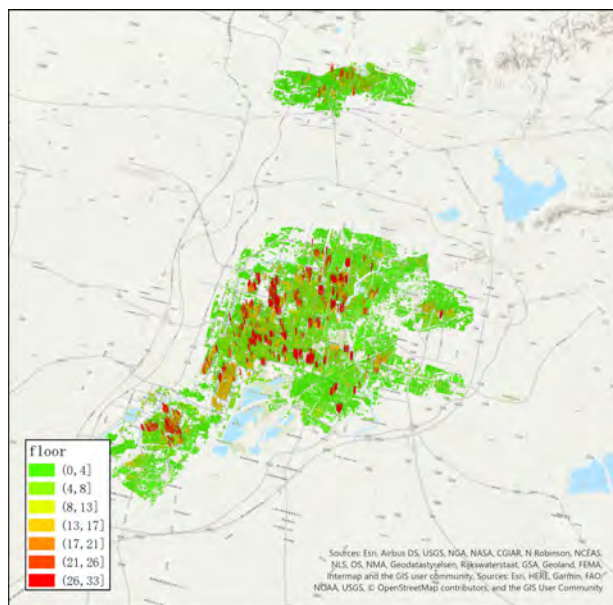
(36) Guiyang



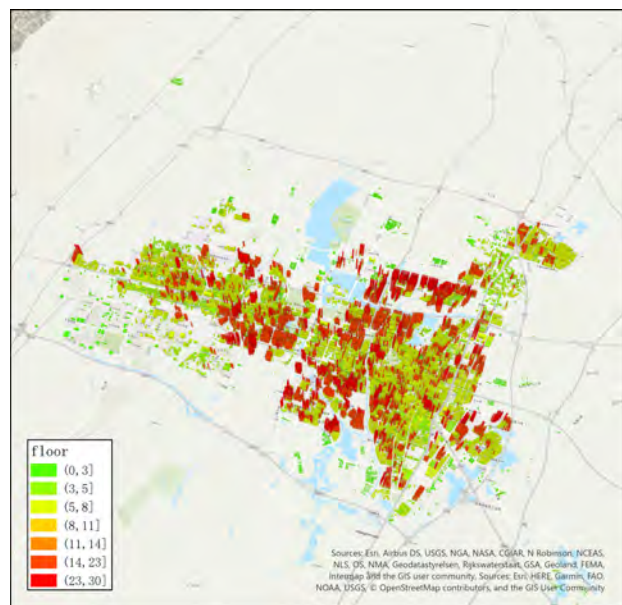
(37) Hohhot



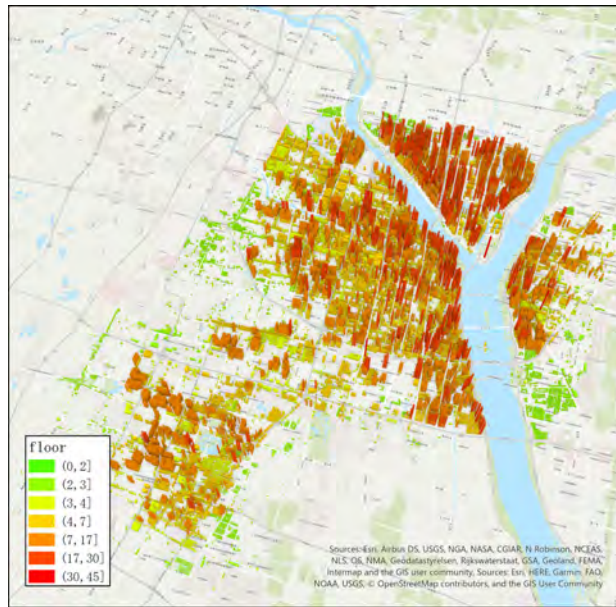
(38) Changsha



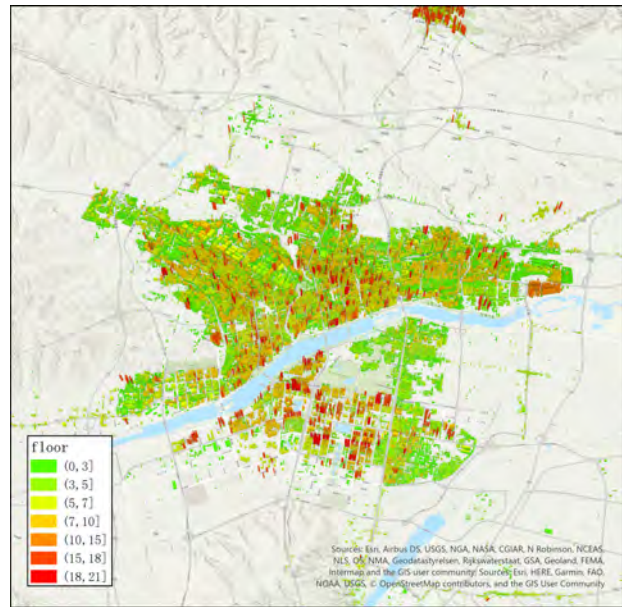
(39) Tangshan



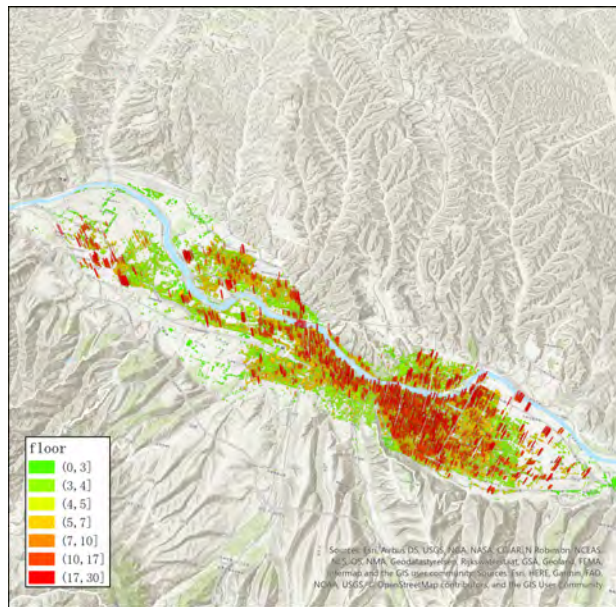
(40) Yinchuan



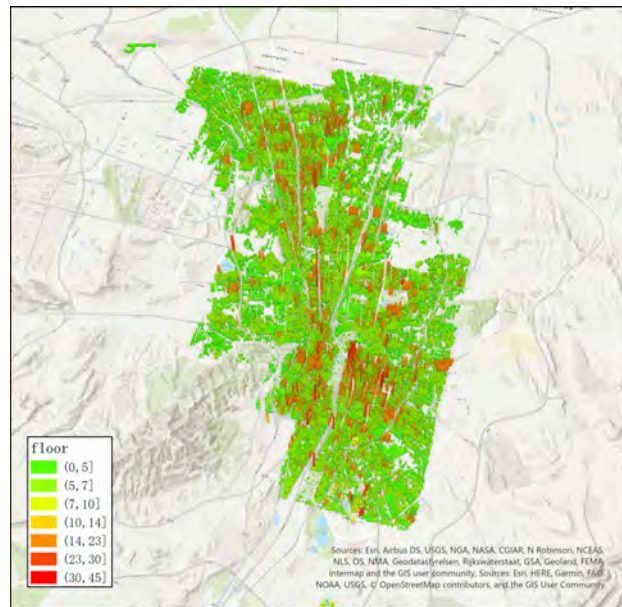
(41) Linyi



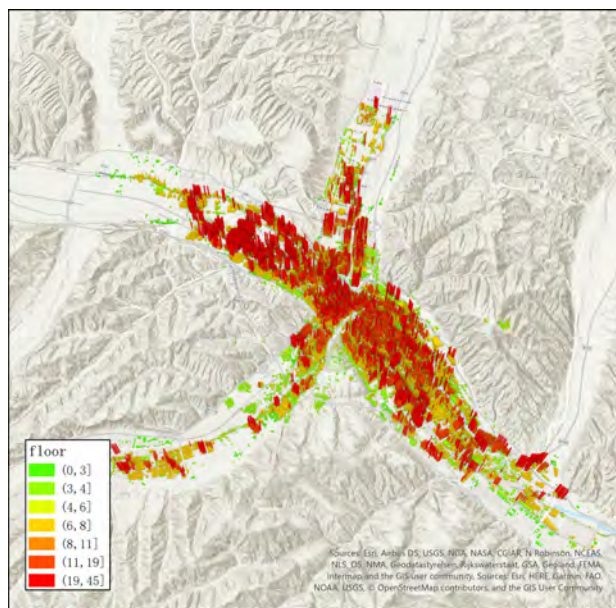
(42) Luoyang



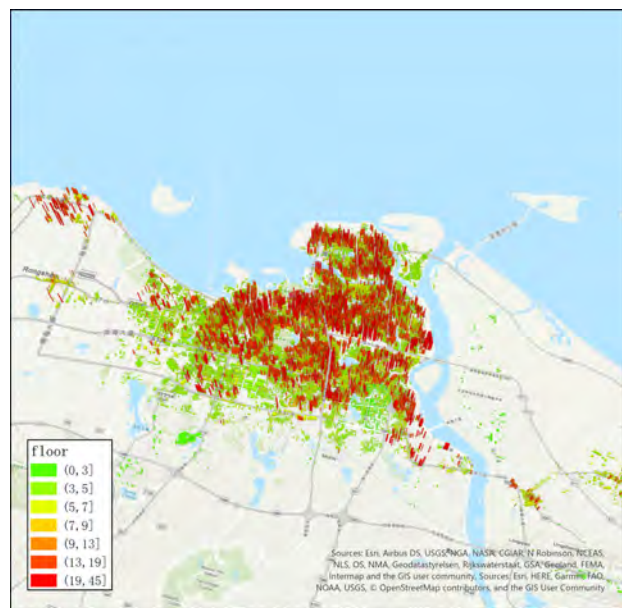
(43) Lanzhou



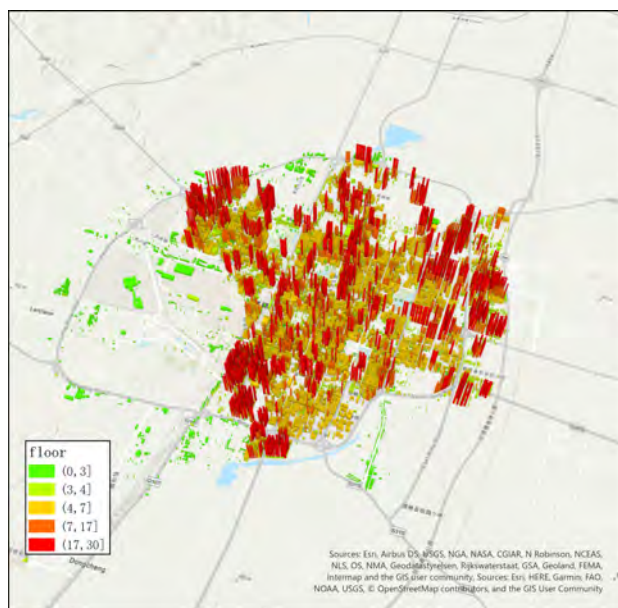
(44) Urumqi



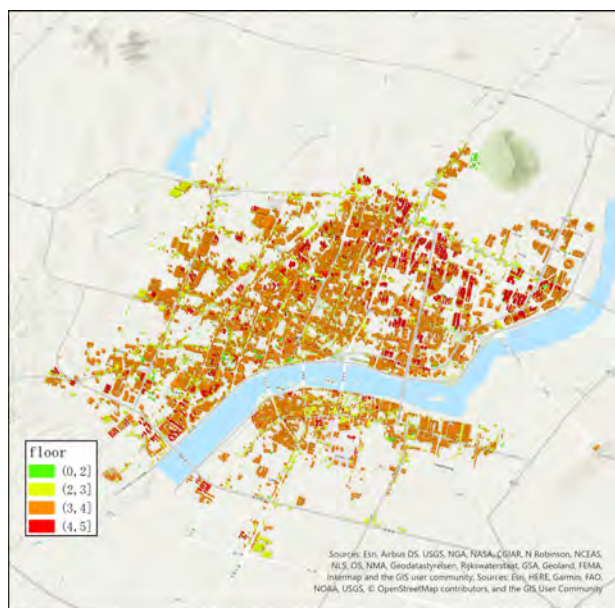
(45) Xining



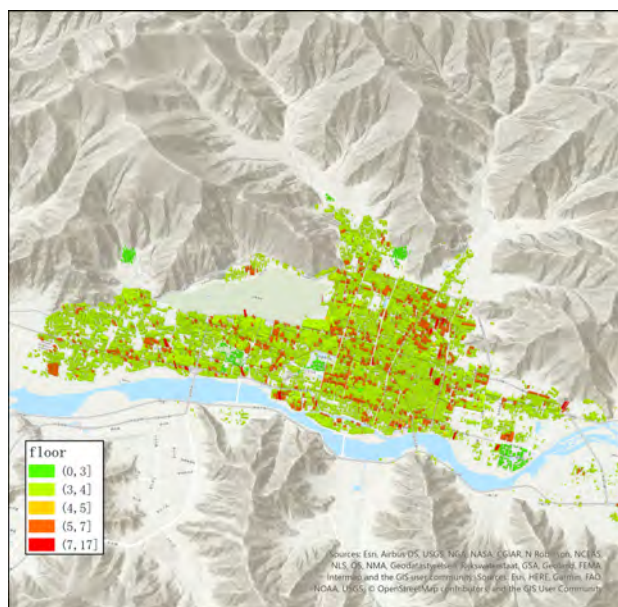
(46) Haikou



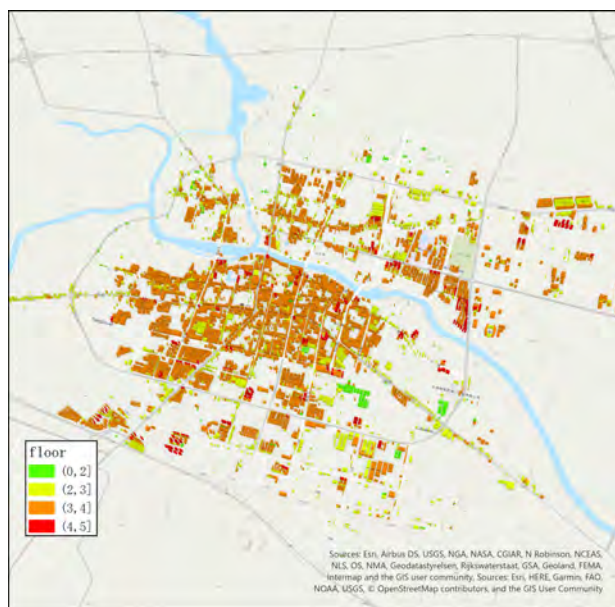
(47) Handan



(48) Nanyang



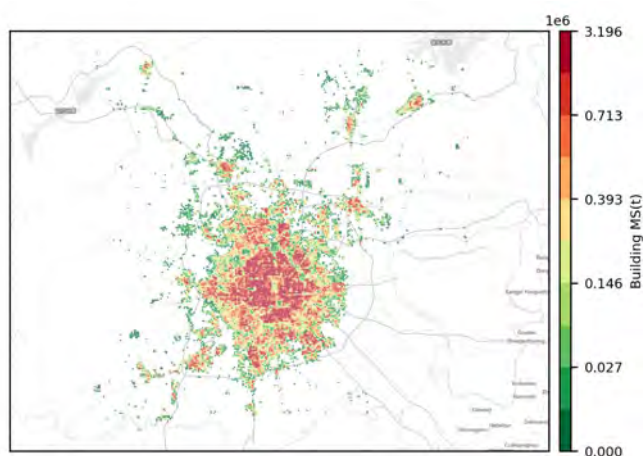
(49) Lhasa



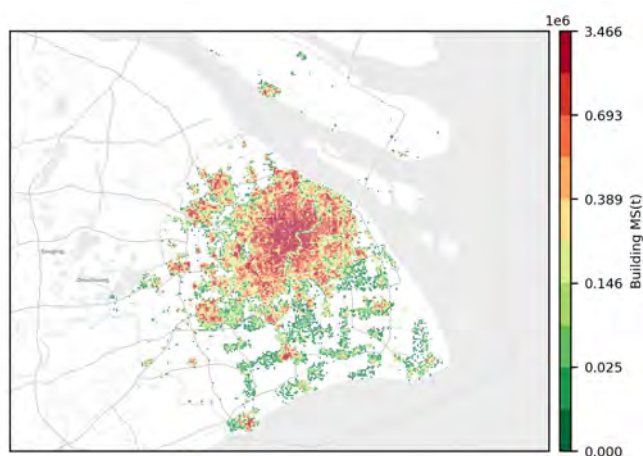
(50) Zhoukou

Supplementary Figure A1: Building geometries of the 50 Chinese cities

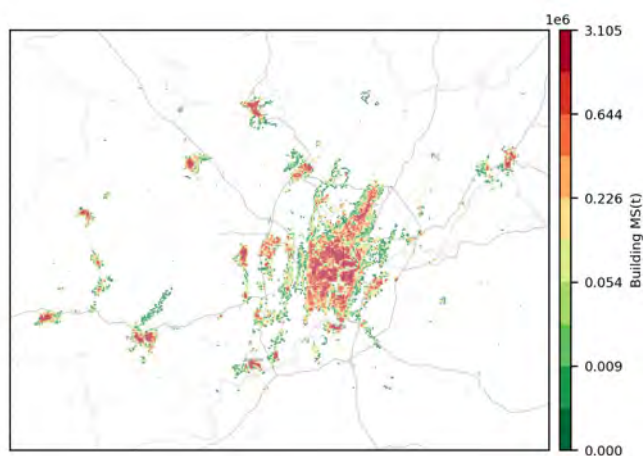
A.2 The spatial distributions of building stocks in 500m*500m grid across the 50 cities



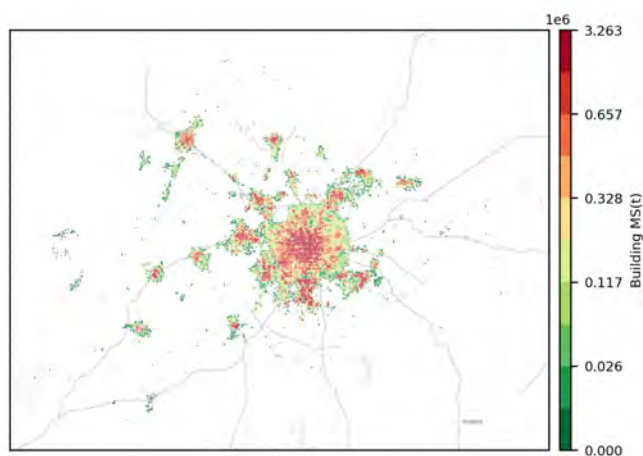
(1) Beijing



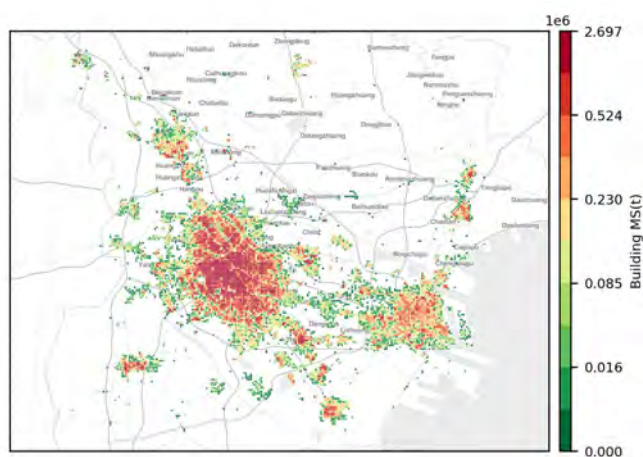
(2) Shanghai



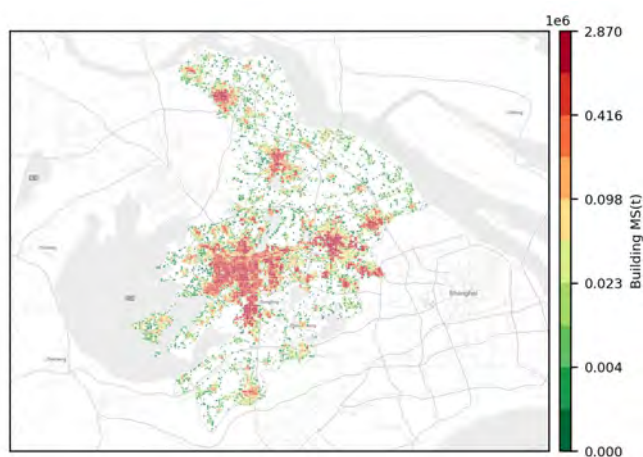
(3) Chongqing



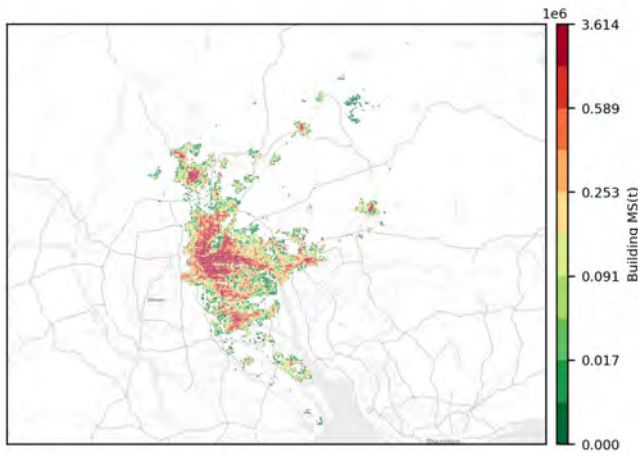
(4) Chengdu



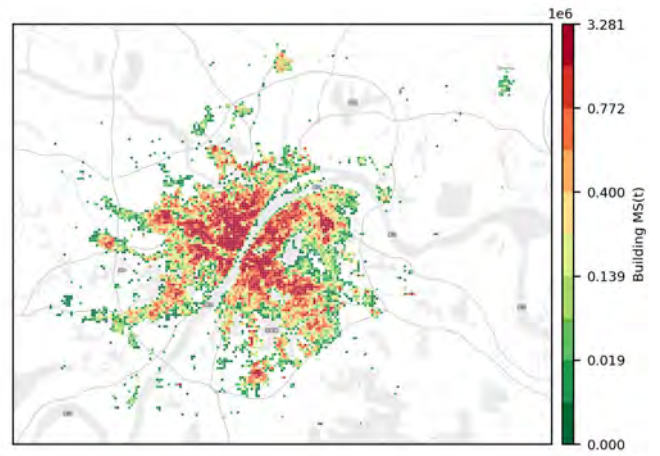
(5) Tianjin



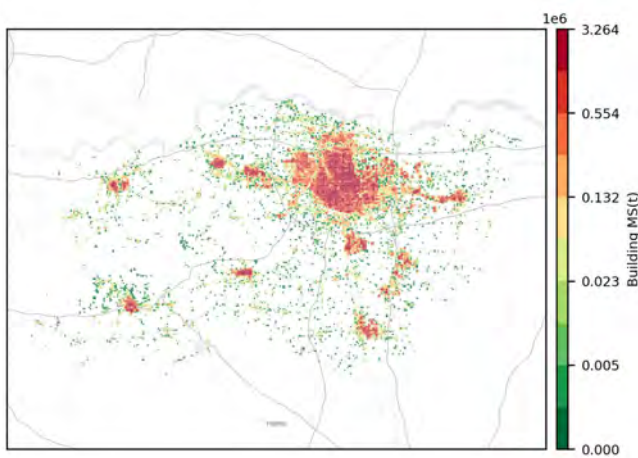
(6) Suzhou



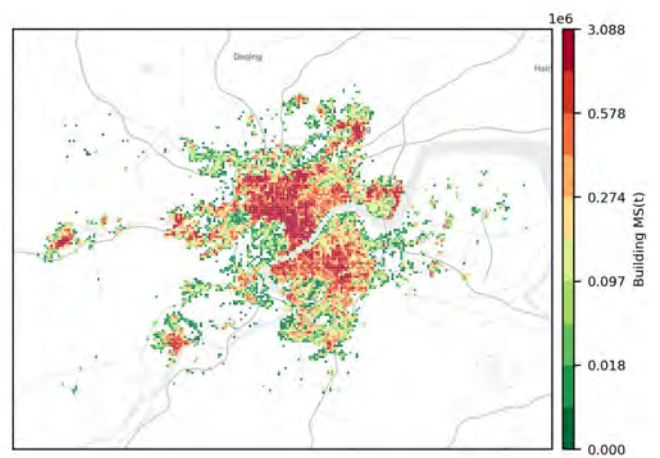
(7) Guangzhou



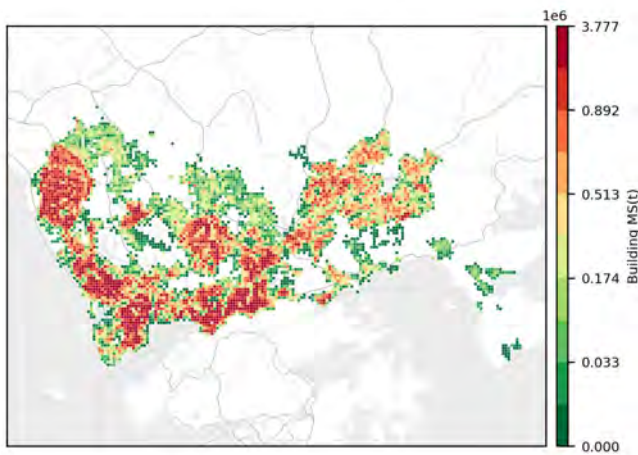
(8) Wuhan



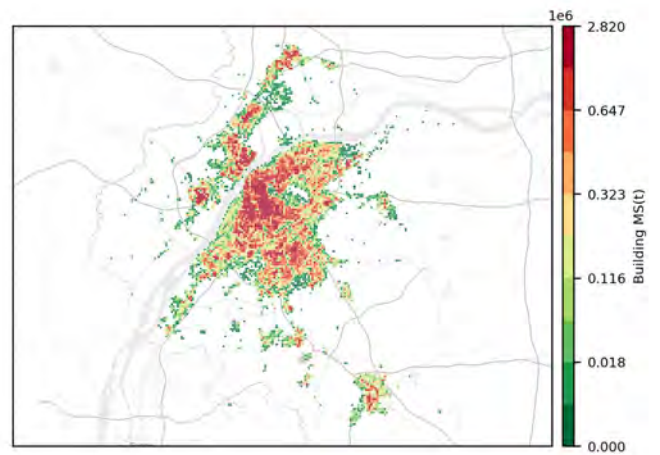
(9) Zhengzhou



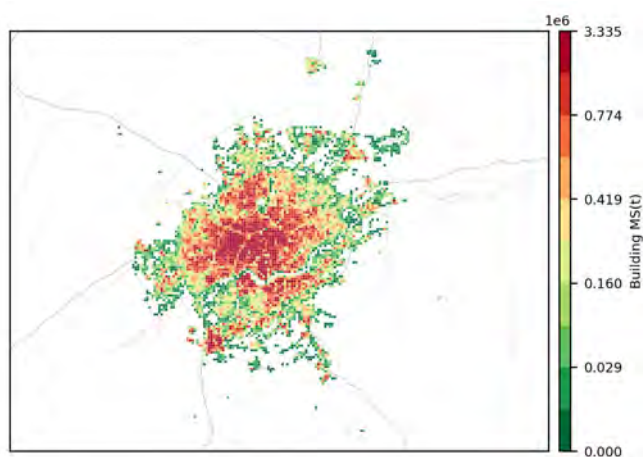
(10) Hangzhou



(11) Shenzhen



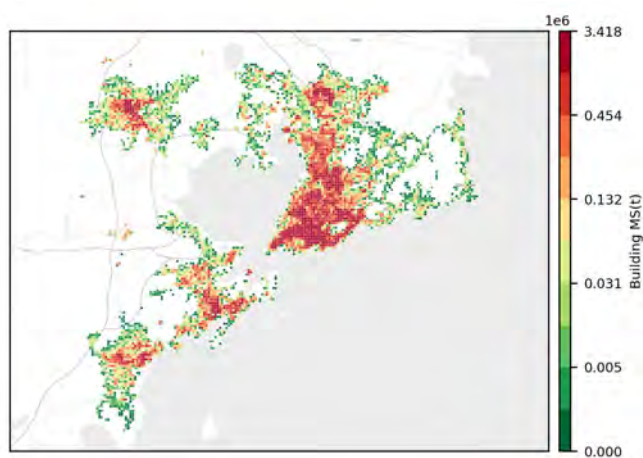
(12) Nanjing



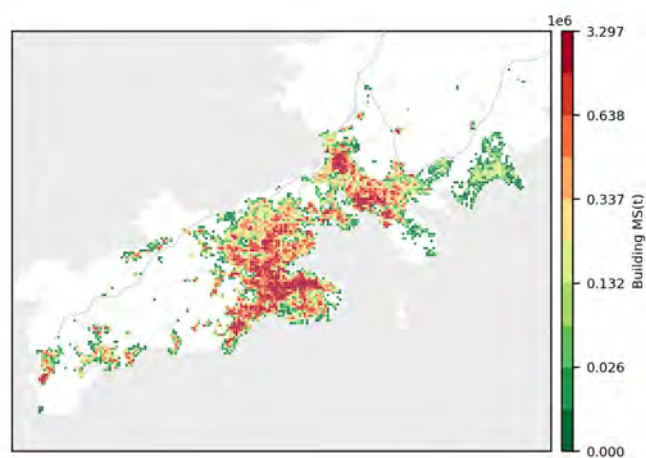
(13) Shenyang



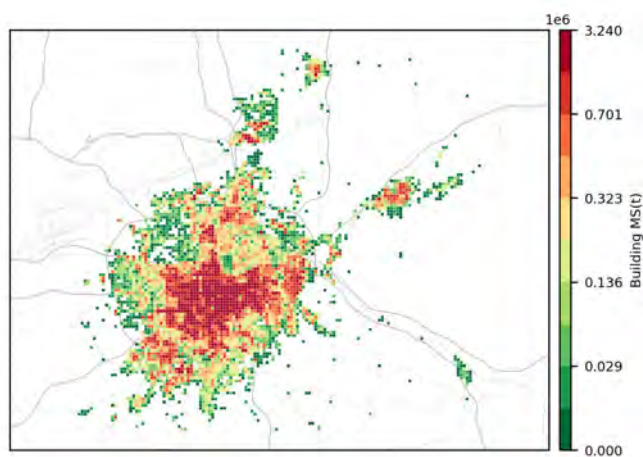
(14) Shijiazhuang



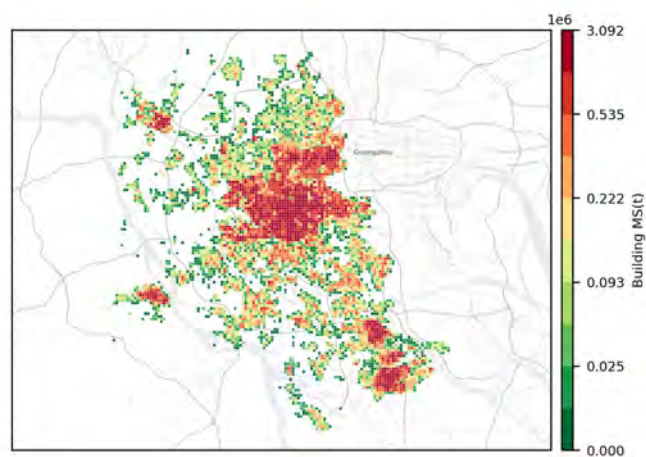
(15) Qingdao



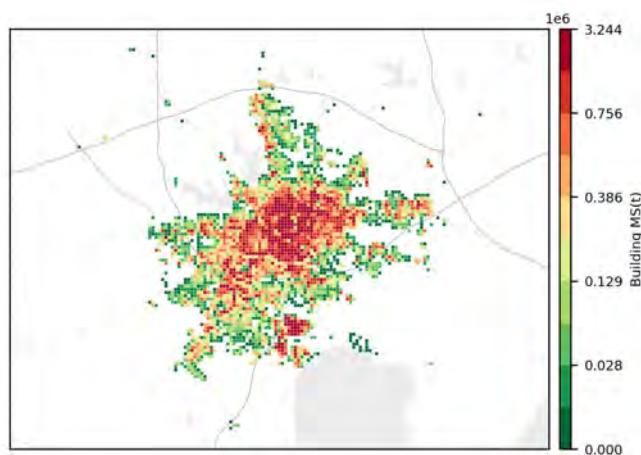
(16) Dalian



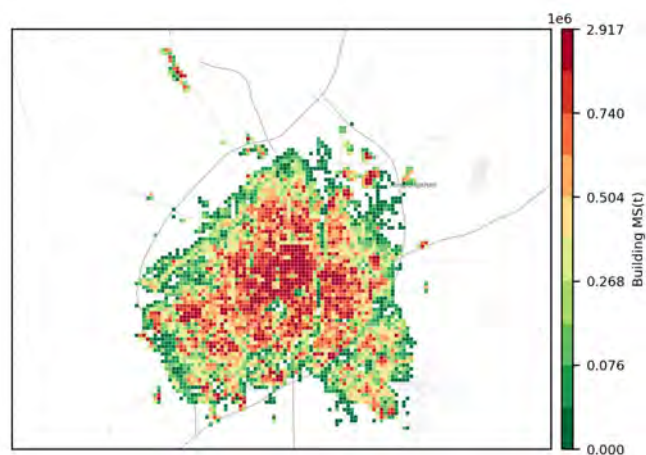
(17) Xi'an



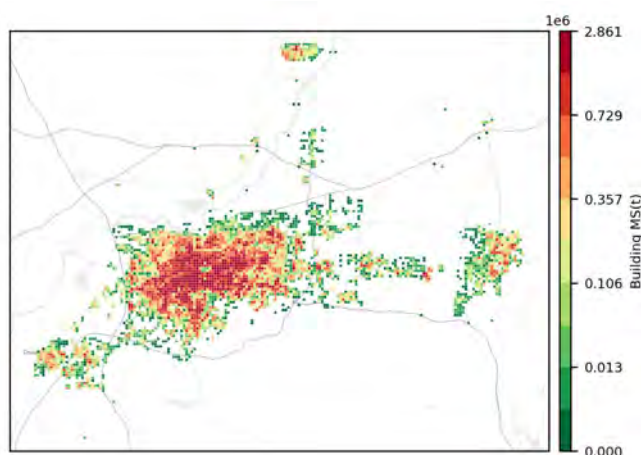
(18) Foshan



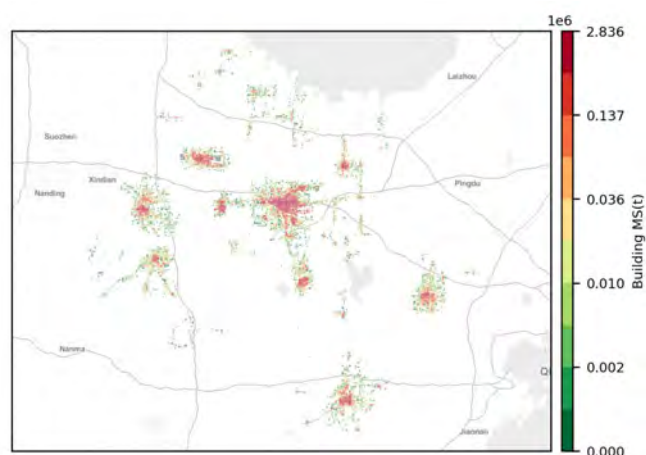
(19) Hefei



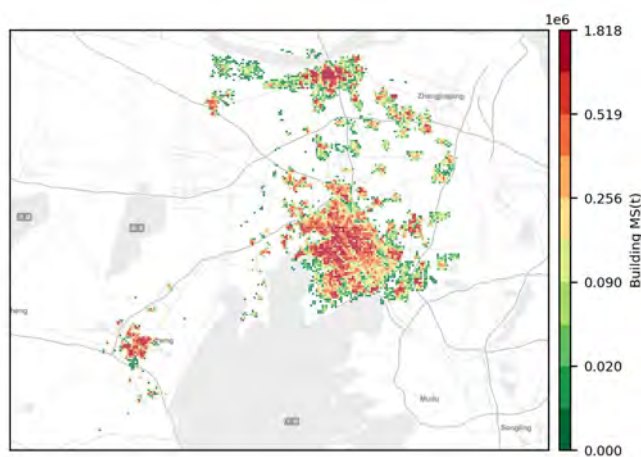
(20) Changchun



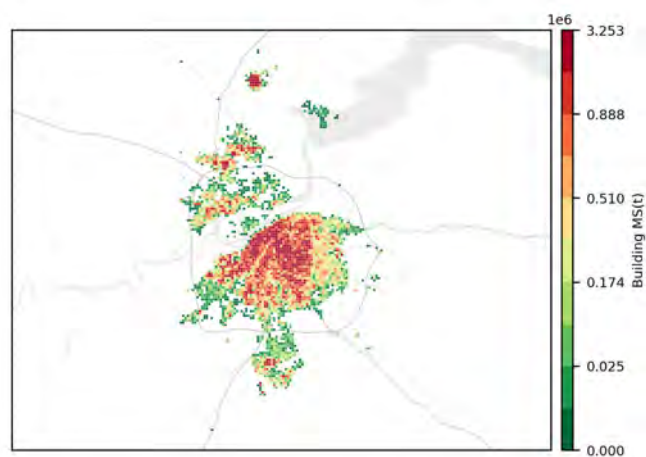
(21) Jinan



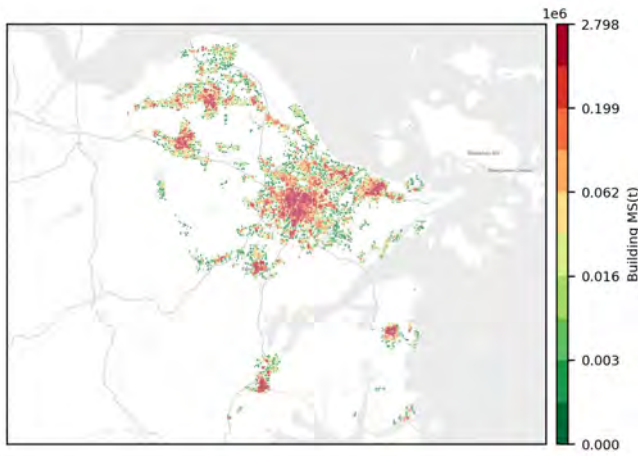
(22) Weifang



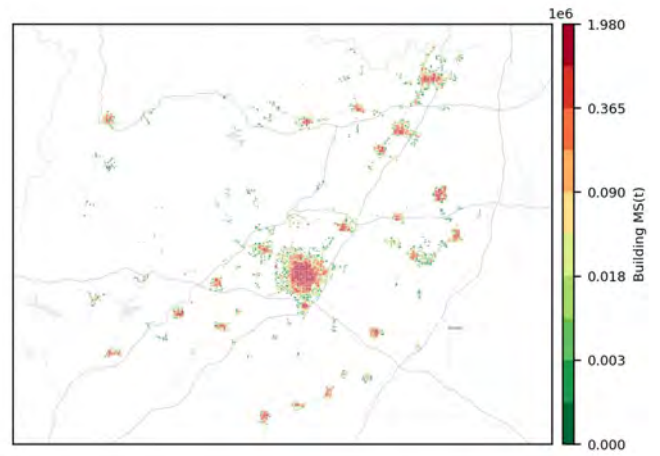
(23) Wuxi



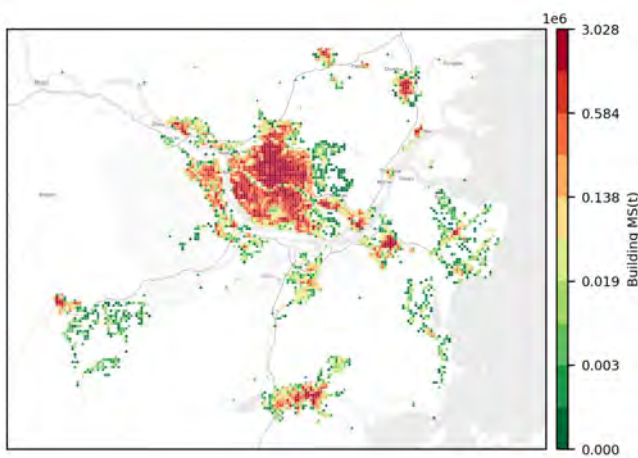
(24) Ha'erbin



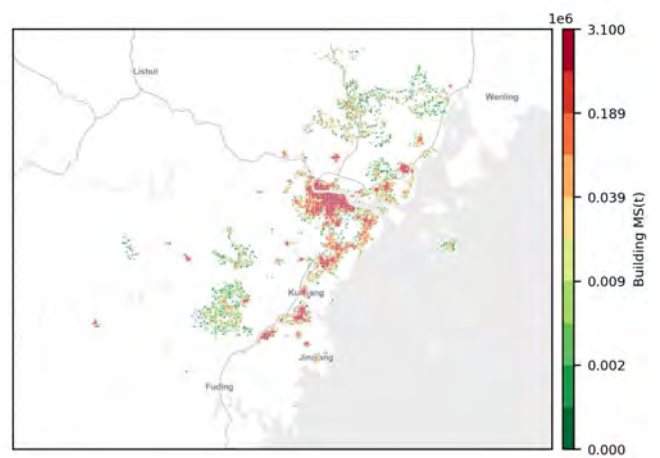
(25) Ningbo



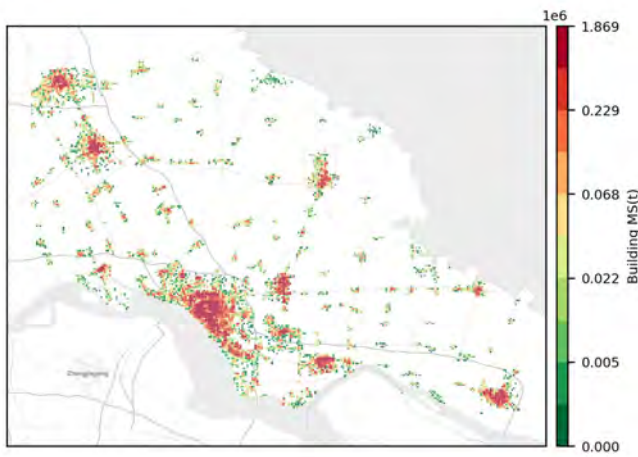
(26) Baoding



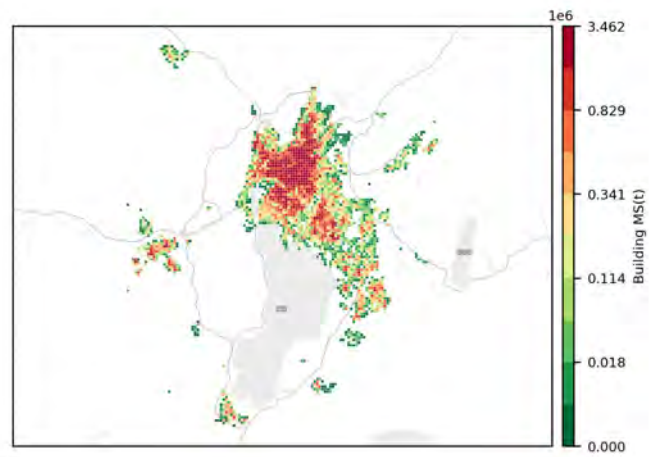
(27) Fuzhou



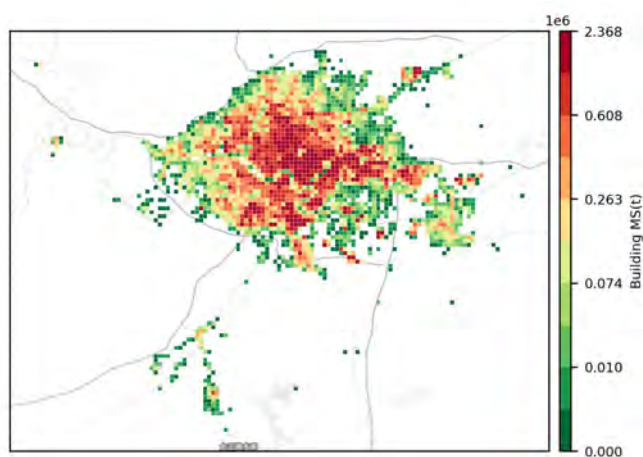
(28) Wenzhou



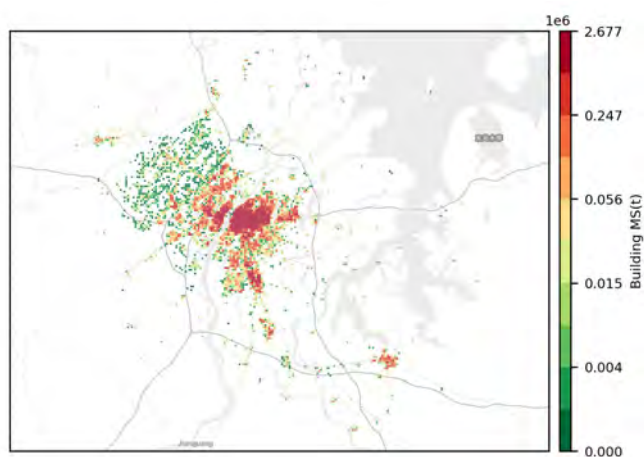
(29) Nantong



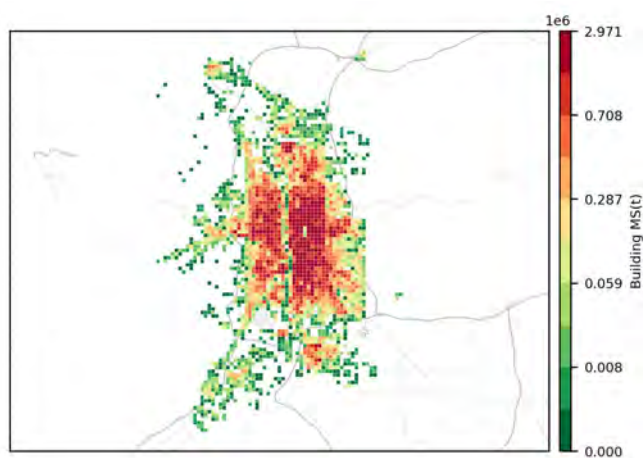
(30) Kunming



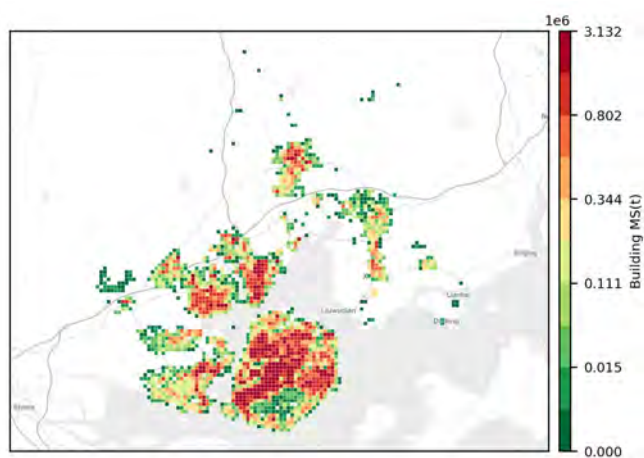
(31) Nanning



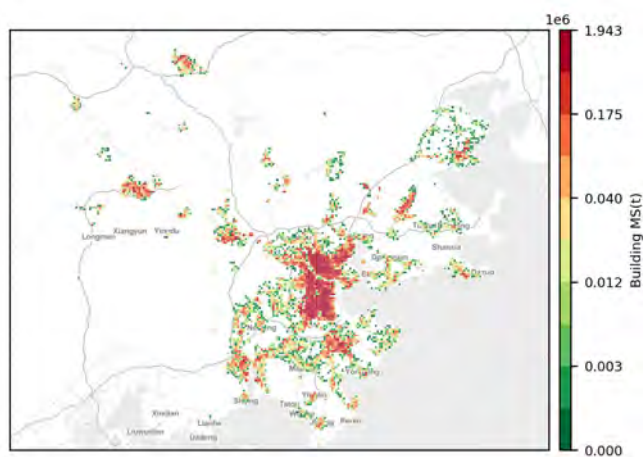
(32) Nanchang



(33) Taiyuan



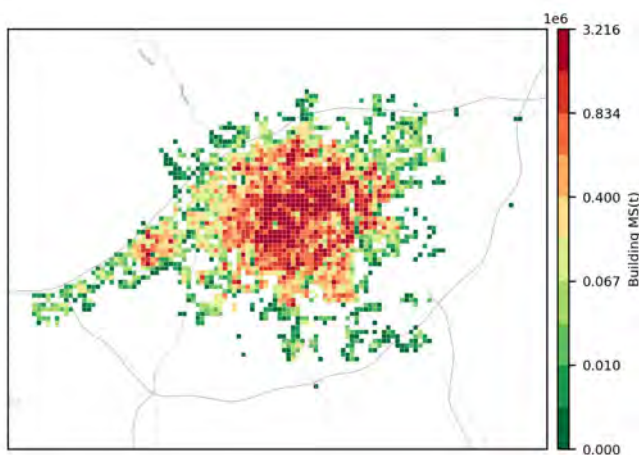
(34) Xiamen



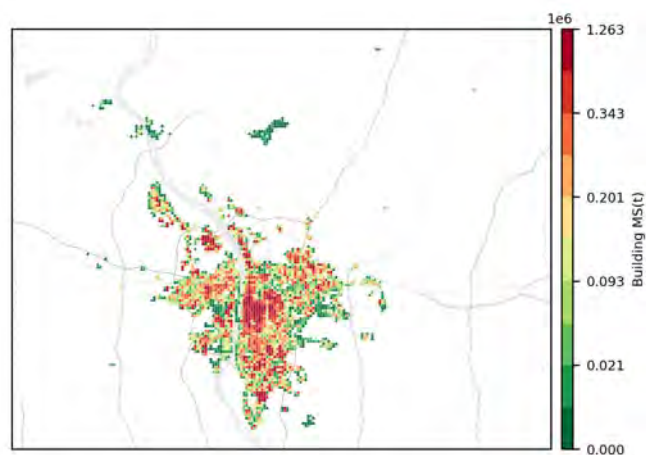
(35) Quanzhou



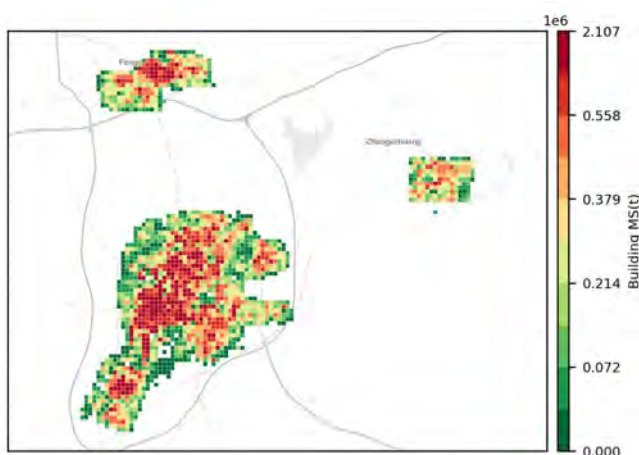
(36) Guiyang



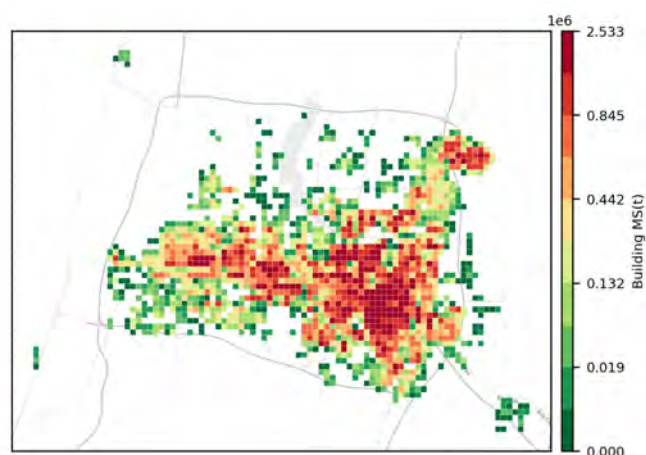
(37) Hohhot



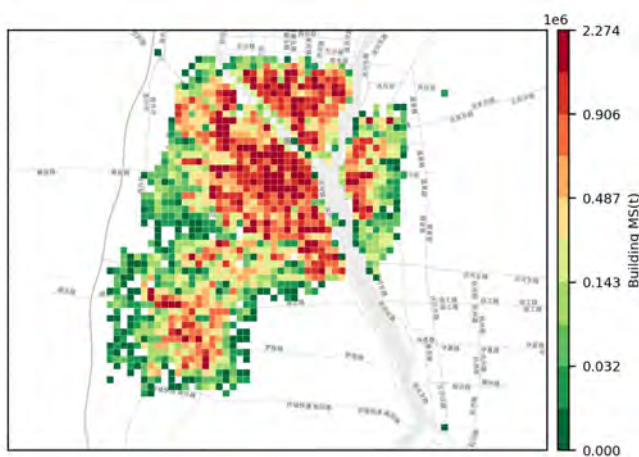
(38) Changsha



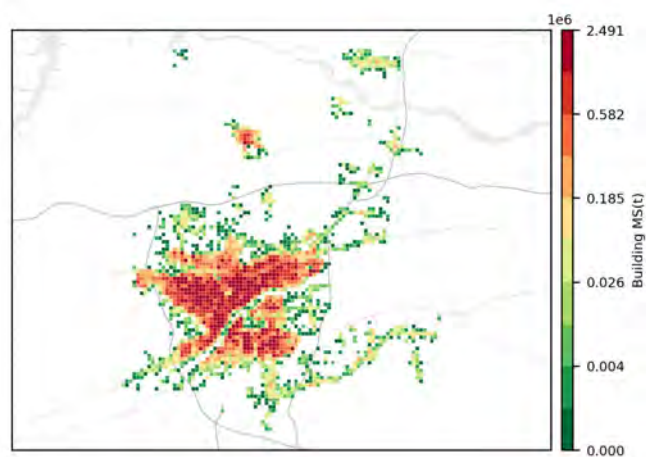
(39) Tangshan



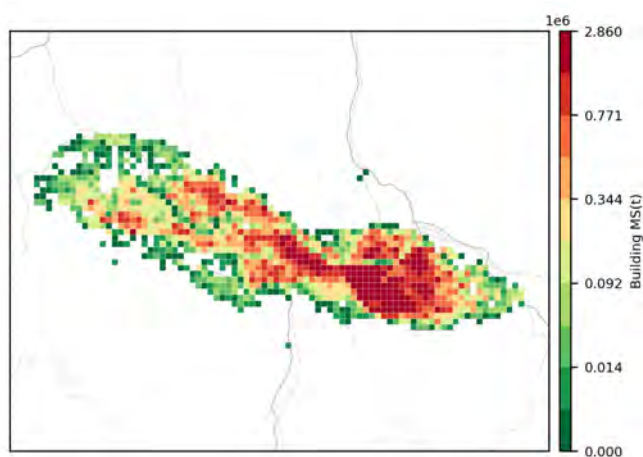
(40) Yinchuan



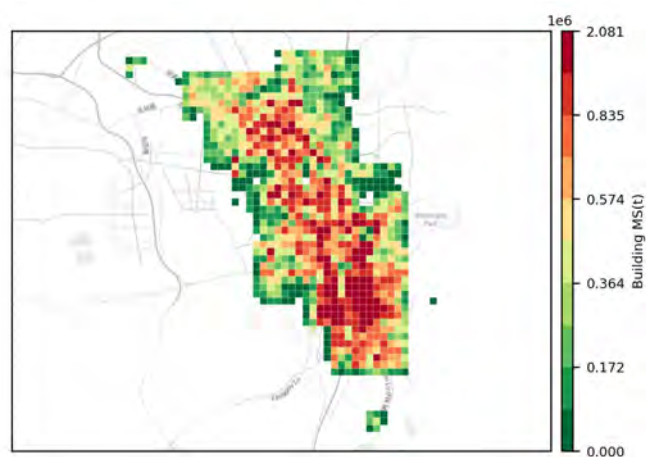
(41) Linyi



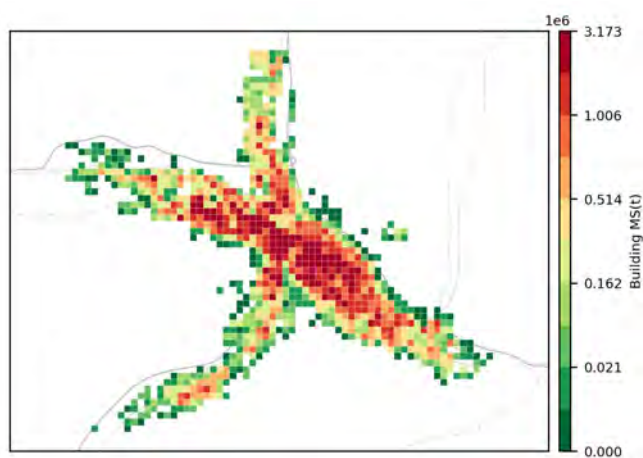
(42) Luoyang



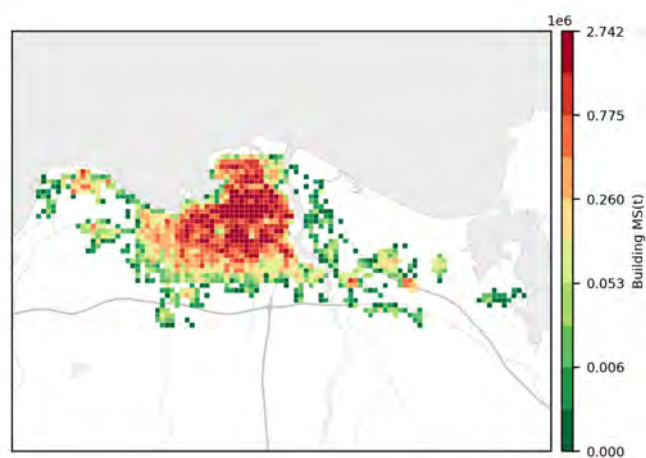
(43) Lanzhou



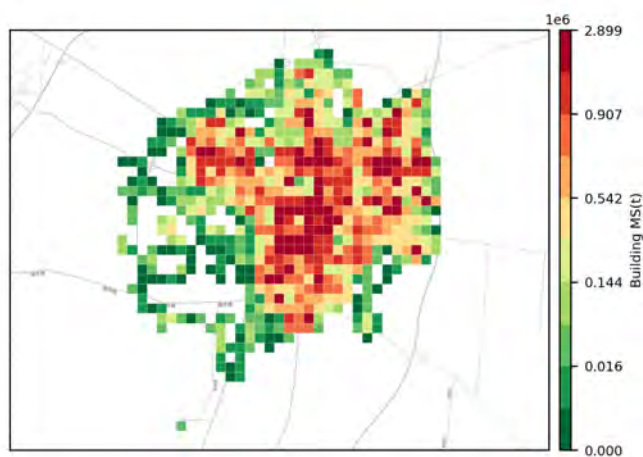
(44) Urumqi



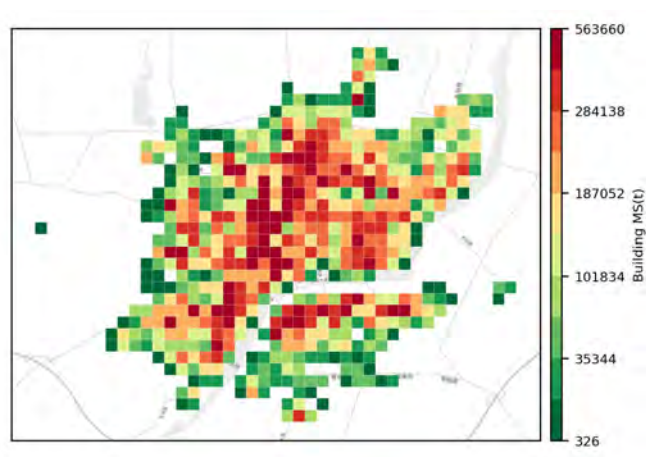
(45) Xining



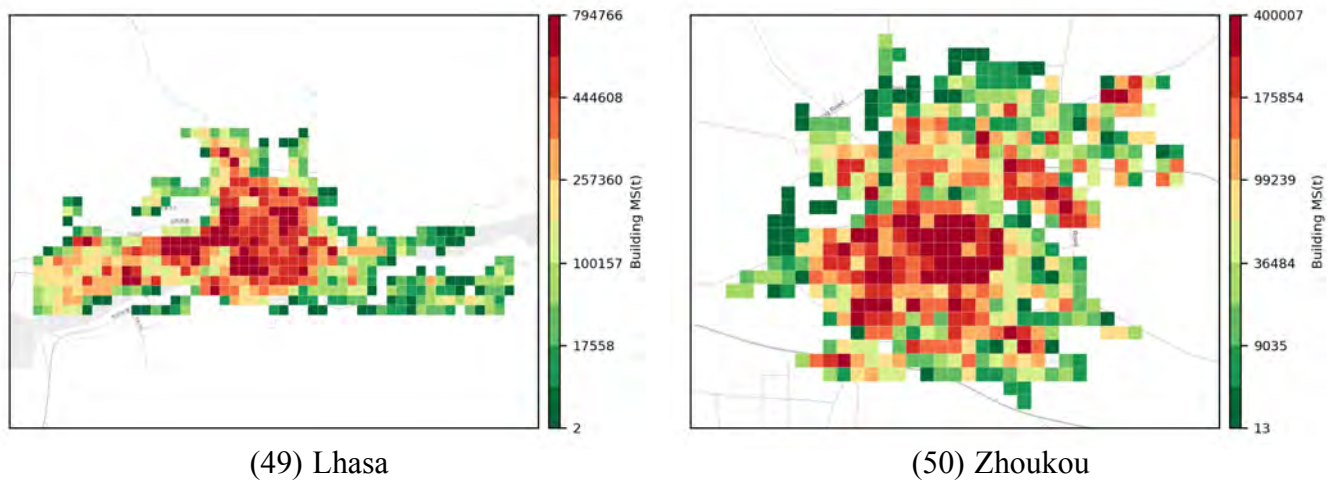
(46) Haikou



(47) Handan



(48) Nanyang



Supplementary Figure A2: Spatial maps of building stocks in a 500m grid scale

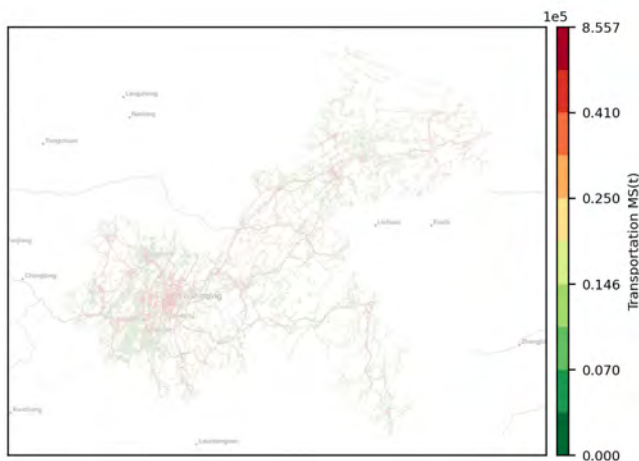
A.3 The spatial distributions of transportation infrastructures material stocks in 500m*500m grid across the 50 cities



(1) Beijing



(2) Shanghai



(3) Chongqing



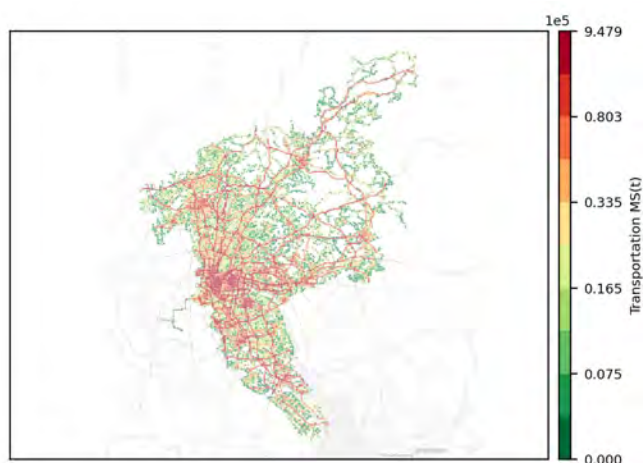
(4) Chengdu



(5) Tianjin



(6) Suzhou



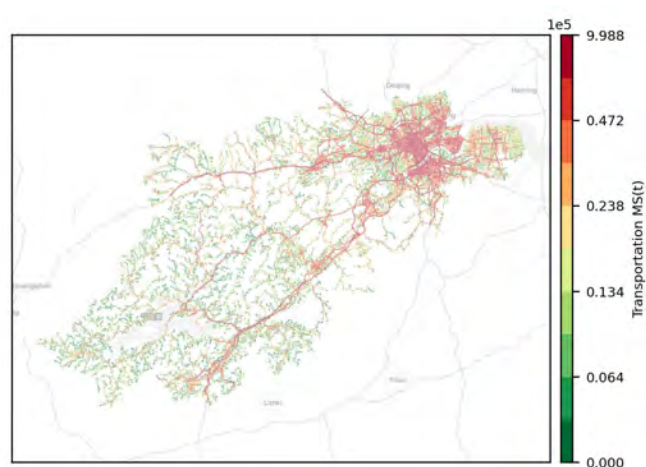
(7) Guangzhou



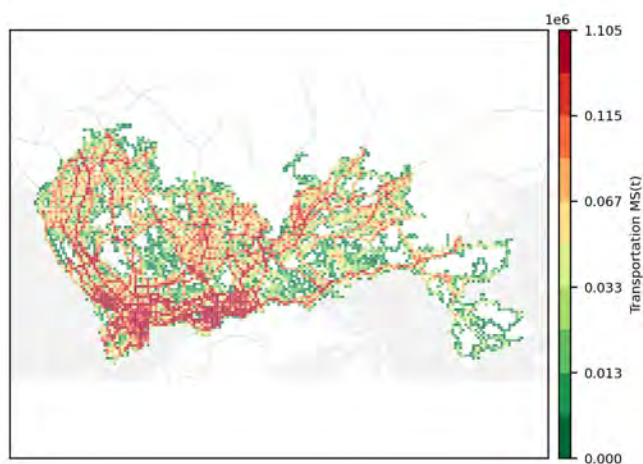
(8) Wuhan



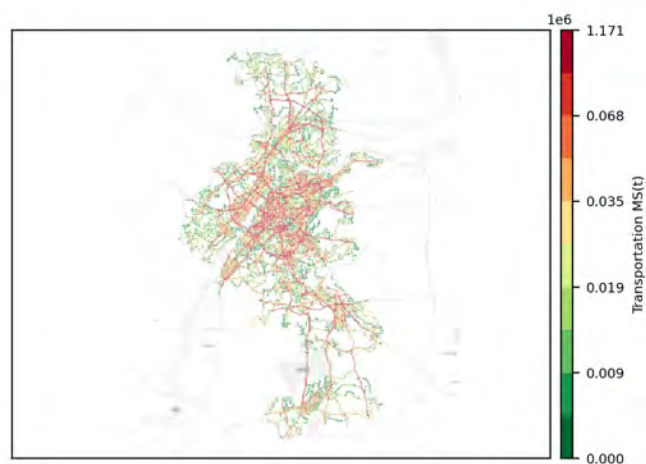
(9) Zhengzhou



(10) Hangzhou



(11) Shenzhen



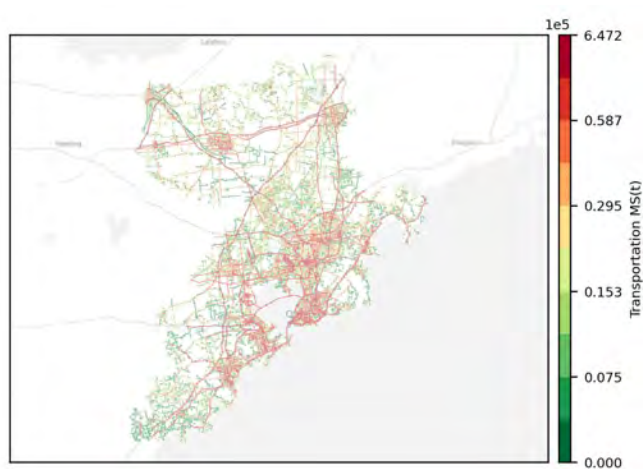
(12) Nanjing



(13) Shenyang



(14) Shijiazhuang



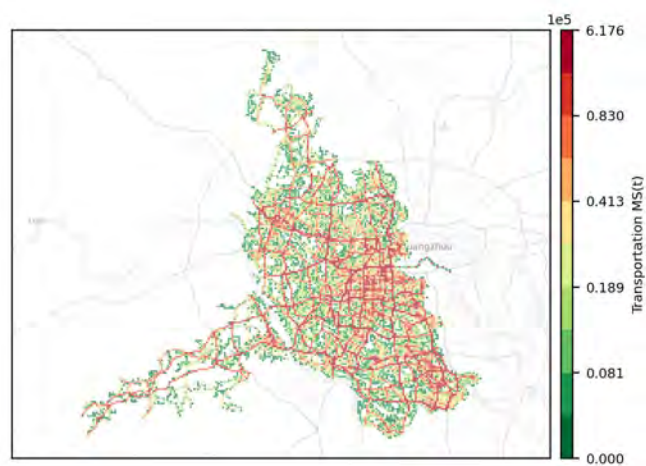
(15) Qingdao



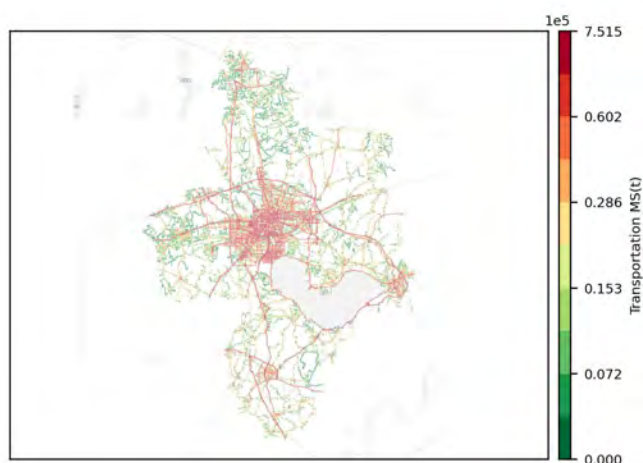
(16) Dalian



(17) Xi'an



(18) Foshan



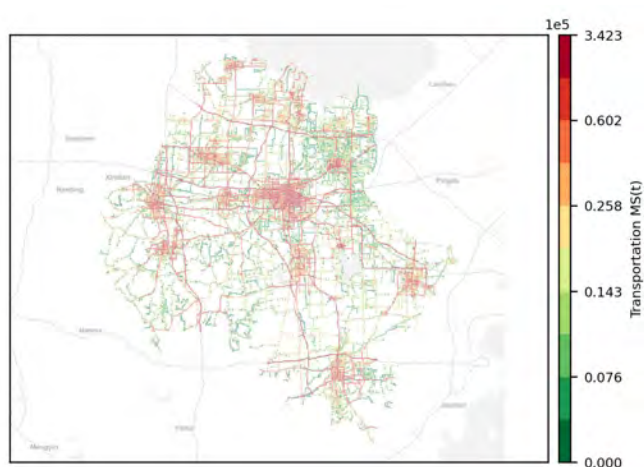
(19) Hefei



(20) Changchun



(21) Jinan



(22) Weifang



(23) Wuxi



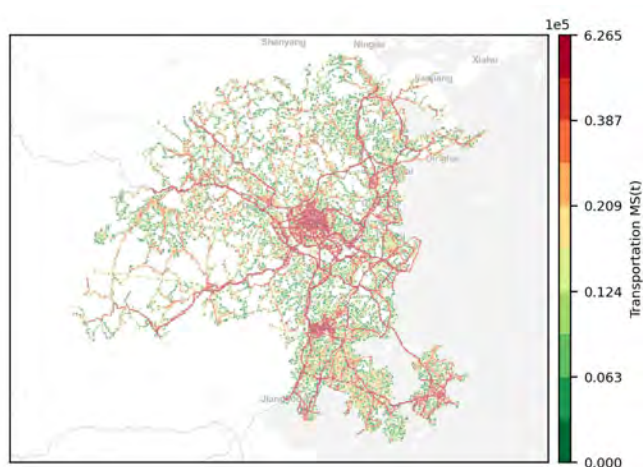
(24) Ha'erbin



(25) Ningbo



(26) Baoding



(27) Fuzhou



(28) Wenzhou



(29) Nantong



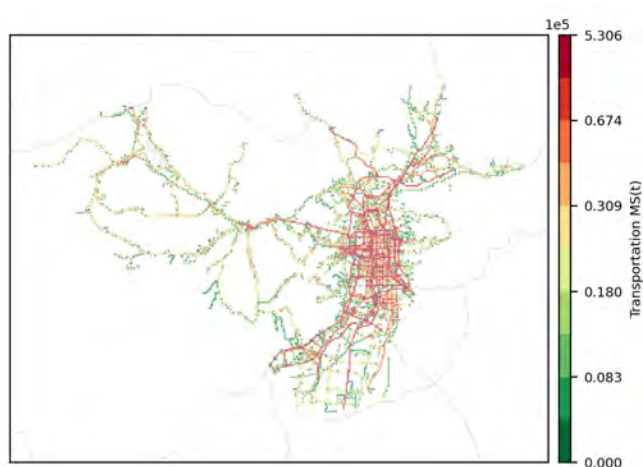
(30) Kunming



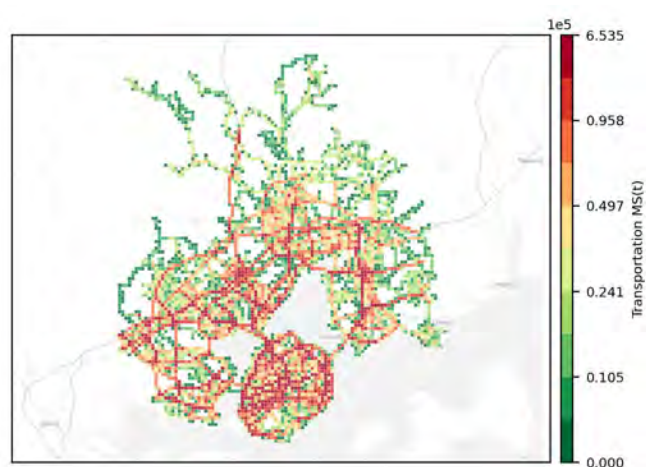
(31) Nanning



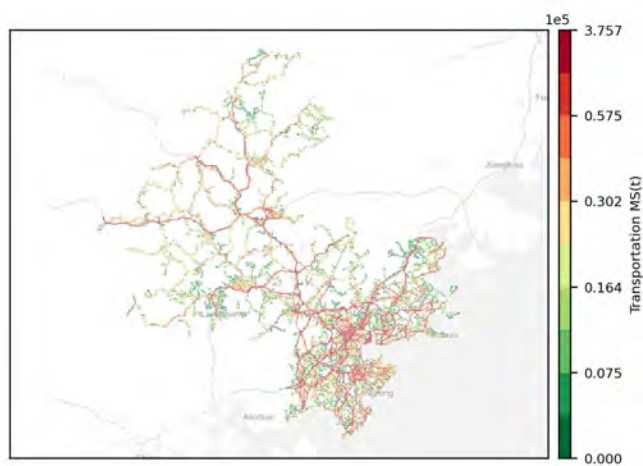
(32) Nanchang



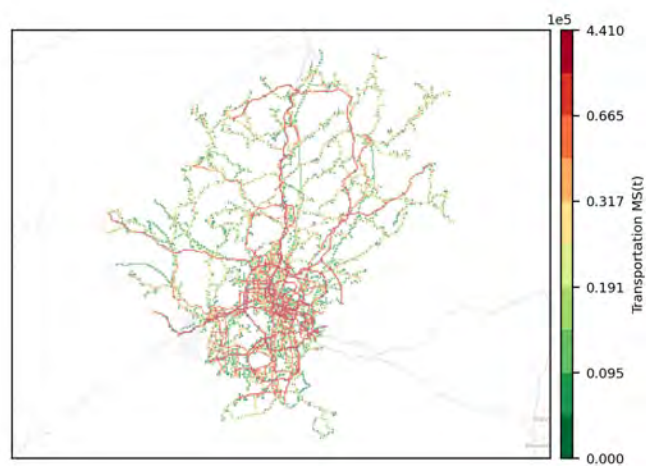
(33) Taiyuan



(34) Xiamen



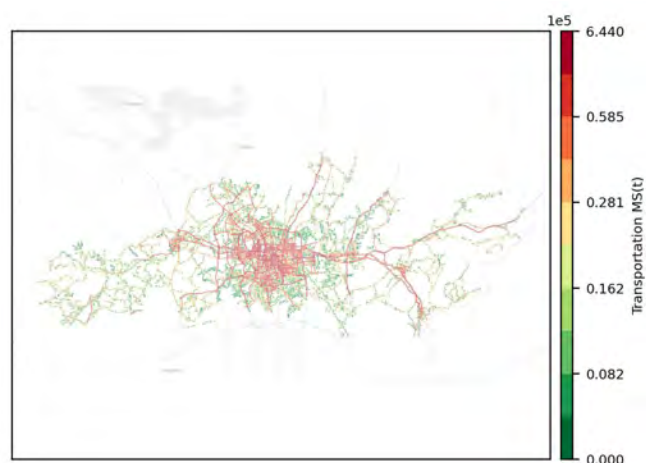
(35) Quanzhou



(36) Guiyang



(37) Hohhot



(38) Changsha



(39) Tangshan



(40) Yinchuan



(41) Linyi



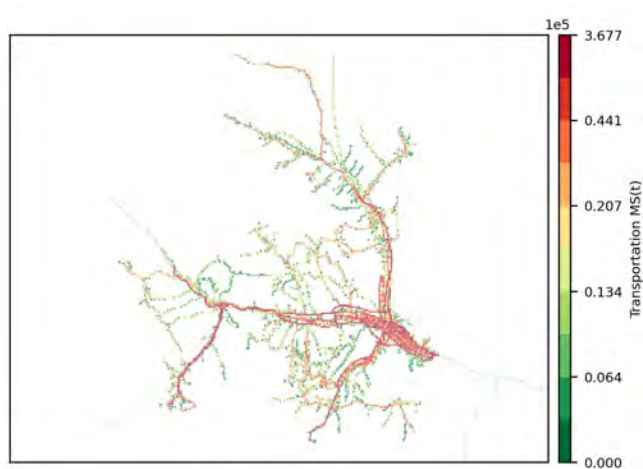
(42) Luoyang



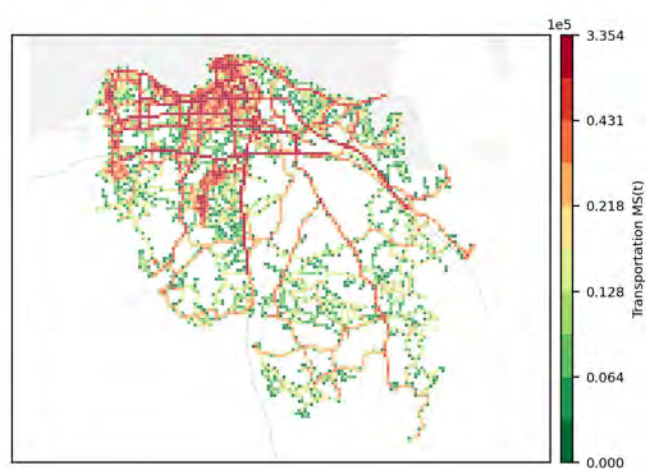
(43) Lanzhou



(44) Urumqi



(45) Xining



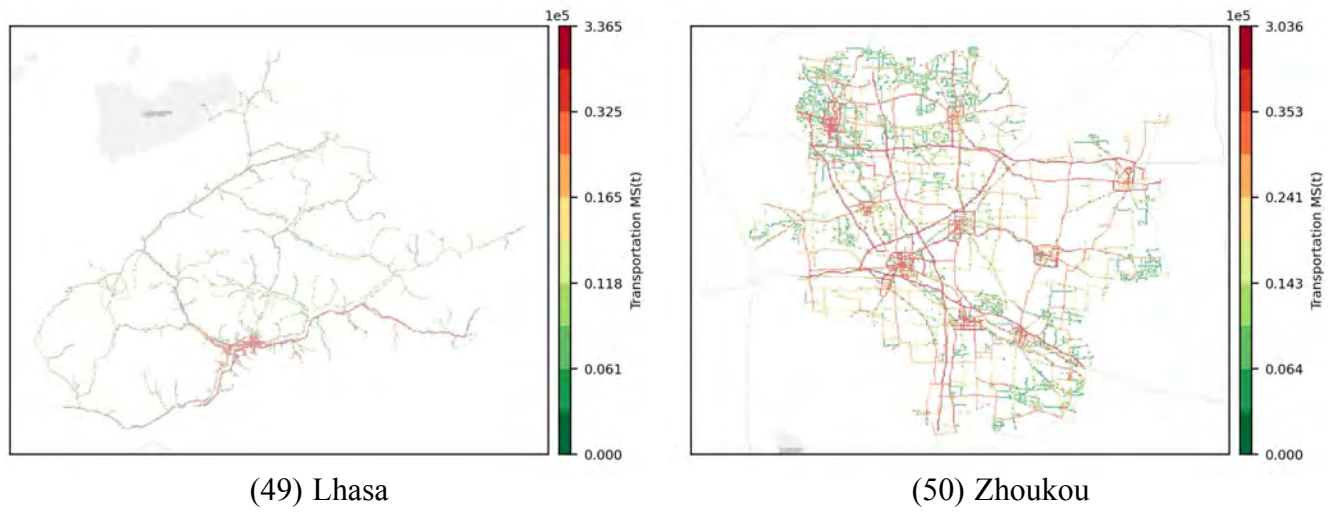
(46) Haikou



(47) Handan

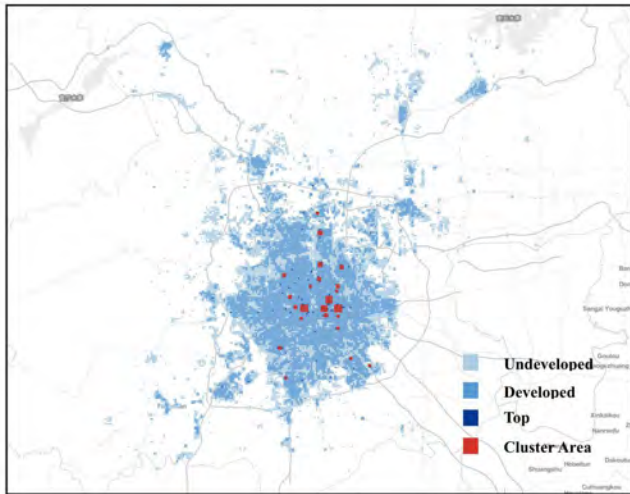


(48) Nanyang

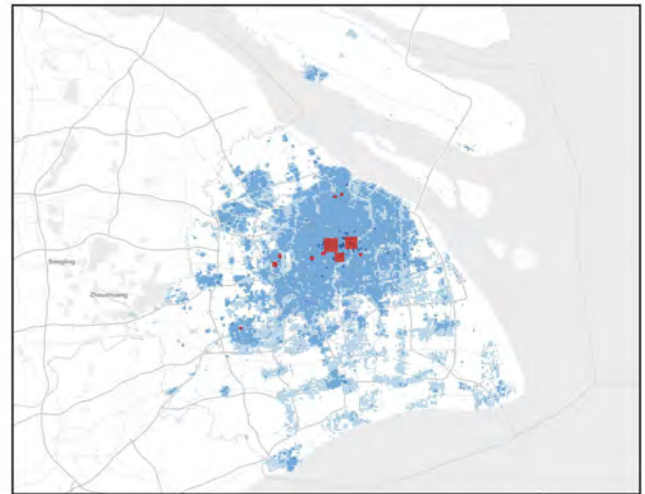


Supplementary Figure A3: Spatial maps of transportation material stocks in a 500m grid scale

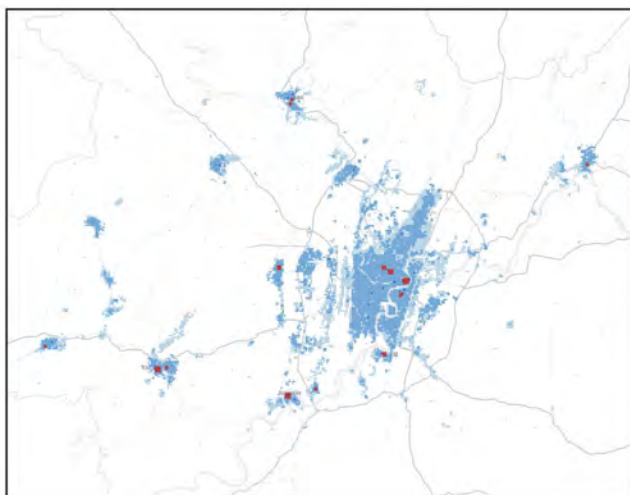
A.4 The spatial distributions of undeveloped, developed, top, and clusters of building stocks grids across the 50 cities



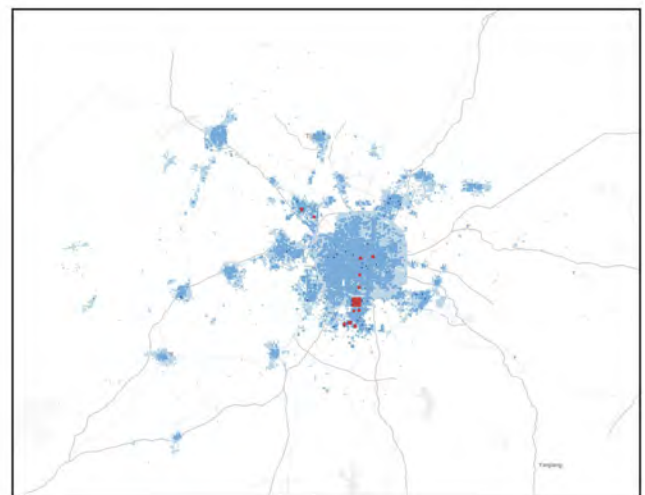
(1) Beijing



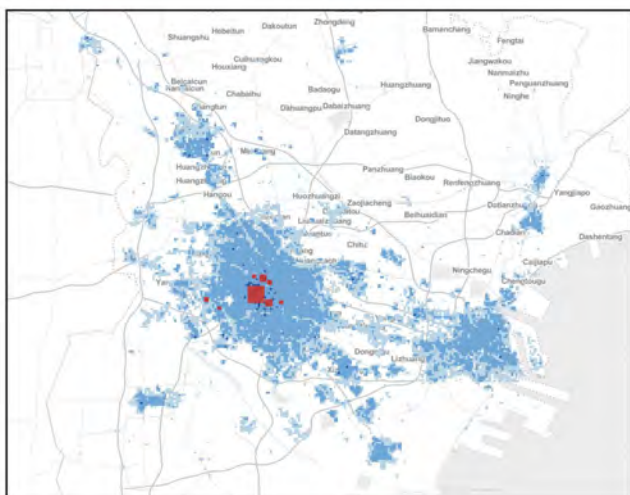
(2) Shanghai



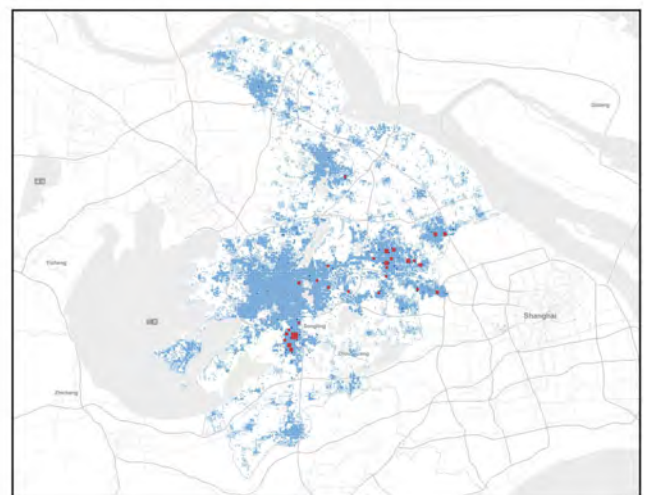
(3) Chongqing



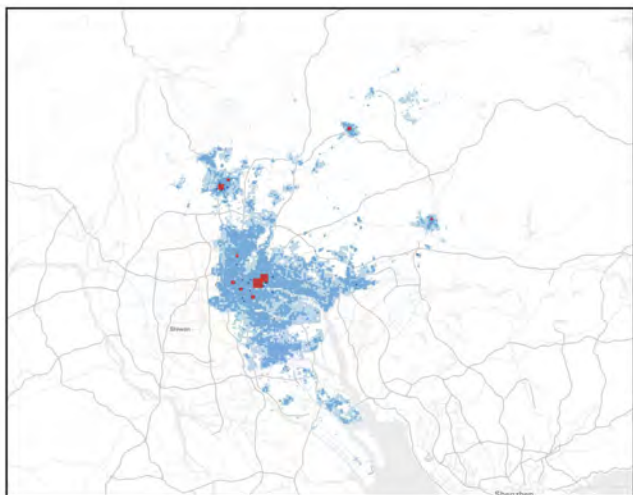
(4) Chengdu



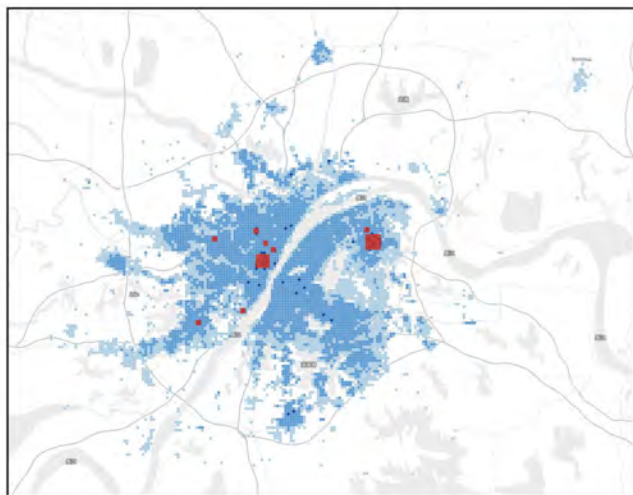
(5) Tianjin



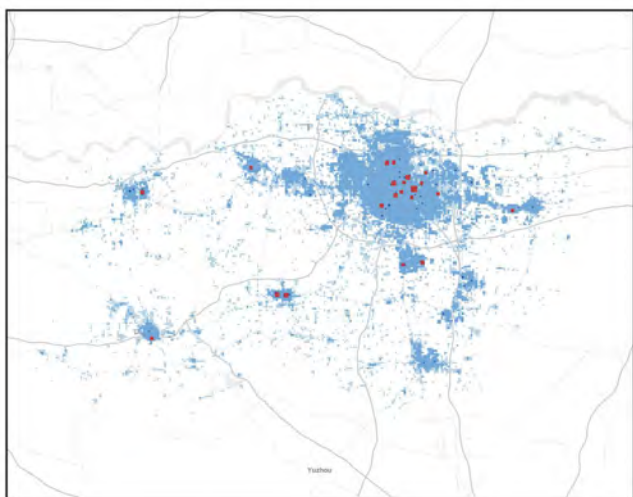
(6) Suzhou



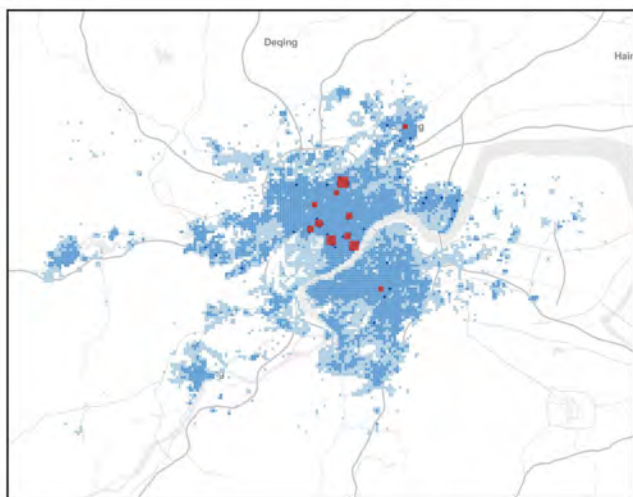
(7) Guangzhou



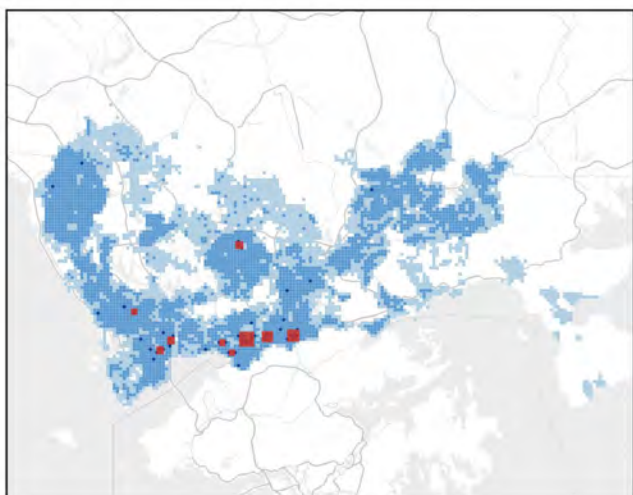
(8) Wuhan



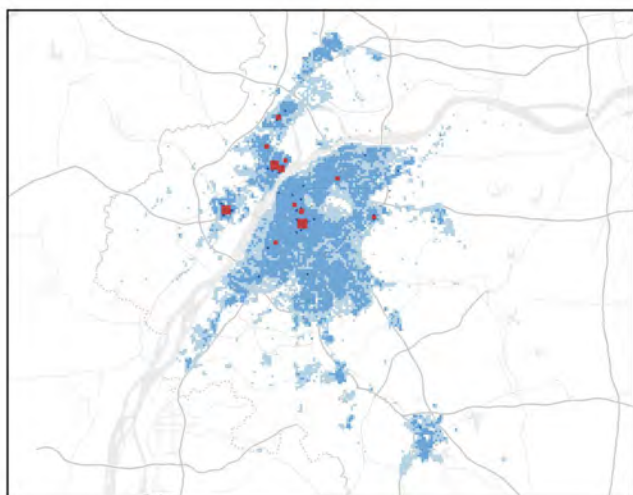
(9) Zhengzhou



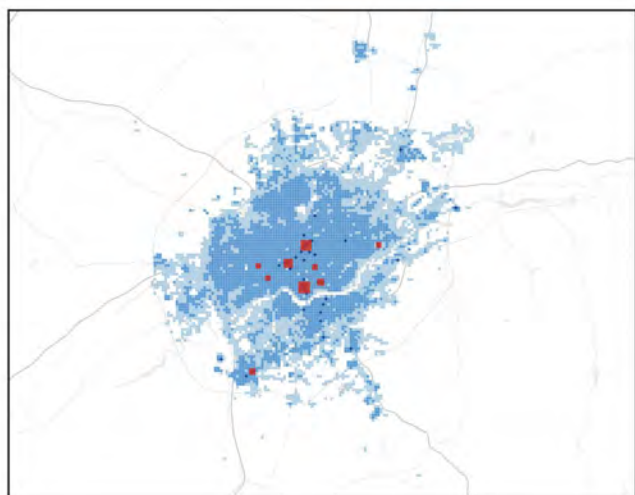
(10) Hangzhou



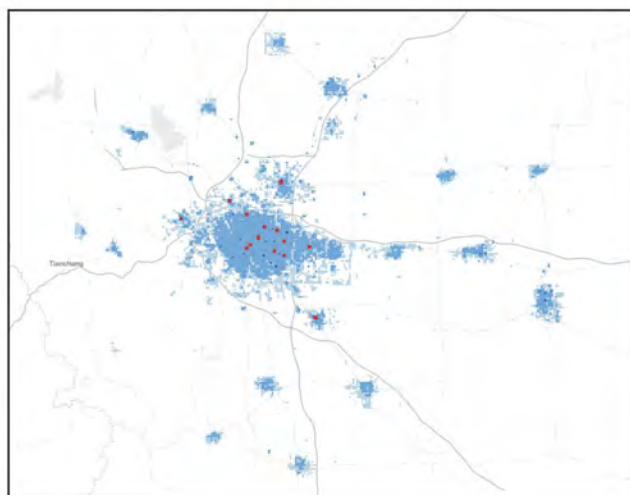
(11) Shenzhen



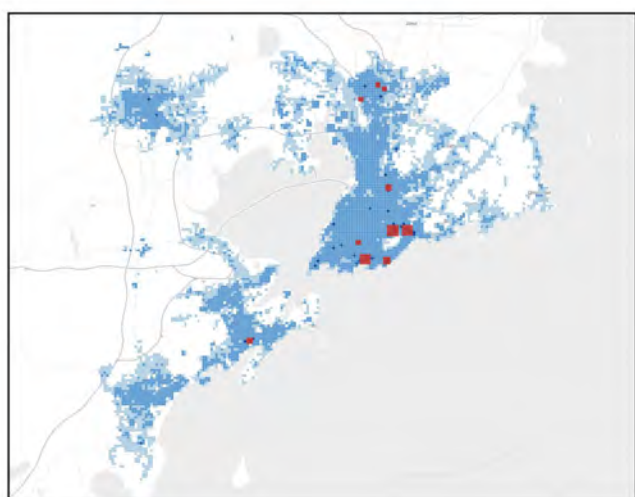
(12) Nanjing



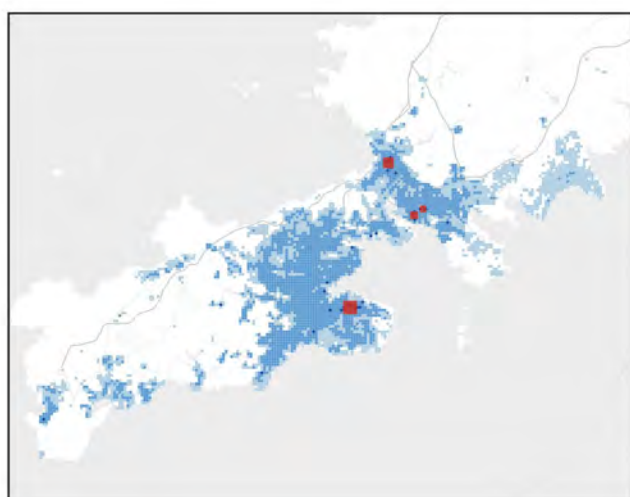
(13) Shenyang



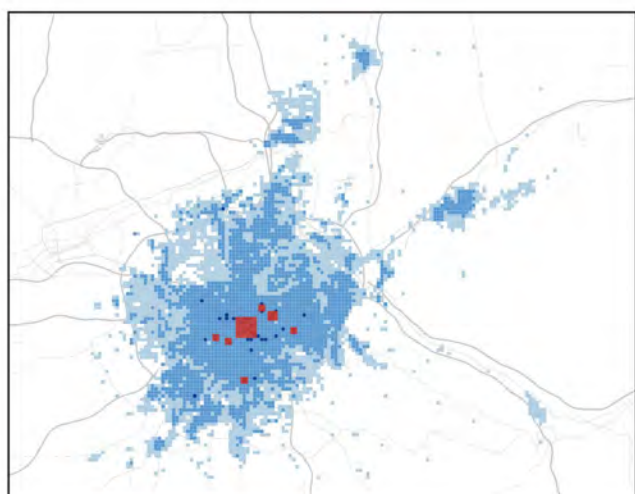
(14) Shijiazhuang



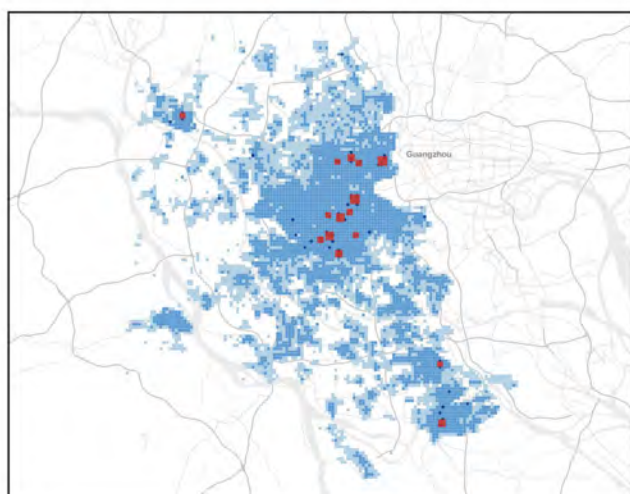
(15) Qingdao



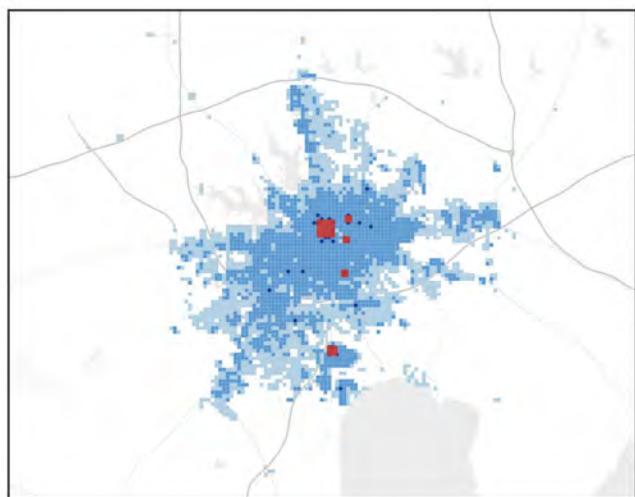
(16) Dalian



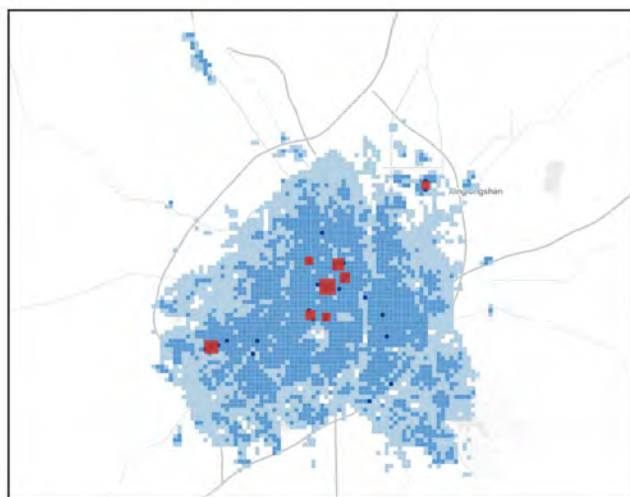
(17) Xi'an



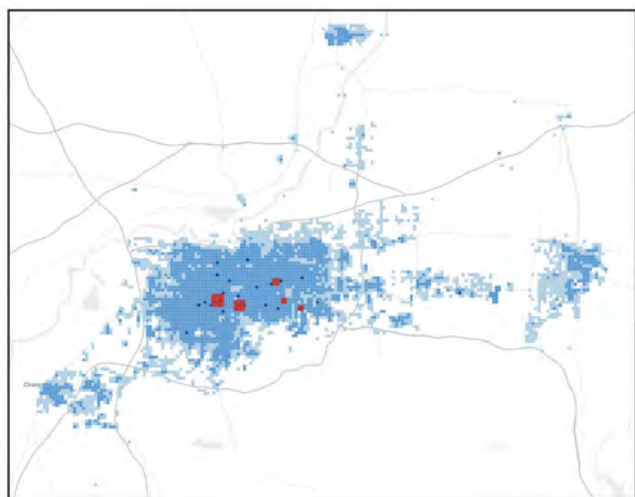
(18) Foshan



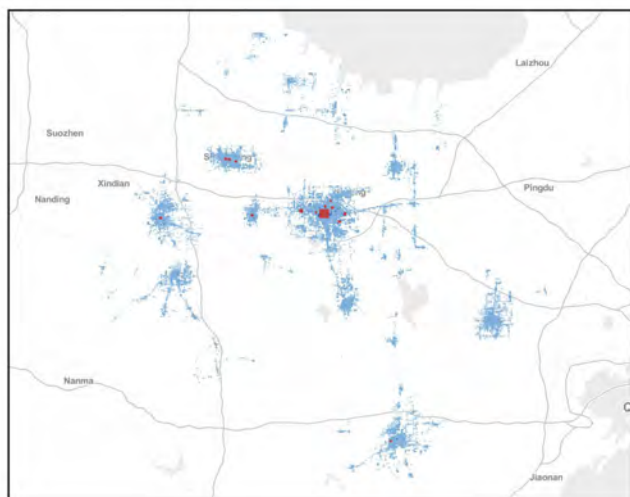
(19) Hefei



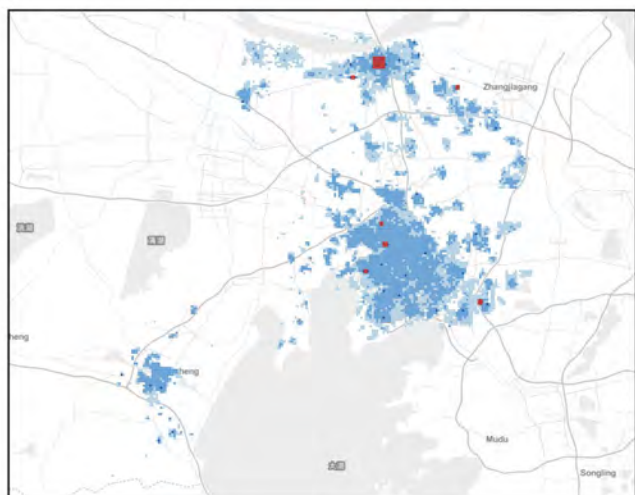
(20) Changchun



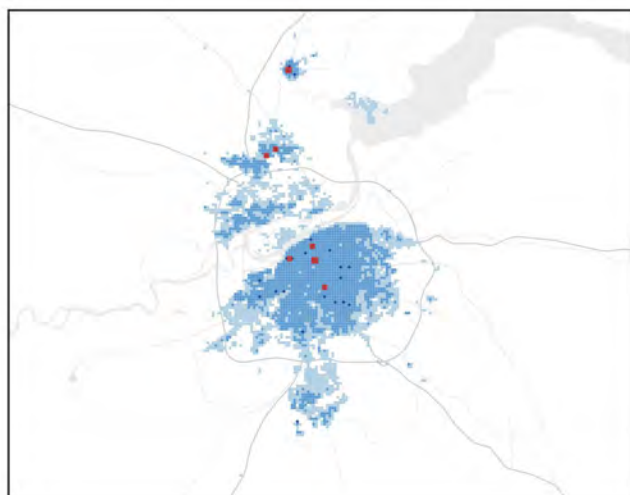
(21) Jinan



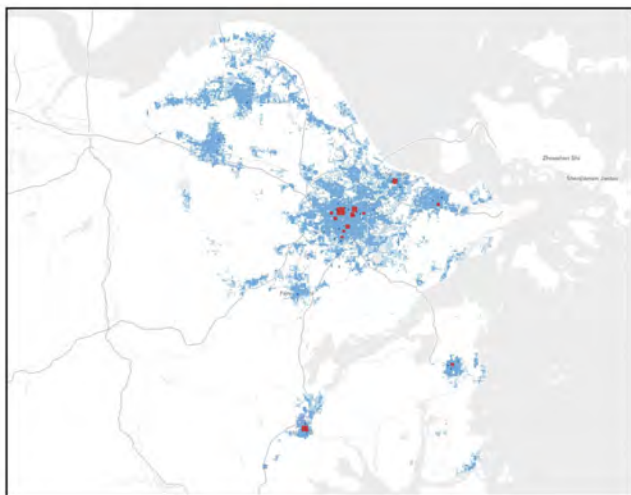
(22) Weifang



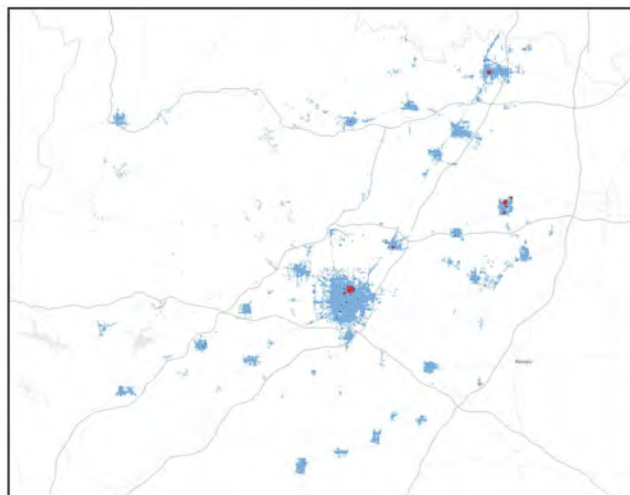
(23) Wuxi



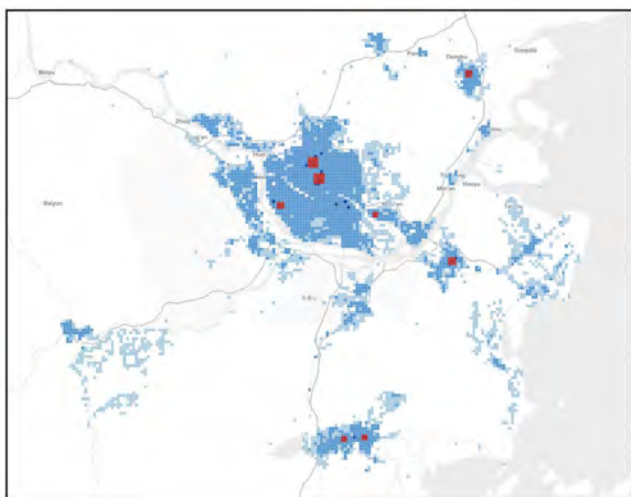
(24) Ha'erbin



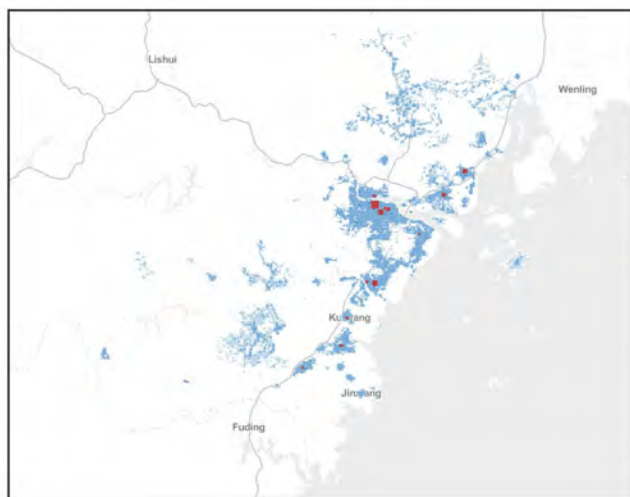
(25) Ningbo



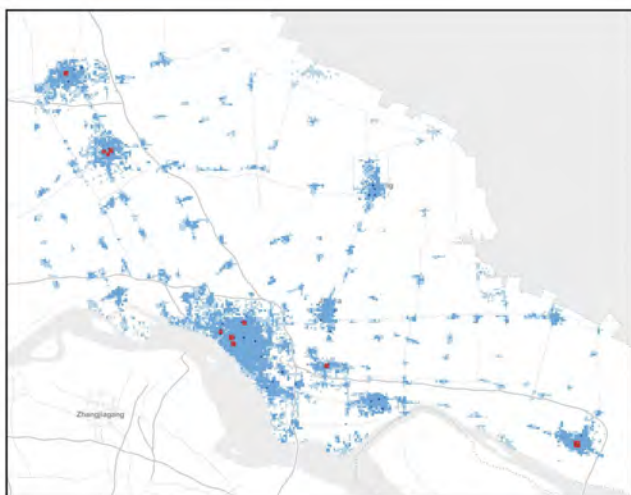
(26) Baoding



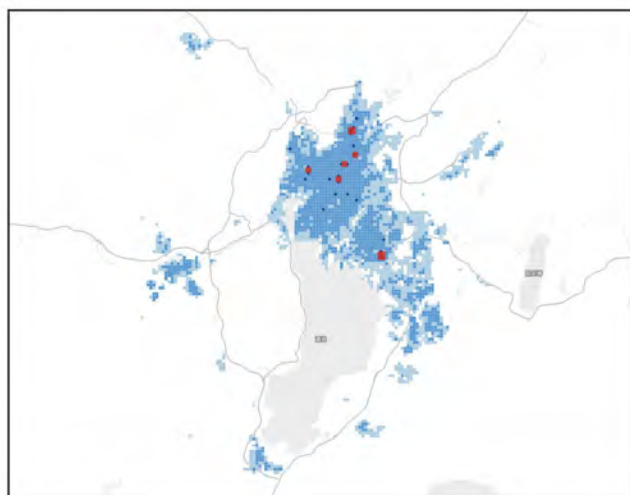
(27) Fuzhou



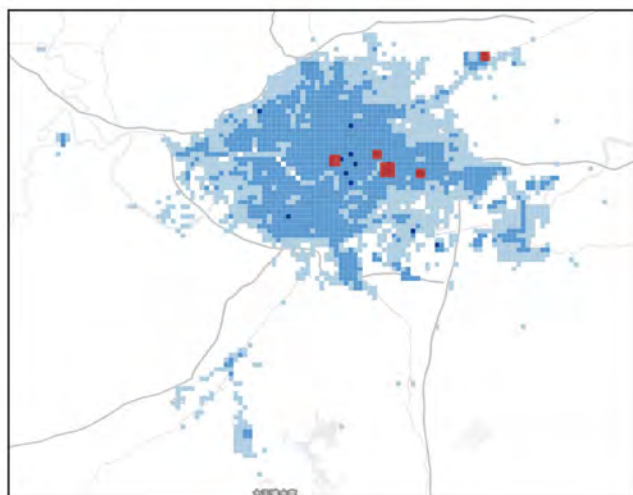
(28) Wenzhou



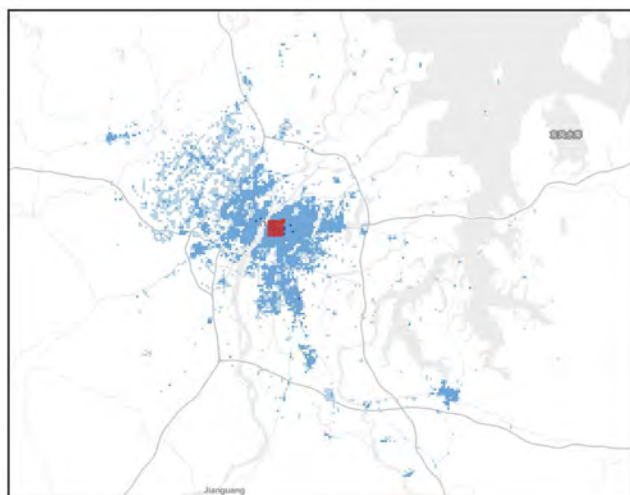
(29) Nantong



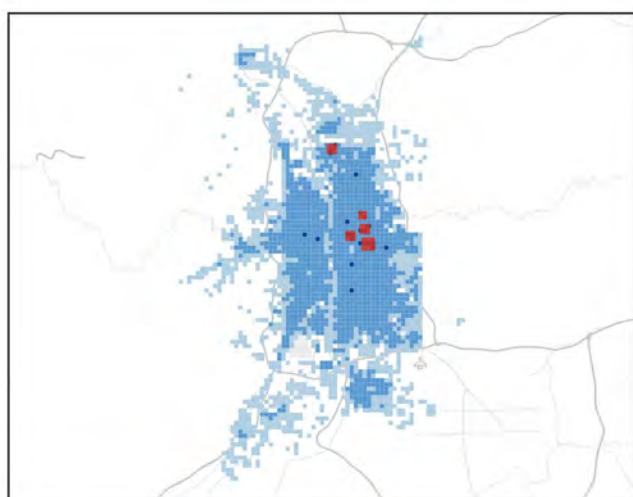
(30) Kunming



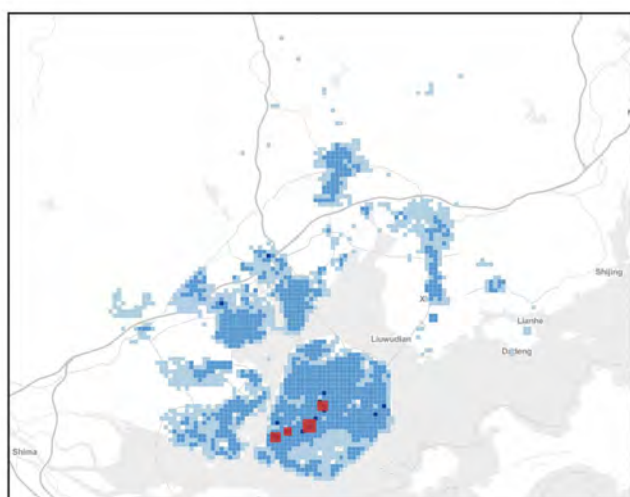
(31) Nanning



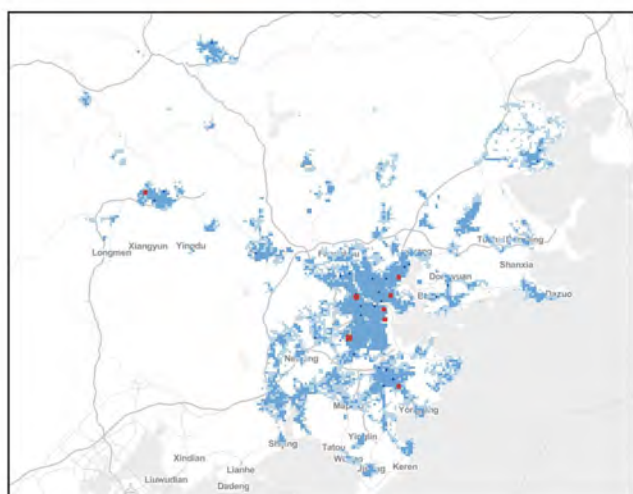
(32) Nanchang



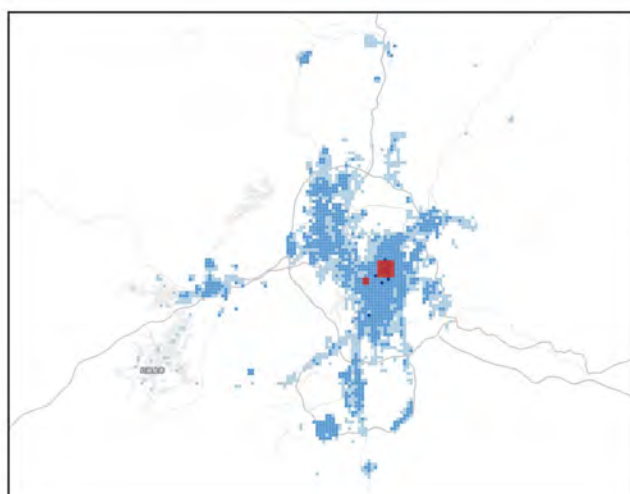
(33) Taiyuan



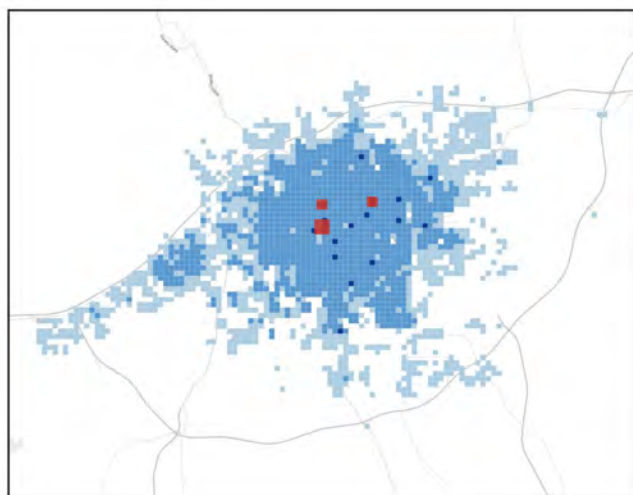
(34) Xiamen



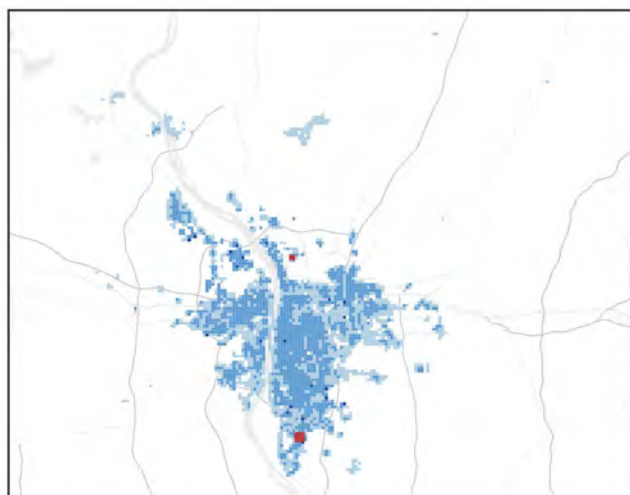
(35) Quanzhou



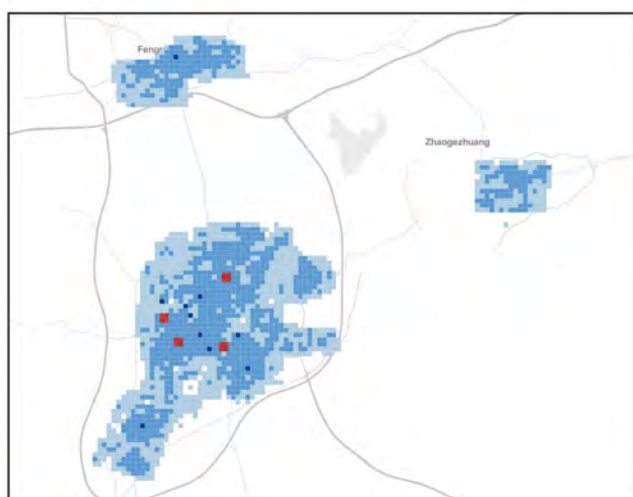
(36) Guiyang



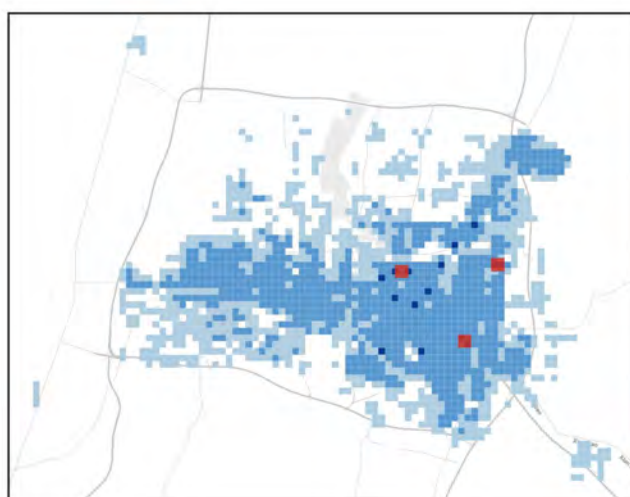
(37) Hohhot



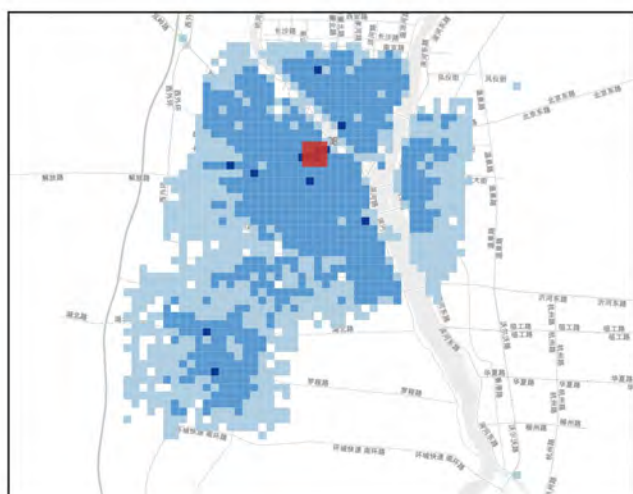
(38) Changsha



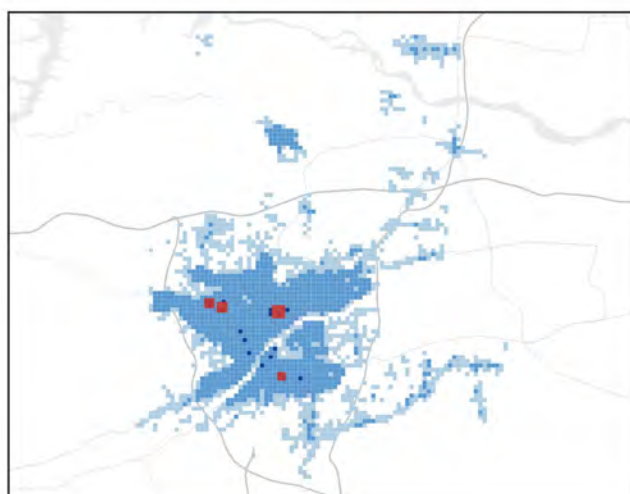
(39) Tangshan



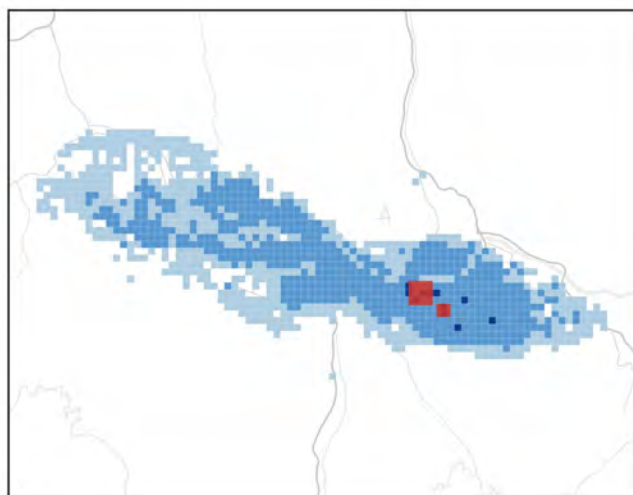
(40) Yinchuan



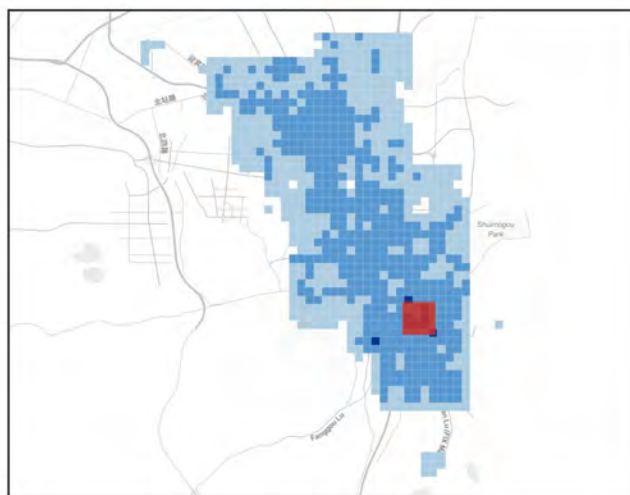
(41) Linyi



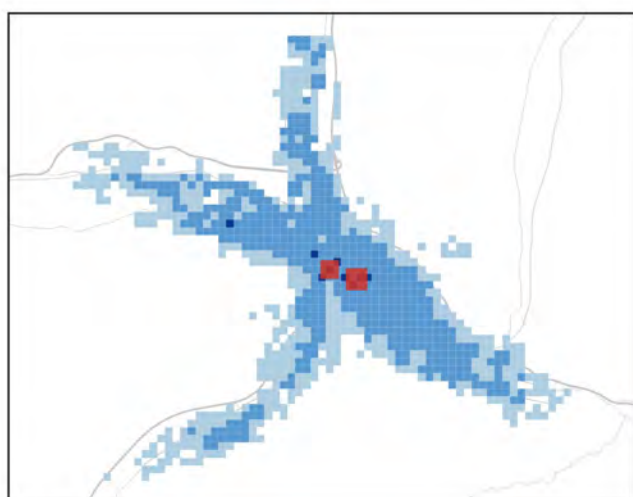
(42) Luoyang



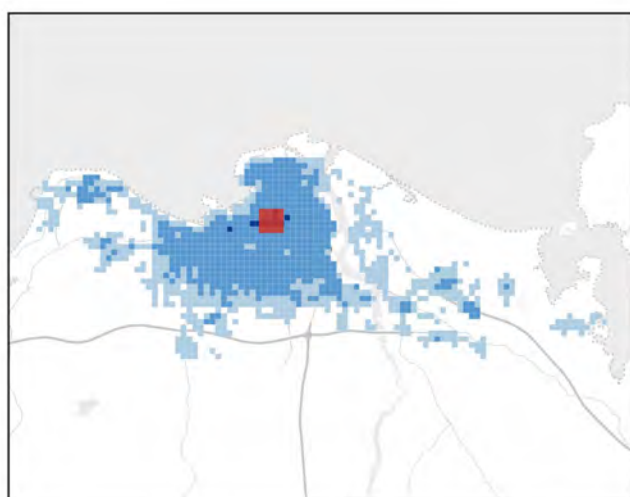
(43) Lanzhou



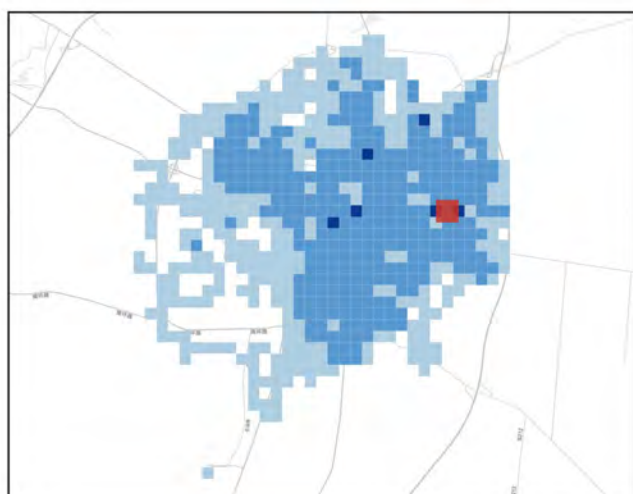
(44) Urumqi



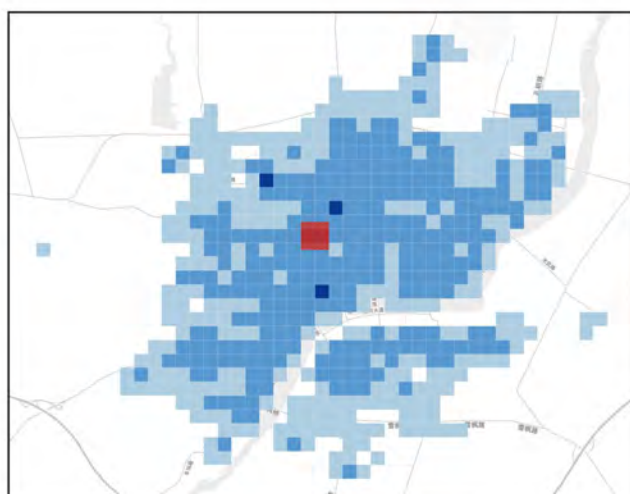
(45) Xining



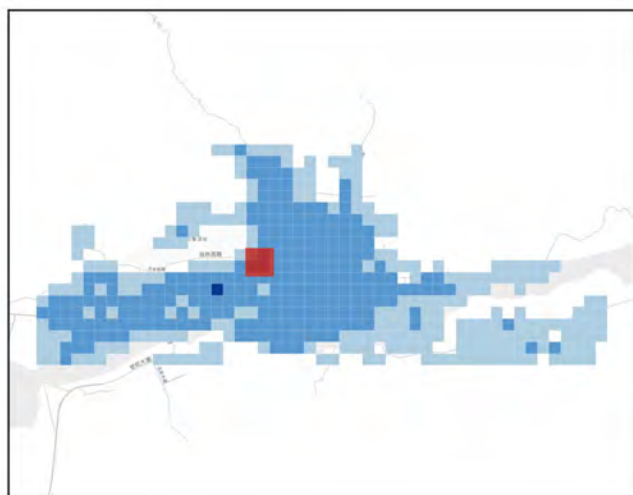
(46) Haikou



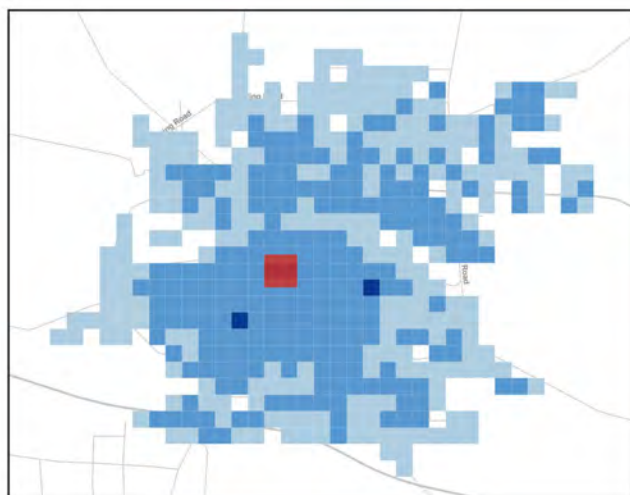
(47) Handan



(48) Nanyang



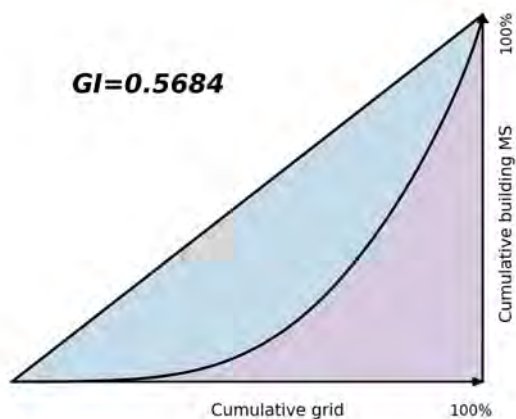
(49) Lhasa



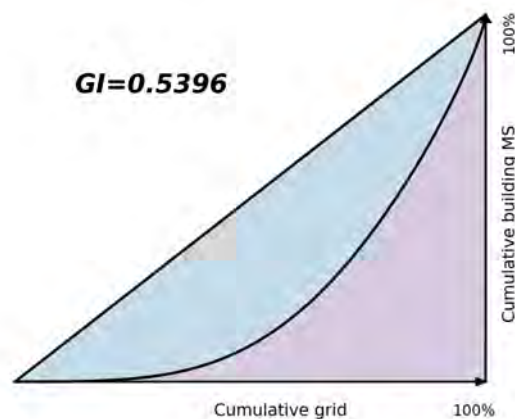
(50) Zhoukou

Supplementary Figure A4: Spatial maps of high building stocks clusters in the 50 Chinese cities

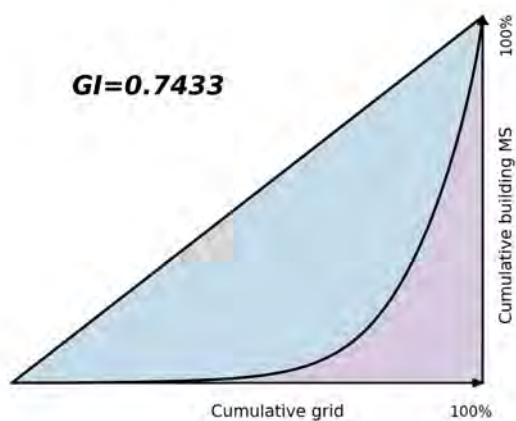
A.5 The Lorentz curves for building stocks in the 50 Chinese cities



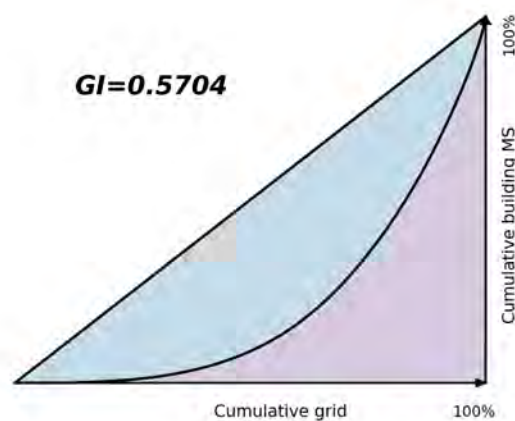
(1) Beijing



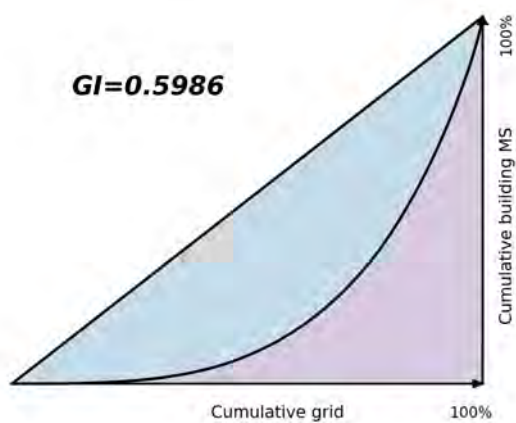
(2) Shanghai



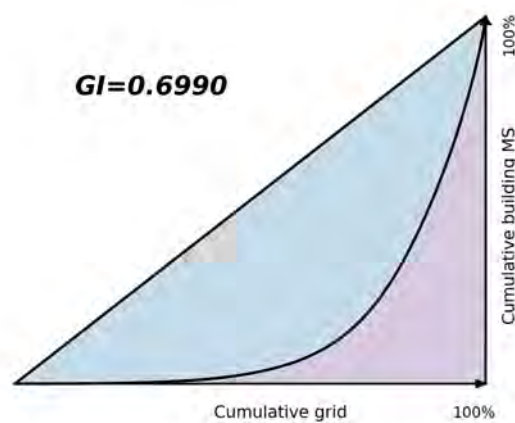
(3) Chongqing



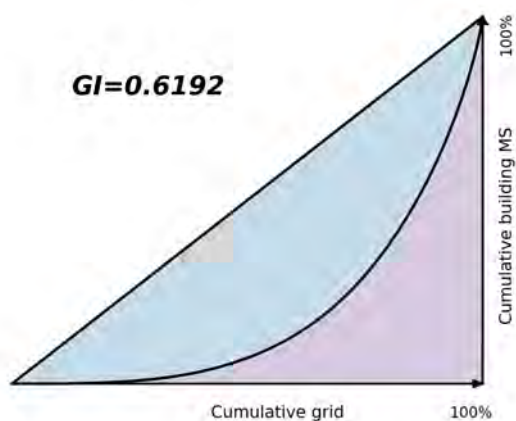
(4) Chengdu



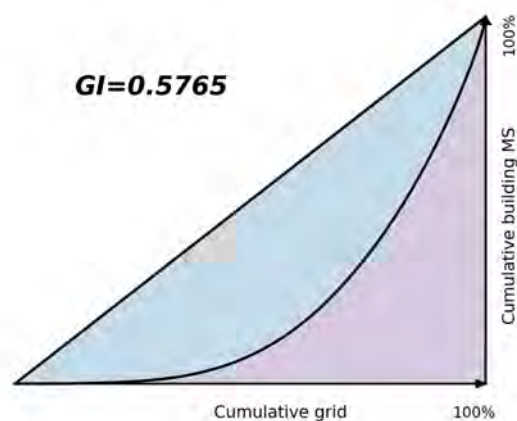
(5) Tianjin



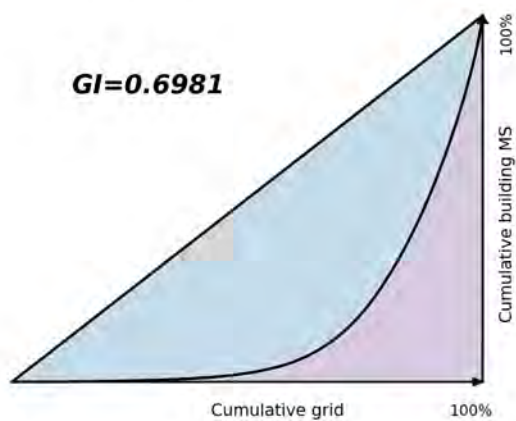
(6) Suzhou



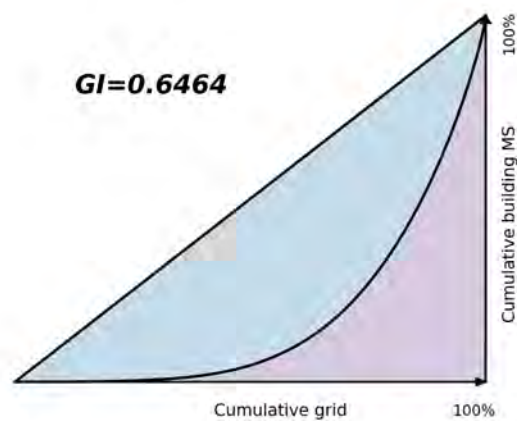
(7) Guangzhou



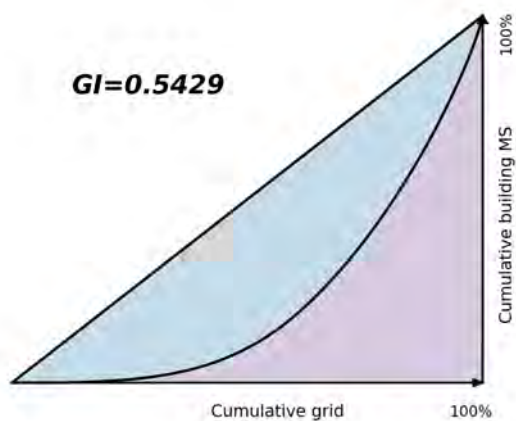
(8) Wuhan



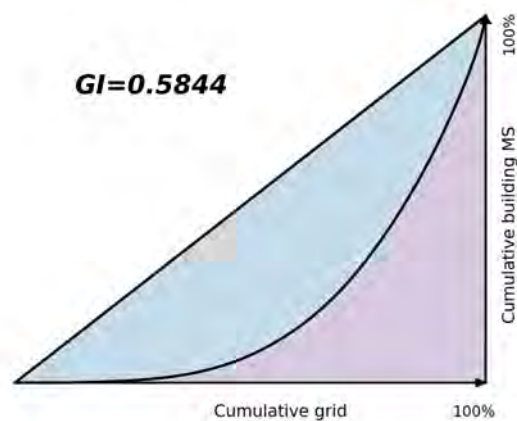
(9) Zhengzhou



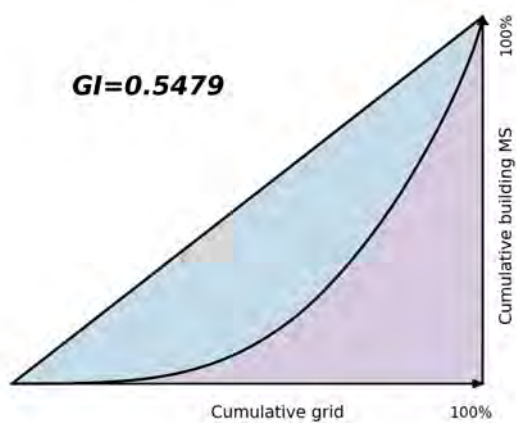
(10) Hangzhou



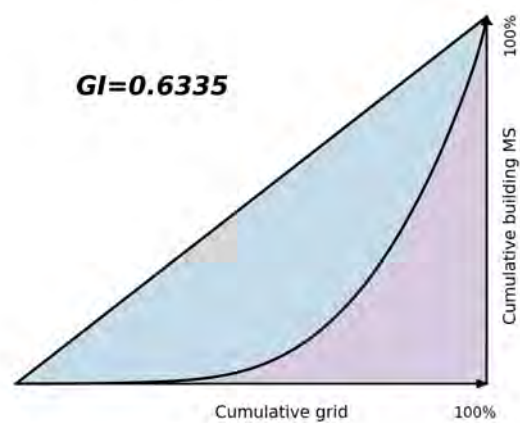
(11) Shenzhen



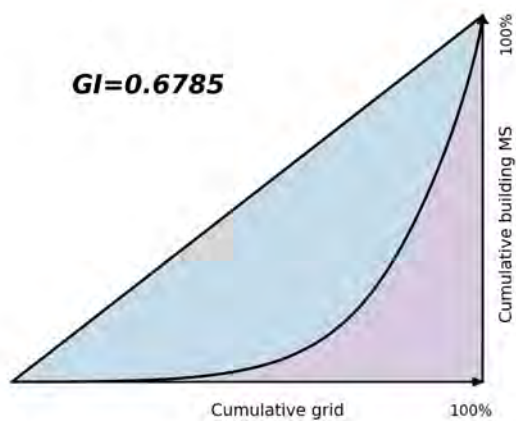
(12) Nanjing



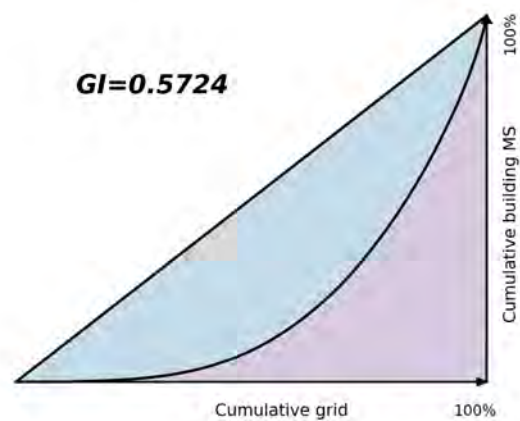
(13) Shenyang



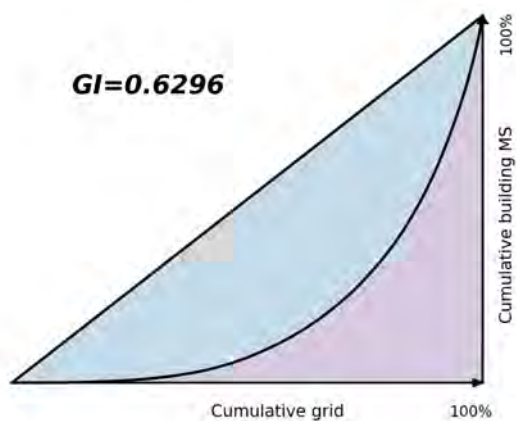
(14) Shijiazhuang



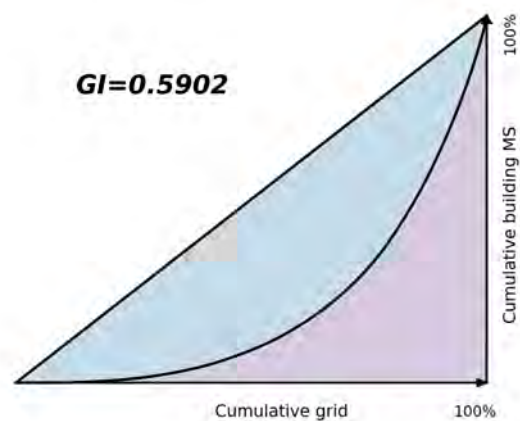
(15) Qingdao



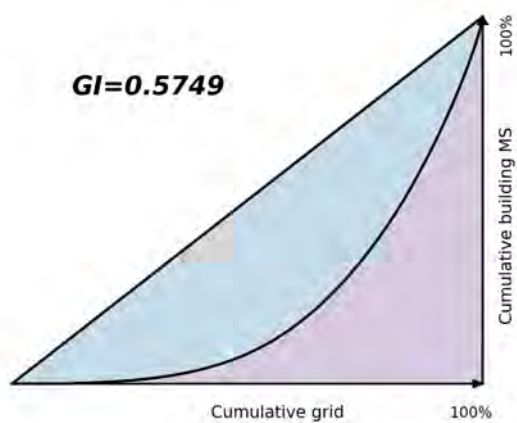
(16) Dalian



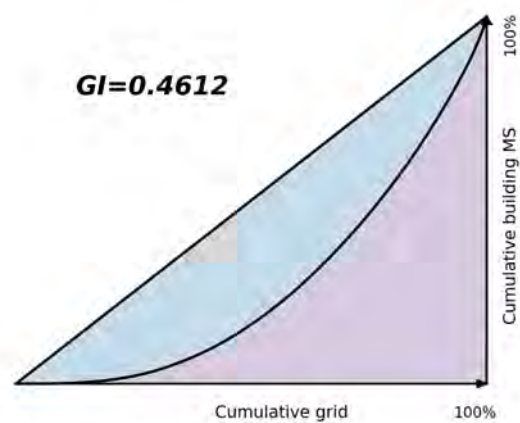
(17) Xi'an



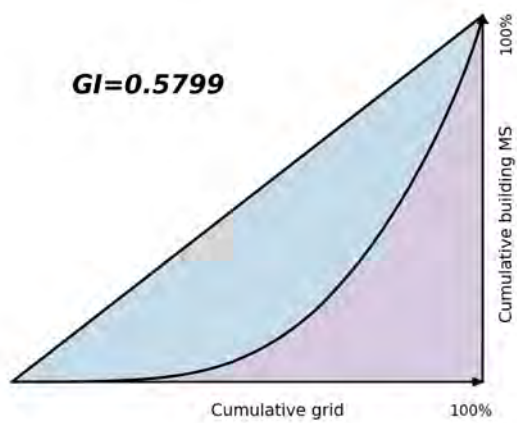
(18) Foshan



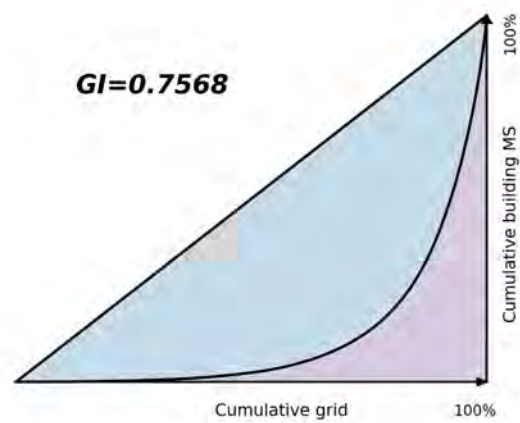
(19) Hefei



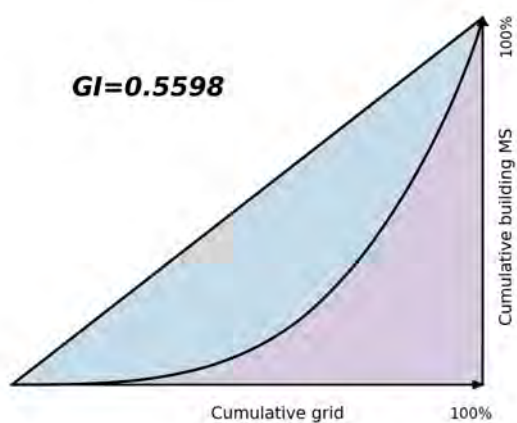
(20) Changchun



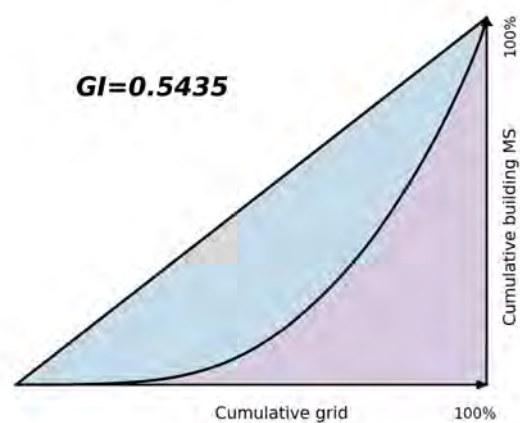
(21) Jinan



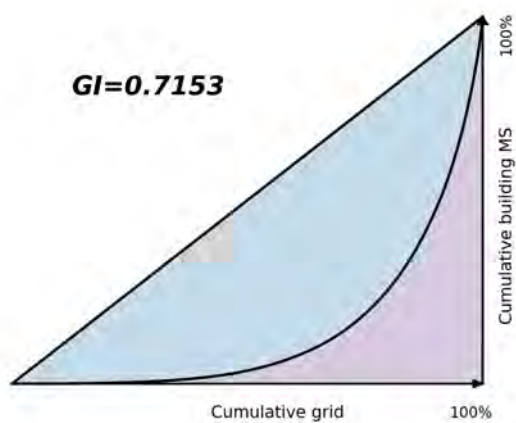
(22) Weifang



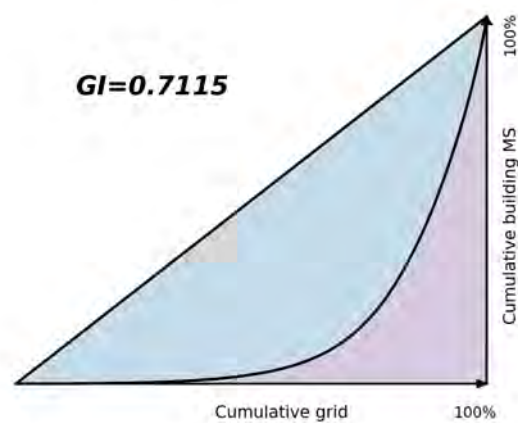
(23) Wuxi



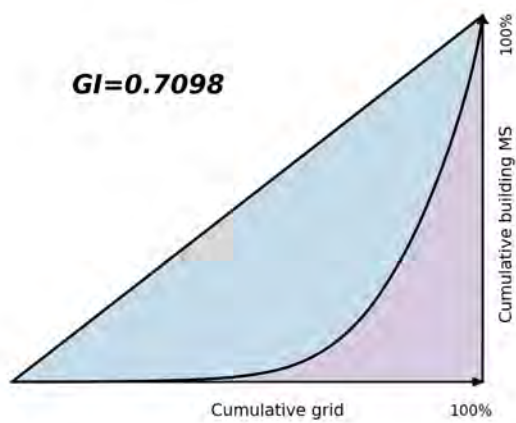
(24) Ha'erbin



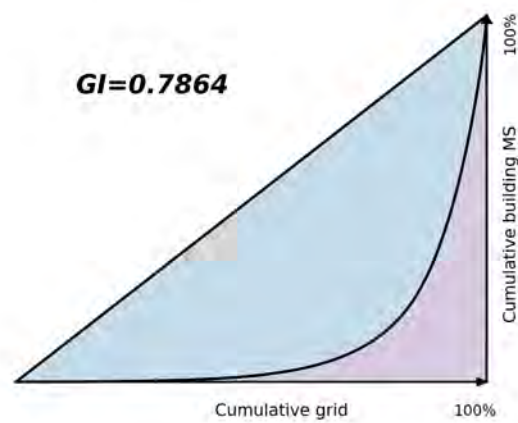
(25) Ningbo



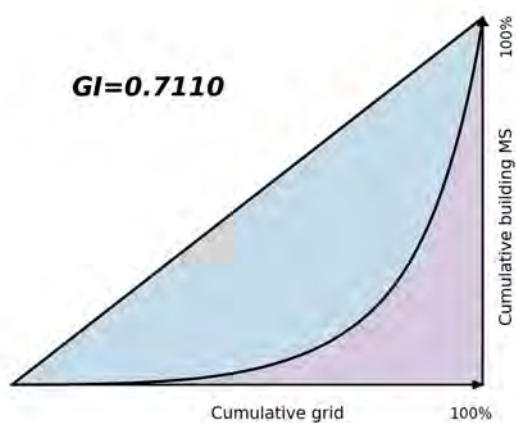
(26) Baoding



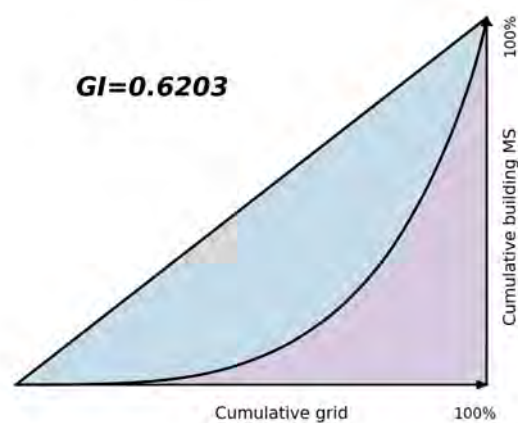
(27) Fuzhou



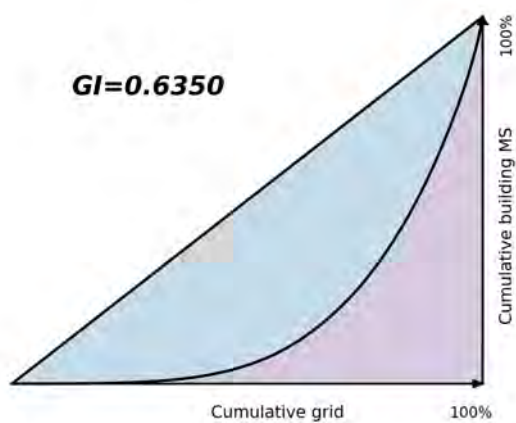
(28) Wenzhou



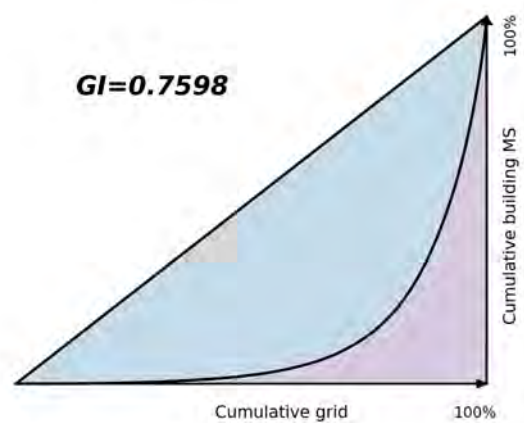
(29) Nantong



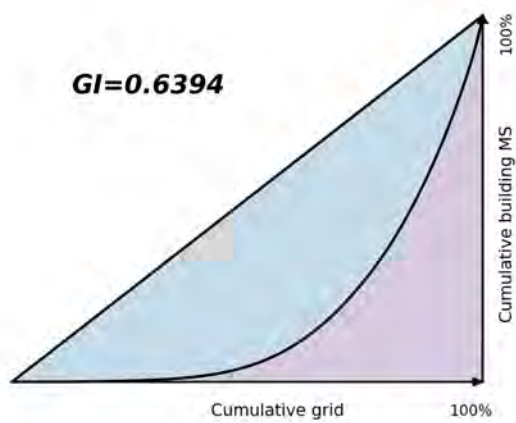
(30) Kunming



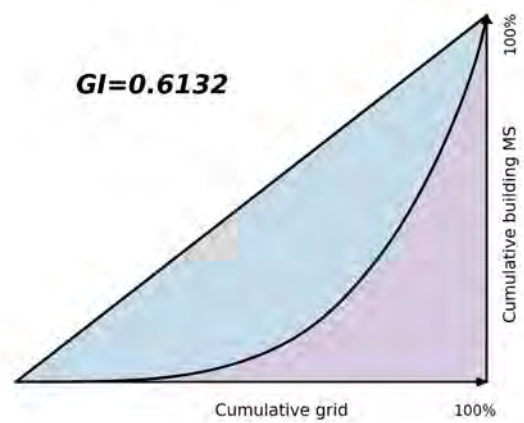
(31) Nanning



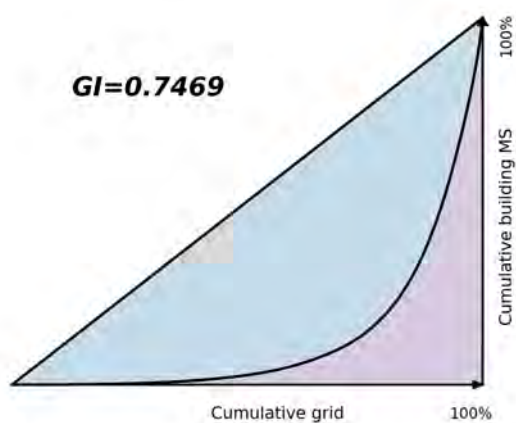
(32) Nanchang



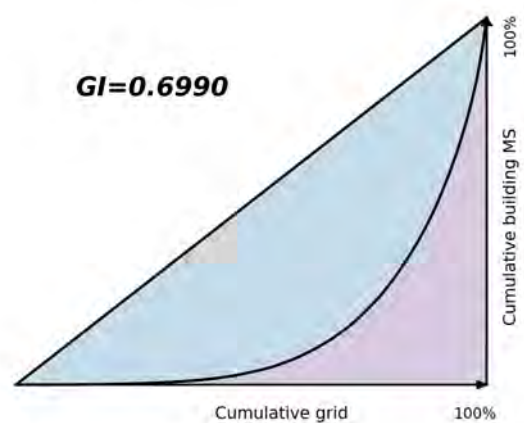
(33) Taiyuan



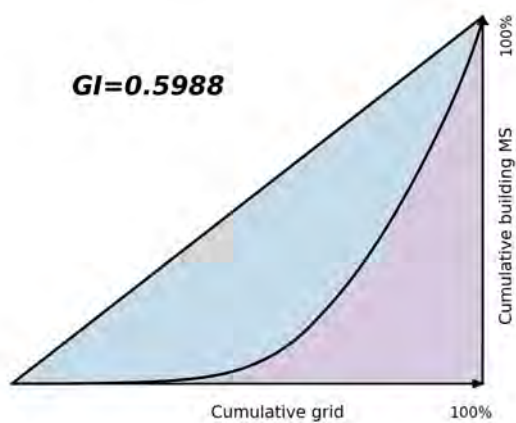
(34) Xiamen



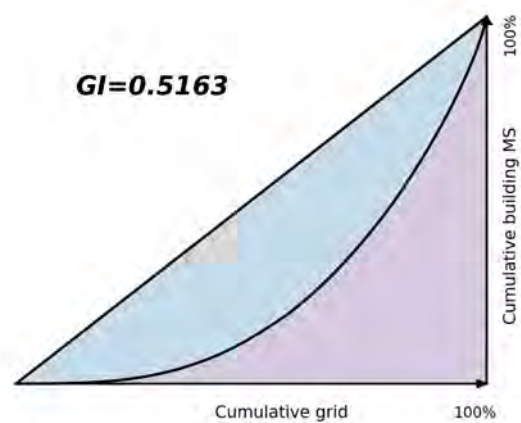
(35) Quanzhou



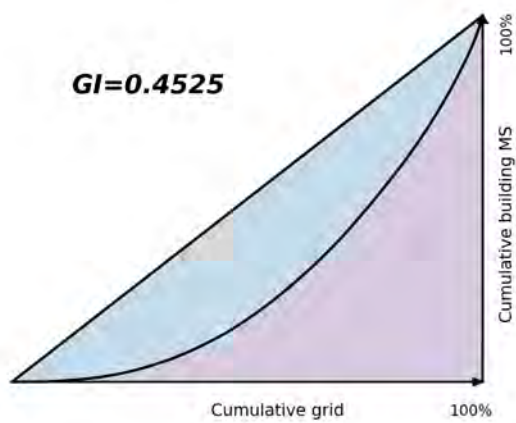
(36) Guiyang



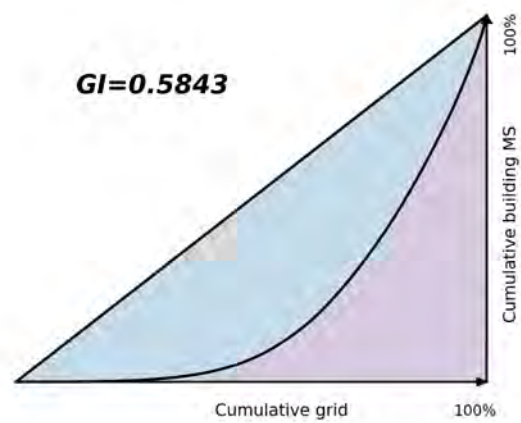
(37) Hohhot



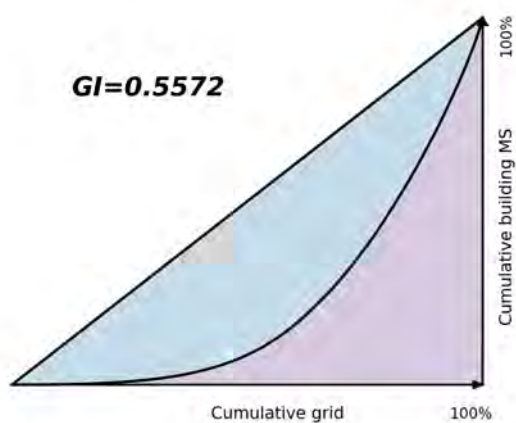
(38) Changsha



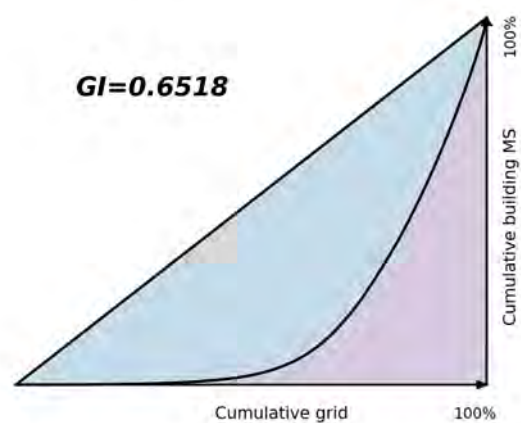
(39) Tangshan



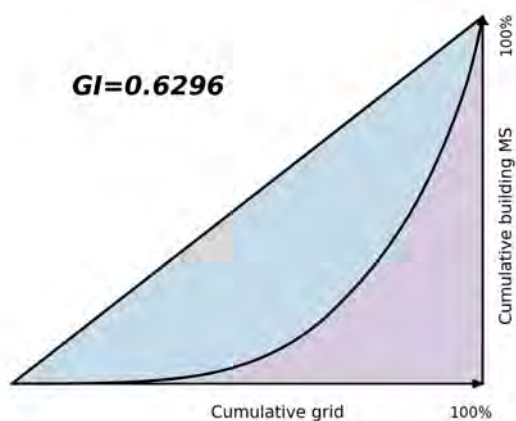
(40) Yinchuan



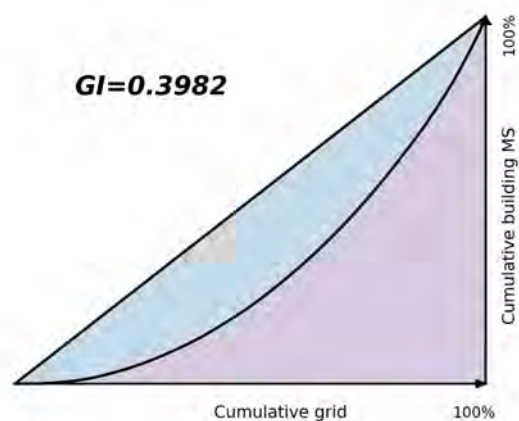
(41) Linyi



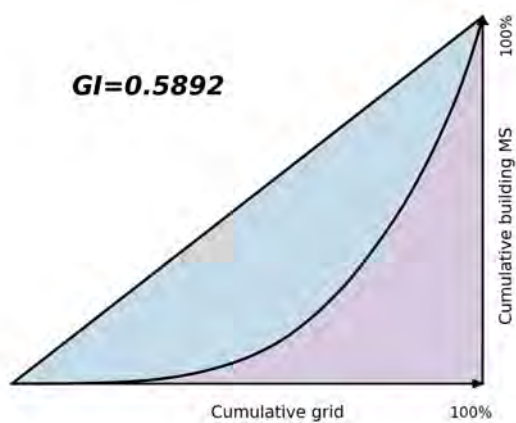
(42) Luoyang



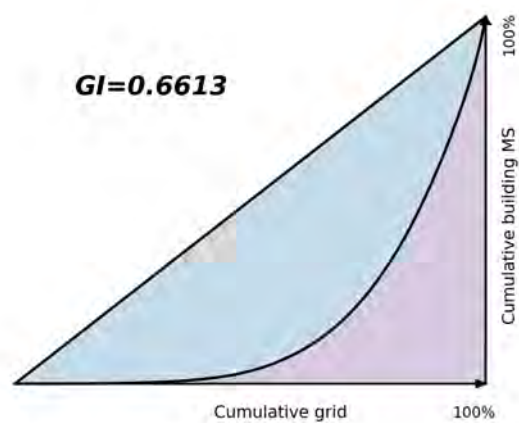
(43) Lanzhou



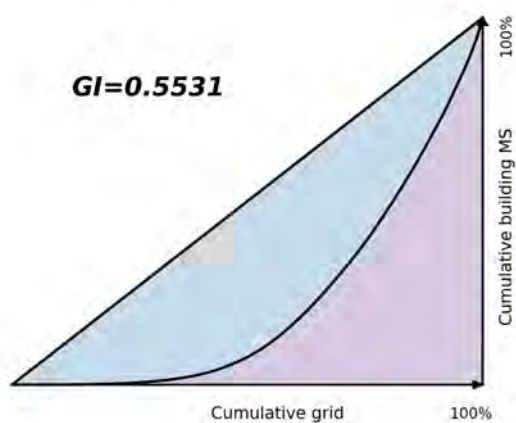
(44) Urumqi



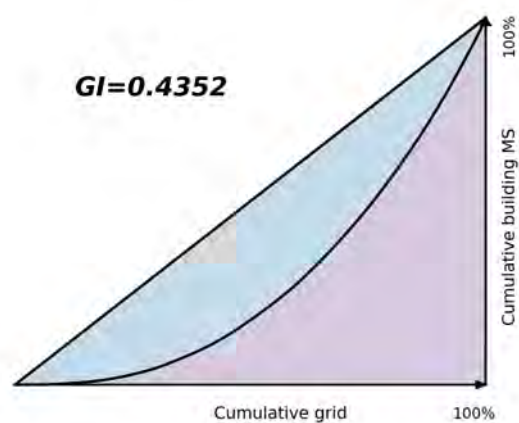
(45) Xining



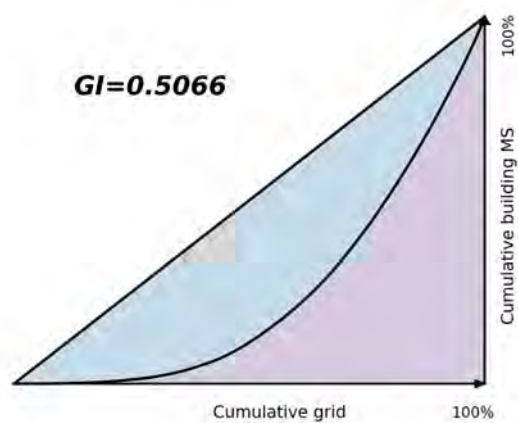
(46) Haikou



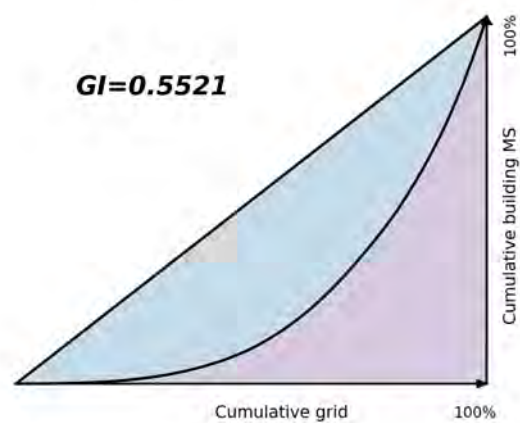
(47) Handan



(48) Nanyang



(49) Lhasa

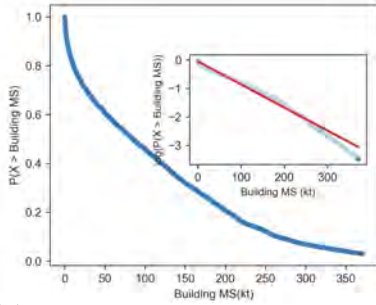


(50) Zhoukou

Supplementary Figure A5: Lorentz curves for building stocks in the 50 Chinese cities

A.6 The CCDF curves for building stocks in the 50 Chinese cities

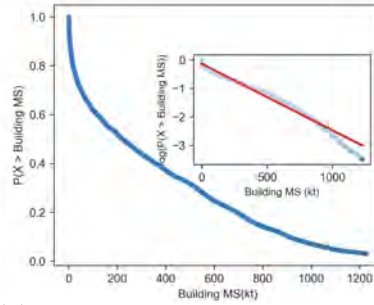
(1) Beijing



(1) 250m

$R^2=0.98$

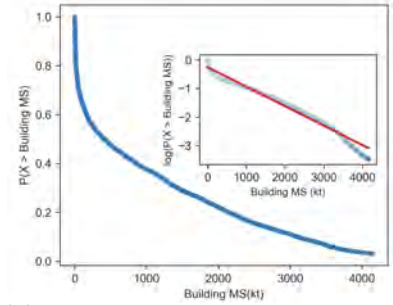
$\mu = 3.30 \times 10^3, \theta = 1.18 \times 10^5$



(2) 500m

$R^2=0.98$

$\mu = 5.81 \times 10^4, \theta = 4.27 \times 10^5$

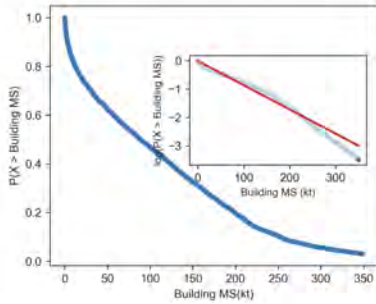


(3) 1000m

$R^2=0.96$

$\mu = 2.83 \times 10^5, \theta = 1.34 \times 10^6$

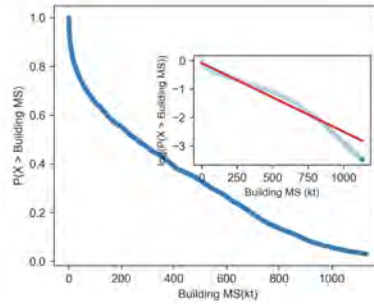
(2) Shanghai



(1) 250m

$R^2=0.96$

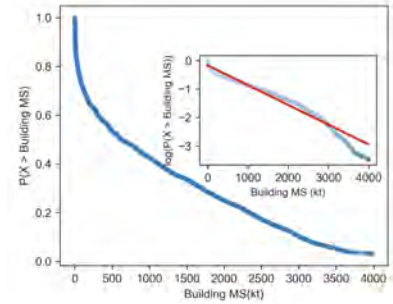
$\mu = 1.65 \times 10^3, \theta = 1.16 \times 10^5$



(2) 500m

$R^2=0.97$

$\mu = 3.44 \times 10^4, \theta = 4.13 \times 10^5$

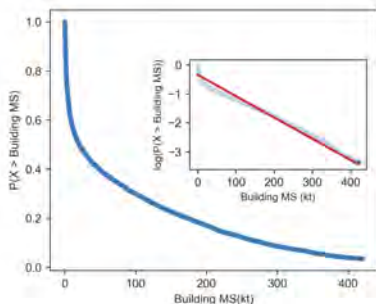


(3) 1000m

$R^2=0.96$

$\mu = 1.57 \times 10^5, \theta = 1.32 \times 10^6$

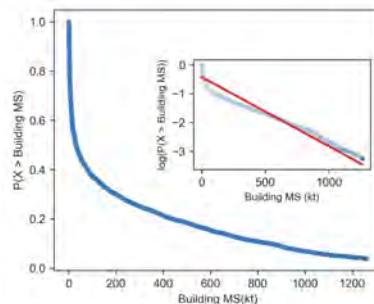
(3) Chongqing



(1) 250m

$R^2=0.97$

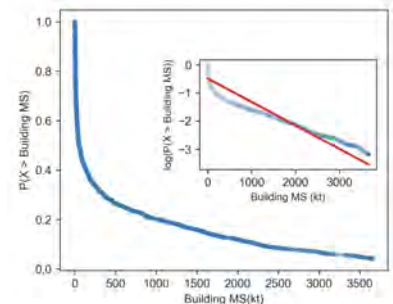
$\mu = 4.55 \times 10^4, \theta = 1.35 \times 10^5$



(2) 500m

$R^2=0.91$

$\mu = 1.77 \times 10^5, \theta = 4.16 \times 10^5$

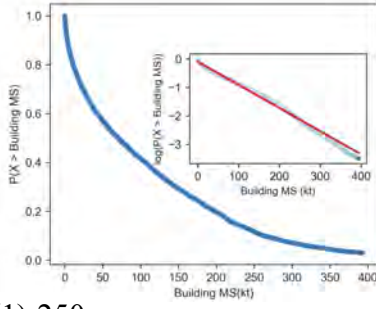


(3) 1000m

$R^2=0.92$

$\mu = 6.32 \times 10^5, \theta = 1.27 \times 10^6$

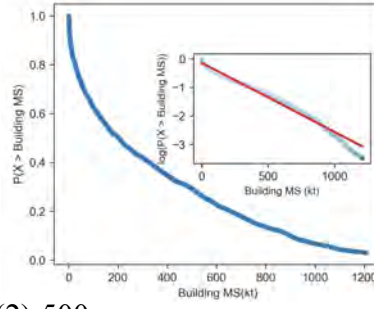
(4) Chengdu



(1) 250m

$R^2=0.99$

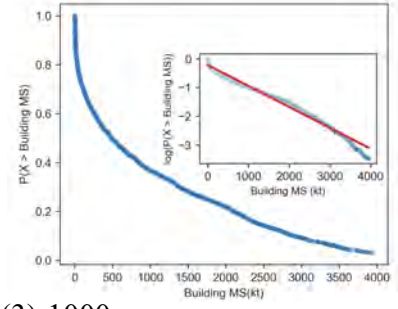
$\mu = 1.25 \times 10^4, \theta = 1.23 \times 10^5$



(2) 500m

$R^2=0.99$

$\mu = 5.77 \times 10^4, \theta = 4.13 \times 10^5$

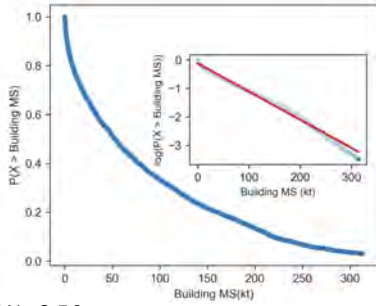


(3) 1000m

$R^2=0.97$

$\mu = 2.22 \times 10^5, \theta = 1.26 \times 10^6$

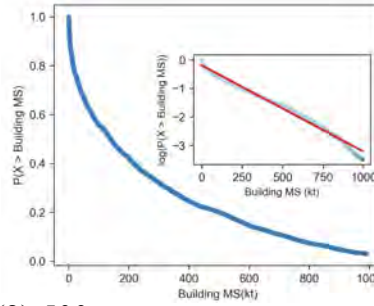
(5) Tianjin



(1) 250m

$R^2=0.99$

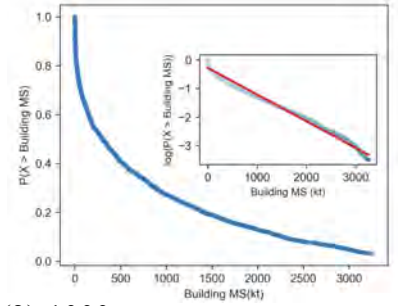
$\mu = 9.67 \times 10^3, \theta = 9.67 \times 10^4$



(2) 500m

$R^2=0.99$

$\mu = 6.39 \times 10^4, \theta = 3.3 \times 10^5$

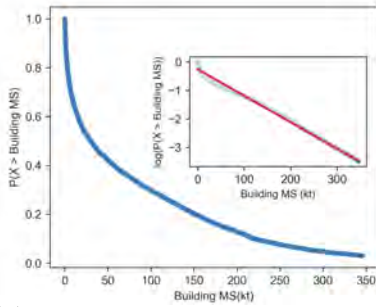


(3) 1000m

$R^2=0.98$

$\mu = 2.61 \times 10^5, \theta = 1.02 \times 10^6$

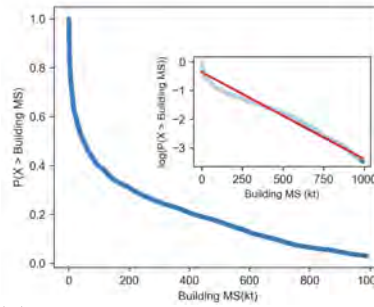
(6) Suzhou



(1) 250m

$R^2=0.99$

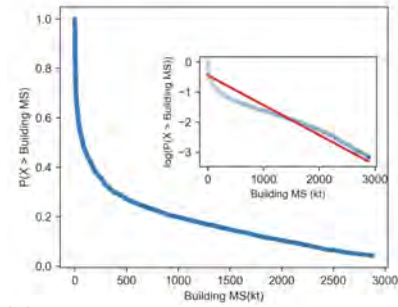
$\mu = 2.87 \times 10^4, \theta = 1.08 \times 10^5$



(2) 500m

$R^2=0.95$

$\mu = 1.18 \times 10^5, \theta = 3.30 \times 10^5$

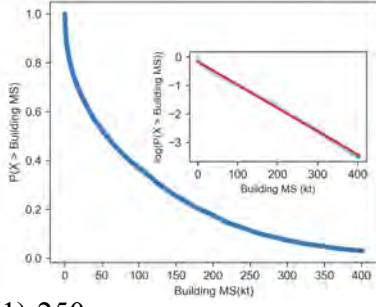


(3) 1000m

$R^2=0.94$

$\mu = 4.22 \times 10^5, \theta = 9.73 \times 10^5$

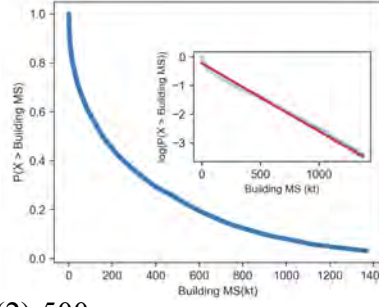
(7) Guangzhou



(1) 250m

$R^2=0.99$

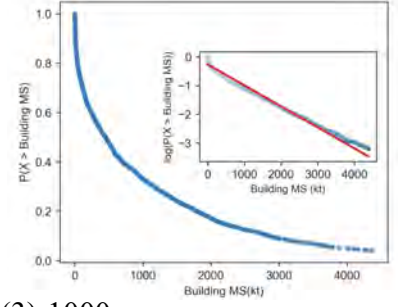
$\mu = 2.28 \times 10^4, \theta = 1.25 \times 10^5$



(2) 500m

$R^2=0.99$

$\mu = 9.38 \times 10^4, \theta = 4.21 \times 10^5$

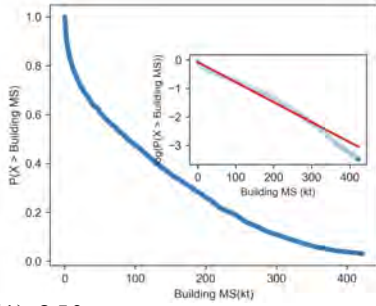


(3) 1000m

$R^2=0.99$

$\mu = 3.77 \times 10^5, \theta = 1.39 \times 10^6$

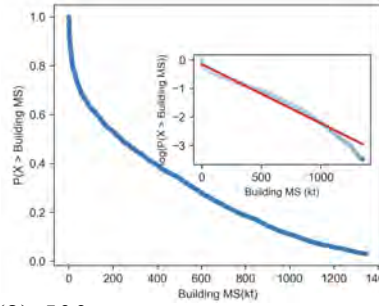
(8) Wuhan



(1) 250m

$R^2=0.98$

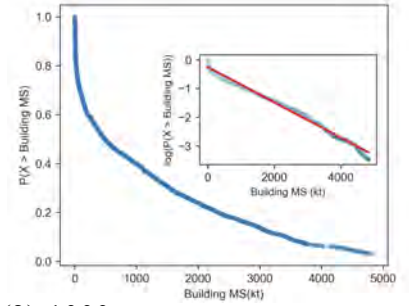
$\mu = 5.63 \times 10^3, \theta = 1.34 \times 10^5$



(2) 500m

$R^2=0.98$

$\mu = 7.23 \times 10^4, \theta = 4.82 \times 10^5$

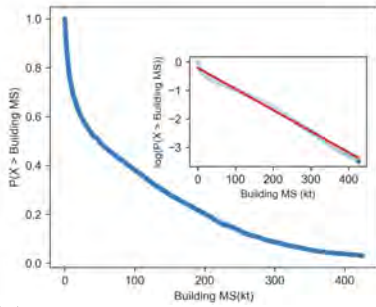


(3) 1000m

$R^2=0.97$

$\mu = 3.22 \times 10^5, \theta = 1.51 \times 10^6$

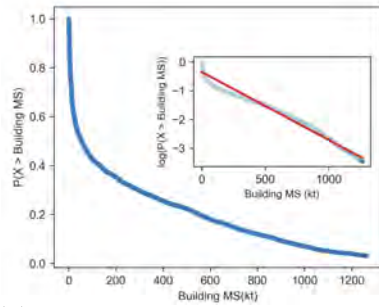
(9) Zhengzhou



(1) 250m

$R^2=0.99$

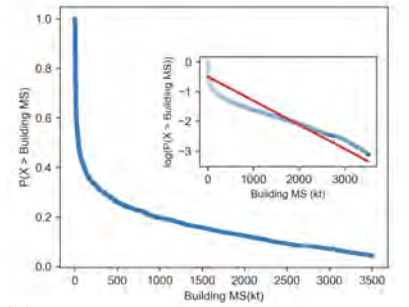
$\mu = 2.66 \times 10^4, \theta = 1.32 \times 10^5$



(2) 500m

$R^2=0.95$

$\mu = 1.50 \times 10^5, \theta = 4.23 \times 10^5$

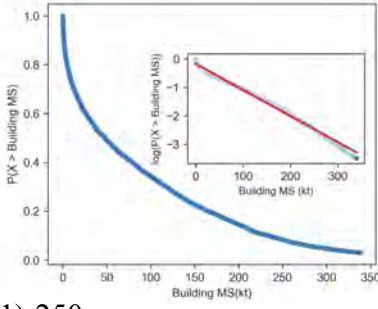


(3) 1000m

$R^2=0.91$

$\mu = 6.05 \times 10^5, \theta = 1.22 \times 10^6$

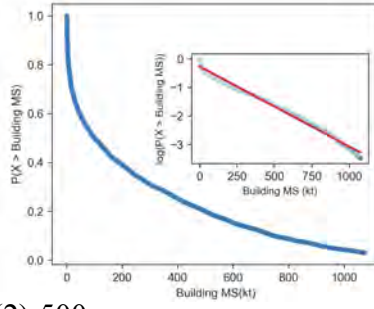
(10) Hangzhou



(1) 250m

$R^2=0.99$

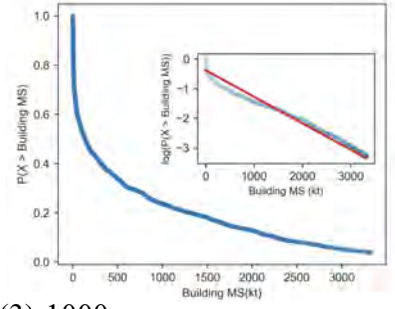
$\mu = 1.87 \times 10^4, \theta = 1.08 \times 10^5$



(2) 500m

$R^2=0.98$

$\mu = 9.57 \times 10^4, \theta = 3.57 \times 10^5$

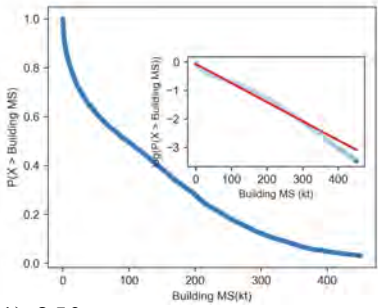


(3) 1000m

$R^2=0.96$

$\mu = 4.09 \times 10^5, \theta = 1.09 \times 10^6$

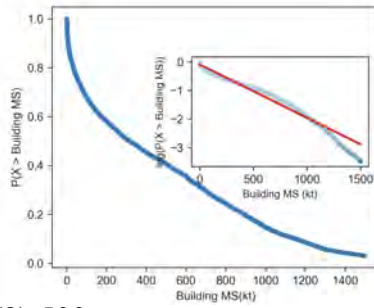
(11) Shenzhen



(1) 250m

$R^2=0.98$

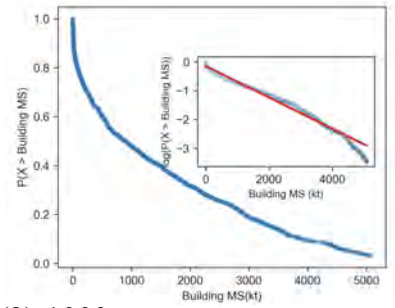
$\mu = 5.20 \times 10^3, \theta = 1.41 \times 10^5$



(2) 500m

$R^2=0.97$

$\mu = 5.08 \times 10^4, \theta = 5.37 \times 10^5$

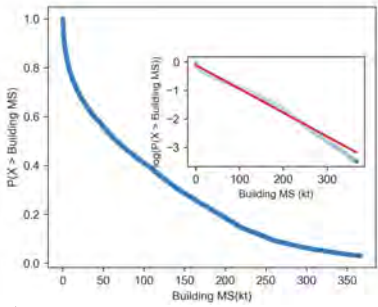


(3) 1000m

$R^2=0.95$

$\mu = 1.43 \times 10^5, \theta = 1.65 \times 10^6$

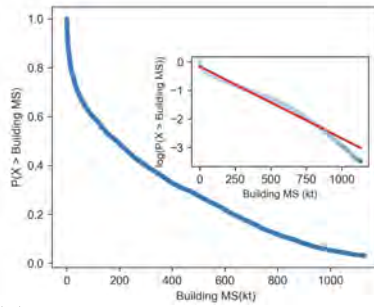
(12) Nanjing



(1) 250m

$R^2=0.99$

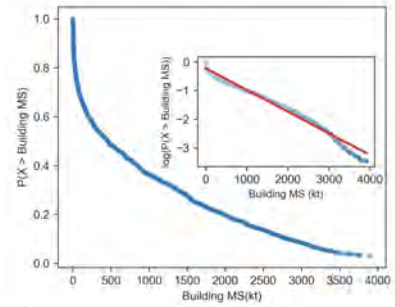
$\mu = 1.09 \times 10^4, \theta = 1.16 \times 10^5$



(2) 500m

$R^2=0.98$

$\mu = 6.34 \times 10^4, \theta = 3.96 \times 10^5$

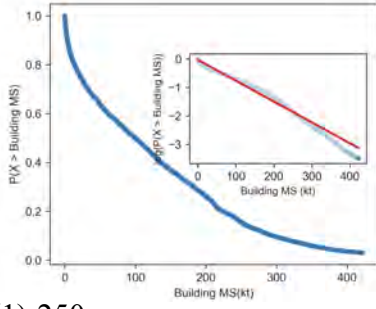


(3) 1000m

$R^2=0.98$

$\mu = 2.44 \times 10^5, \theta = 1.25 \times 10^6$

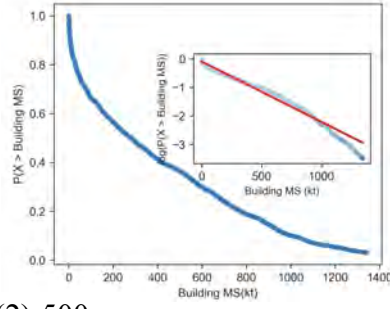
(13) Shenyang



(1) 250m

$R^2=0.98$

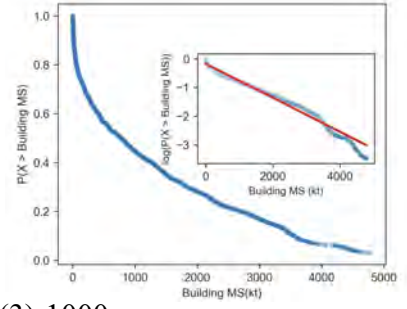
$\mu = 8.17 \times 10^2, \theta = 1.31 \times 10^5$



(2) 500m

$R^2=0.98$

$\mu = 4.56 \times 10^4, \theta = 4.73 \times 10^5$

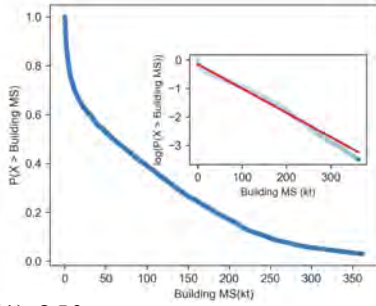


(3) 1000m

$R^2=0.96$

$\mu = 1.77 \times 10^5, \theta = 1.52 \times 10^6$

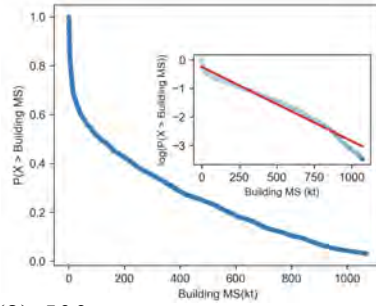
(14) Shijiazhuang



(1) 250m

$R^2=0.99$

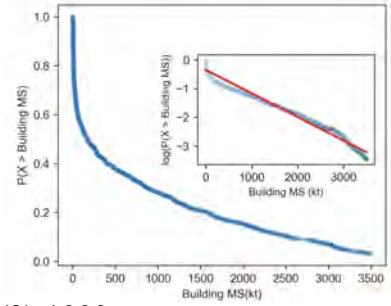
$\mu = 1.58 \times 10^4, \theta = 1.14 \times 10^5$



(2) 500m

$R^2=0.97$

$\mu = 9.51 \times 10^4, \theta = 3.84 \times 10^5$

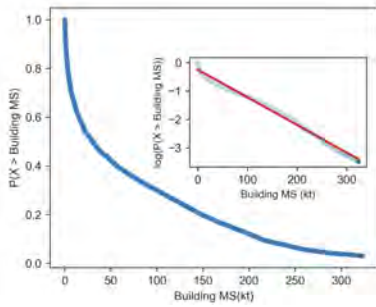


(3) 1000m

$R^2=0.96$

$\mu = 3.62 \times 10^5, \theta = 1.13 \times 10^6$

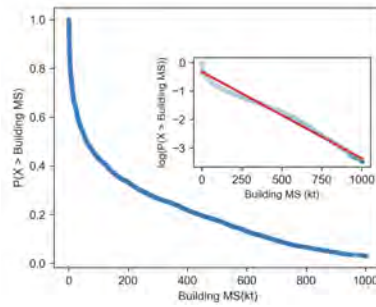
(15) Qingdao



(1) 250m

$R^2=0.98$

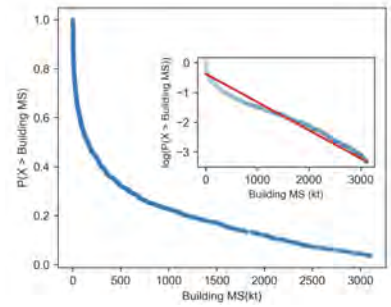
$\mu = 2.59 \times 10^4, \theta = 1.03 \times 10^5$



(2) 500m

$R^2=0.96$

$\mu = 1.06 \times 10^5, \theta = 3.28 \times 10^5$

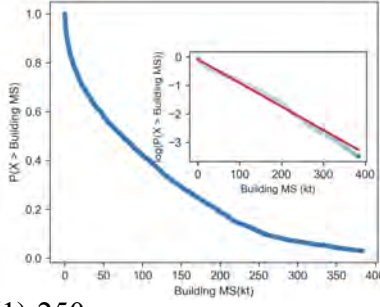


(3) 1000m

$R^2=0.96$

$\mu = 3.72 \times 10^5, \theta = 1.02 \times 10^6$

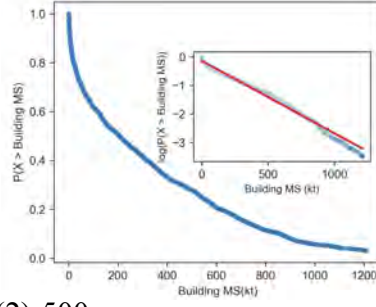
(16) Dalian



(1) 250m

$R^2=0.99$

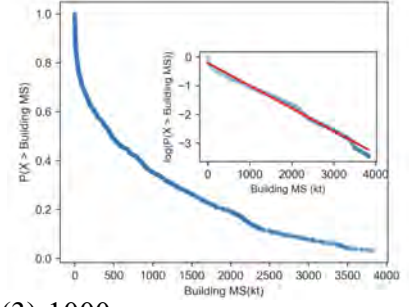
$\mu = 7.82 \times 10^3, \theta = 1.17 \times 10^5$



(2) 500m

$R^2=0.99$

$\mu = 5.41 \times 10^4, \theta = 3.94 \times 10^5$

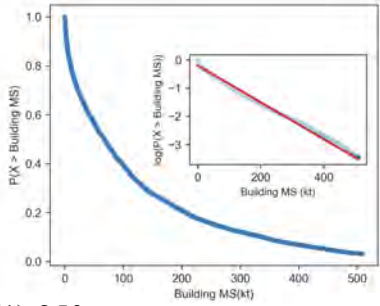


(3) 1000m

$R^2=0.99$

$\mu = 2.29 \times 10^5, \theta = 1.21 \times 10^6$

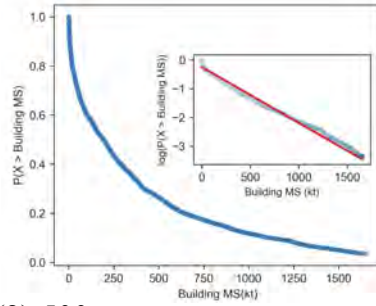
(17) Xi'an



(1) 250m

$R^2=0.99$

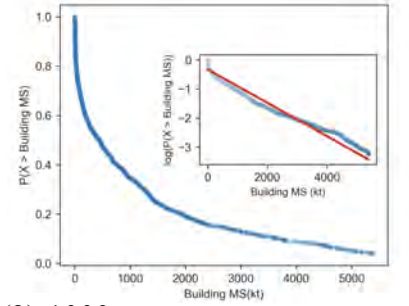
$\mu = 3.22 \times 10^4, \theta = 1.55 \times 10^5$



(2) 500m

$R^2=0.98$

$\mu = 1.29 \times 10^5, \theta = 5.16 \times 10^5$

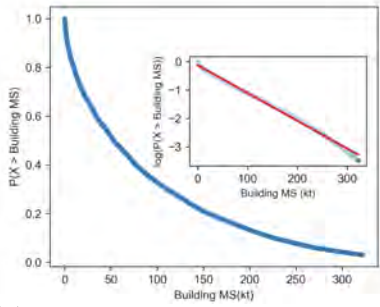


(3) 1000m

$R^2=0.97$

$\mu = 5.74 \times 10^5, \theta = 1.74 \times 10^6$

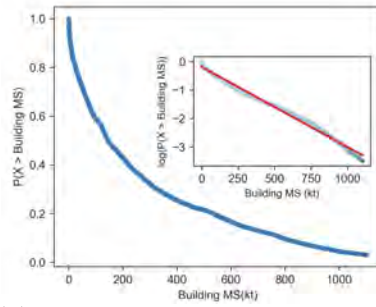
(18) Foshan



(1) 250m

$R^2=0.99$

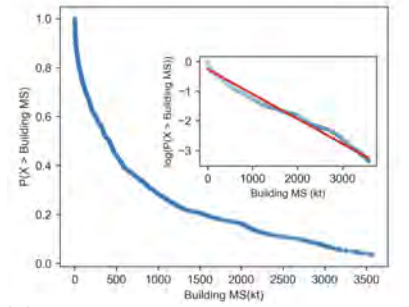
$\mu = 1.20 \times 10^4, \theta = 1.00 \times 10^5$



(2) 500m

$R^2=0.99$

$\mu = 6.74 \times 10^4, \theta = 3.55 \times 10^5$

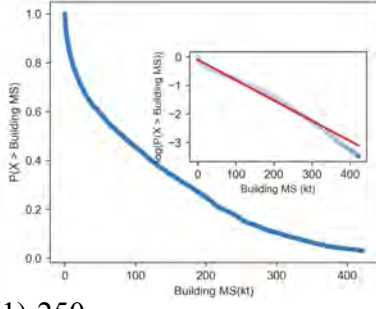


(3) 1000m

$R^2=0.97$

$\mu = 2.54 \times 10^5, \theta = 1.12 \times 10^6$

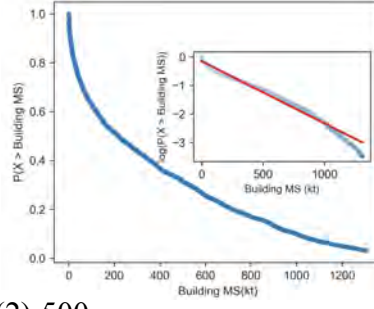
(19) Hefei



(1) 250m

$R^2=0.98$

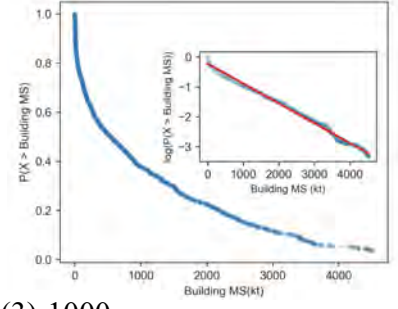
$\mu = 9.75 \times 10^3, \theta = 1.34 \times 10^5$



(2) 500m

$R^2=0.98$

$\mu = 6.92 \times 10^4, \theta = 4.59 \times 10^5$

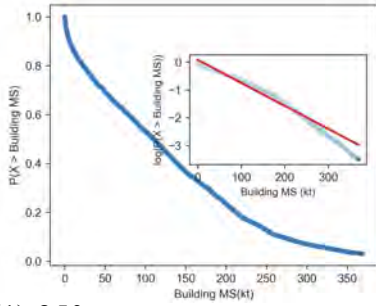


(3) 1000m

$R^2=0.98$

$\mu = 2.67 \times 10^5, \theta = 1.40 \times 10^6$

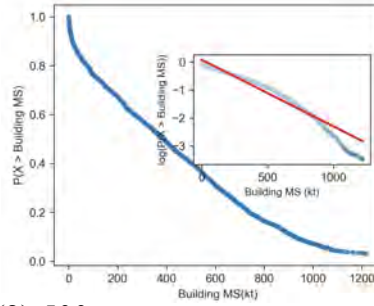
(20) Changchun



(1) 250m

$R^2=0.97$

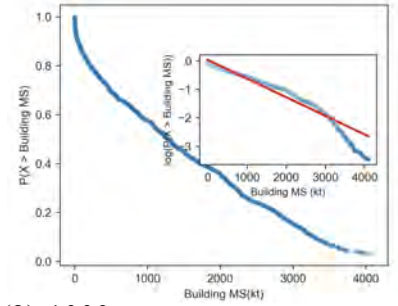
$\mu = -1.35 \times 10^4, \theta = 1.15 \times 10^5$



(2) 500m

$R^2=0.95$

$\mu = -3.24 \times 10^4, \theta = 4.20 \times 10^5$

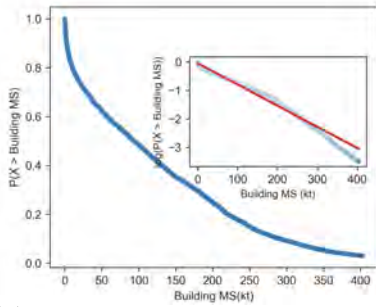


(3) 1000m

$R^2=0.93$

$\mu = -1.63 \times 10^5, \theta = 1.37 \times 10^6$

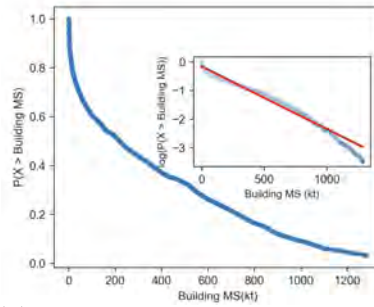
(21) Jinan



(1) 250m

$R^2=0.98$

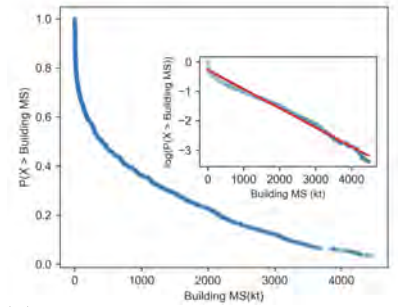
$\mu = 6.08 \times 10^2, \theta = 1.25 \times 10^5$



(2) 500m

$R^2=0.98$

$\mu = 7.38 \times 10^4, \theta = 4.58 \times 10^5$

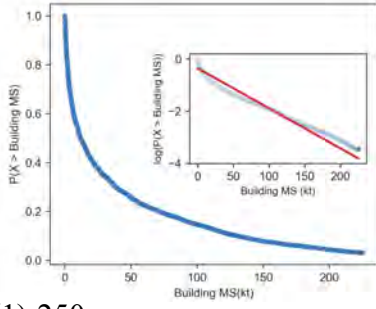


(3) 1000m

$R^2=0.96$

$\mu = 3.32 \times 10^5, \theta = 1.41 \times 10^6$

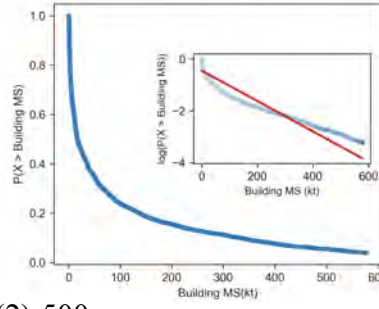
(22) Weifang



(1) 250m

$R^2=0.94$

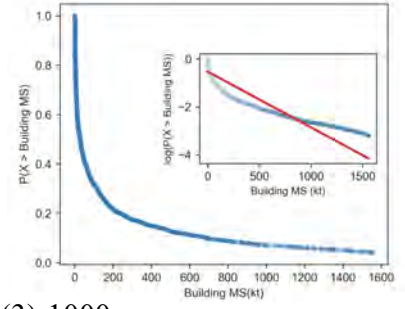
$\mu = 3.18 \times 10^4, \theta = 7.53 \times 10^4$



(2) 500m

$R^2=0.87$

$\mu = 7.76 \times 10^4, \theta = 1.71 \times 10^5$

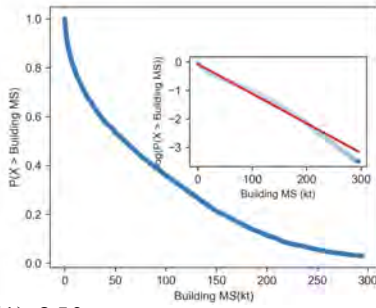


(3) 1000m

$R^2=0.84$

$\mu = 3.51 \times 10^5, \theta = 5.83 \times 10^5$

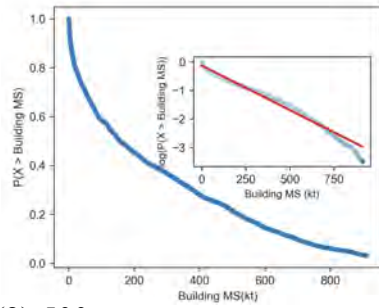
(23) Wuxi



(1) 250m

$R^2=0.99$

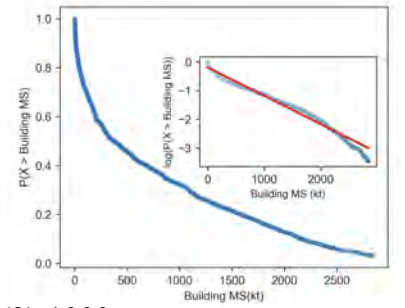
$\mu = 3.88 \times 10^3, \theta = 9.10 \times 10^4$



(2) 500m

$R^2=0.98$

$\mu = 4.18 \times 10^4, \theta = 3.21 \times 10^5$

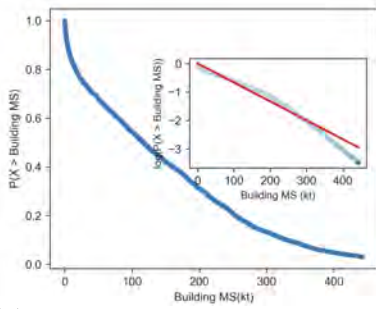


(3) 1000m

$R^2=0.97$

$\mu = 1.36 \times 10^5, \theta = 9.24 \times 10^5$

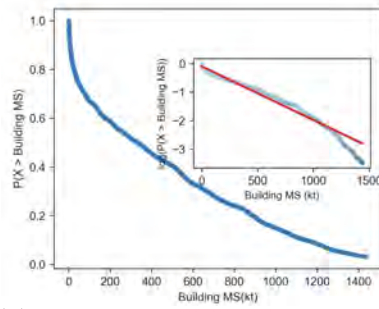
(24) Ha'erbin



(1) 250m

$R^2=0.97$

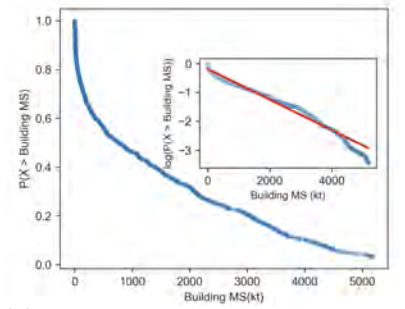
$\mu = -6.85 \times 10^3, \theta = 1.40 \times 10^5$



(2) 500m

$R^2=0.97$

$\mu = 5.19 \times 10^4, \theta = 5.32 \times 10^5$

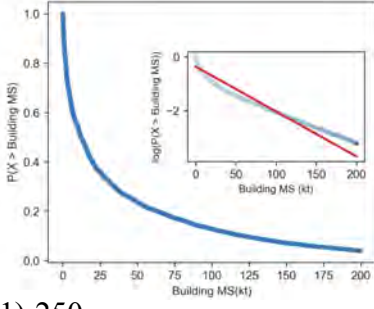


(3) 1000m

$R^2=0.94$

$\mu = 2.28 \times 10^5, \theta = 1.69 \times 10^6$

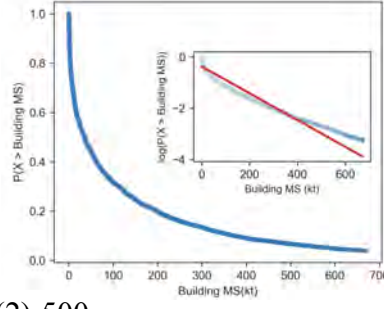
(25) Ningbo



(1) 250m

$R^2=0.95$

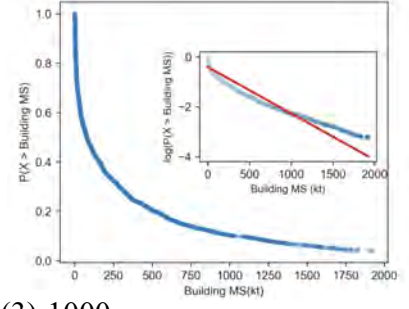
$\mu = 2.60 \times 10^4, \theta = 6.58 \times 10^4$



(2) 500m

$R^2=0.92$

$\mu = 7.23 \times 10^4, \theta = 1.92 \times 10^5$

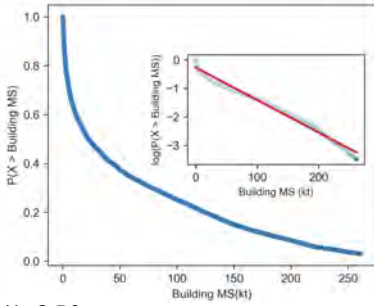


(3) 1000m

$R^2=0.92$

$\mu = 3.13 \times 10^5, \theta = 6.62 \times 10^5$

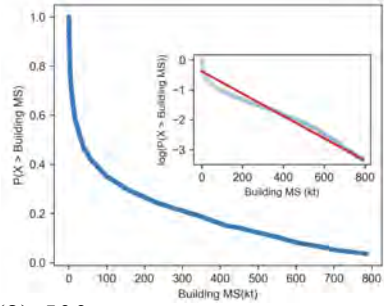
(26) Baoding



(1) 250m

$R^2=0.98$

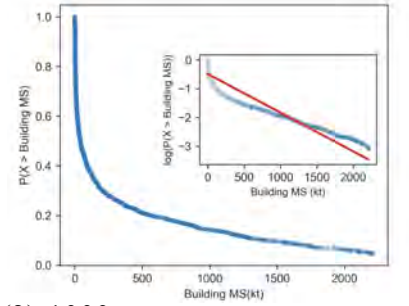
$\mu = 2.12 \times 10^4, \theta = 8.43 \times 10^4$



(2) 500m

$R^2=0.93$

$\mu = 1.03 \times 10^5, \theta = 2.69 \times 10^5$

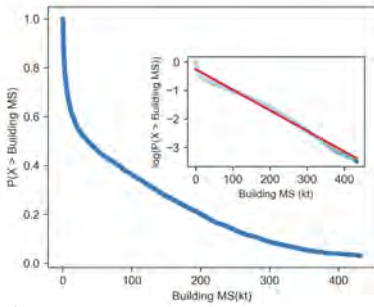


(3) 1000m

$R^2=0.91$

$\mu = 3.84 \times 10^5, \theta = 7.73 \times 10^5$

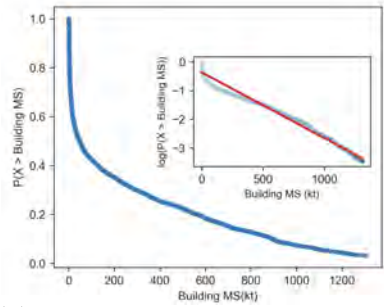
(27) Fuzhou



(1) 250m

$R^2=0.99$

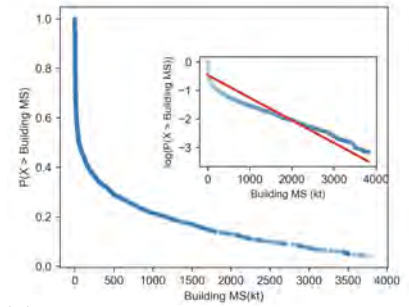
$\mu = 3.41 \times 10^4, \theta = 1.36 \times 10^5$



(2) 500m

$R^2=0.95$

$\mu = 1.60 \times 10^5, \theta = 4.37 \times 10^5$

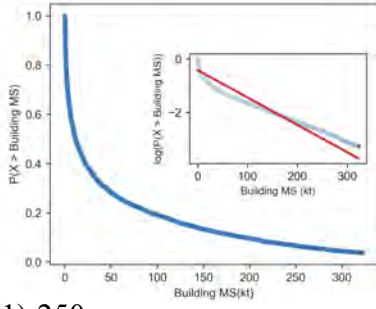


(3) 1000m

$R^2=0.93$

$\mu = 6.27 \times 10^5, \theta = 1.32 \times 10^6$

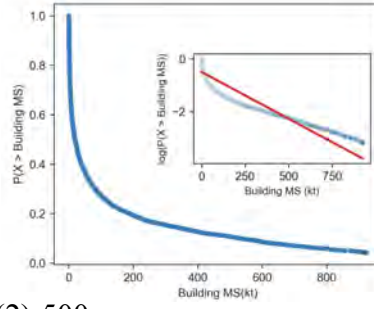
(28) Wenzhou



(1) 250m

$R^2=0.94$

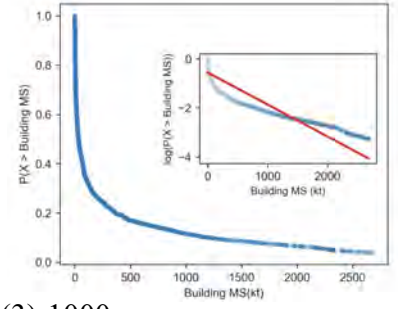
$\mu = 5.00 \times 10^4, \theta = 1.09 \times 10^5$



(2) 500m

$R^2=0.82$

$\mu = 1.42 \times 10^5, \theta = 2.82 \times 10^5$

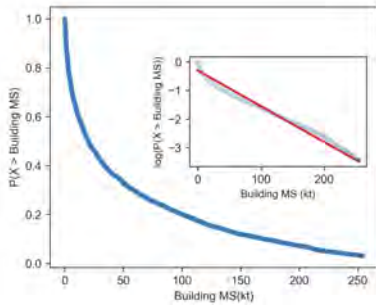


(3) 1000m

$R^2=0.83$

$\mu = 6.23 \times 10^5, \theta = 1.01 \times 10^6$

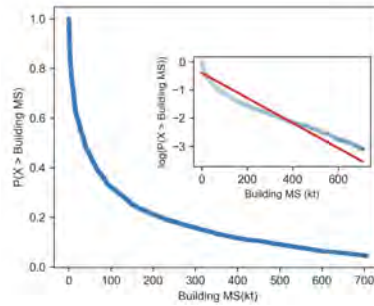
(29) Nantong



(1) 250m

$R^2=0.98$

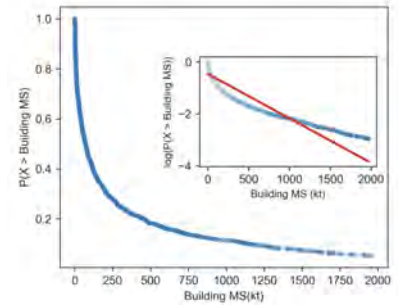
$\mu = 2.43 \times 10^4, \theta = 8.03 \times 10^4$



(2) 500m

$R^2=0.90$

$\mu = 8.81 \times 10^4, \theta = 2.24 \times 10^5$

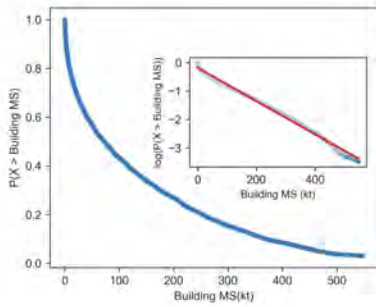


(3) 1000m

$R^2=0.90$

$\mu = 3.44 \times 10^5, \theta = 6.89 \times 10^5$

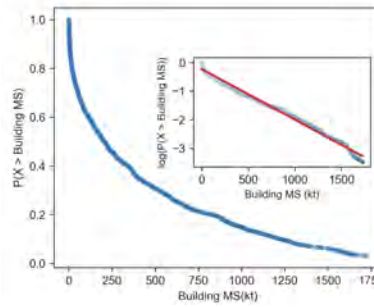
(30) Kunming



(1) 250m

$R^2=0.99$

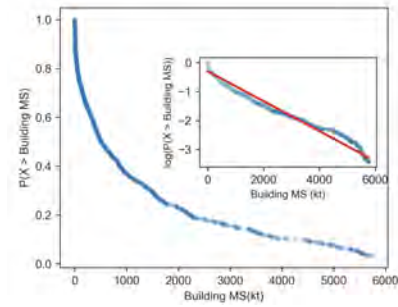
$\mu = 3.20 \times 10^4, \theta = 1.71 \times 10^5$



(2) 500m

$R^2=0.98$

$\mu = 1.30 \times 10^5, \theta = 5.67 \times 10^5$

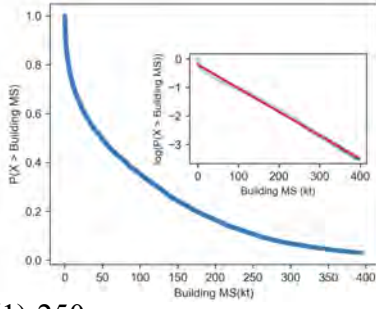


(3) 1000m

$R^2=0.97$

$\mu = 5.09 \times 10^5, \theta = 1.84 \times 10^6$

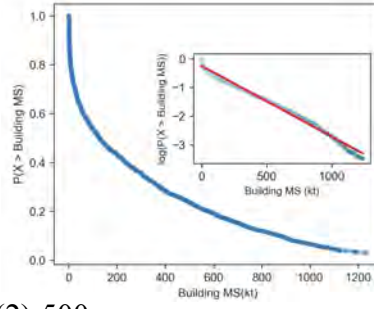
(31) Nanning



(1) 250m

$R^2=0.99$

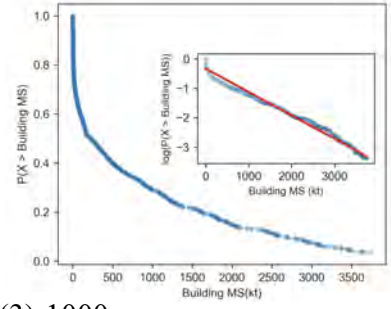
$\mu = 2.68 \times 10^4, \theta = 1.24 \times 10^5$



(2) 500m

$R^2=0.98$

$\mu = 1.00 \times 10^5, \theta = 4.05 \times 10^5$

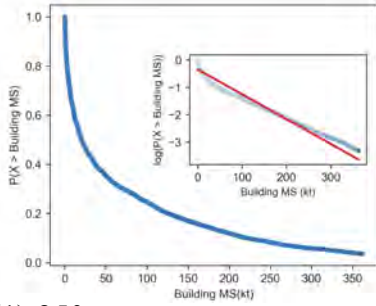


(3) 1000m

$R^2=0.97$

$\mu = 3.78 \times 10^5, \theta = 1.21 \times 10^6$

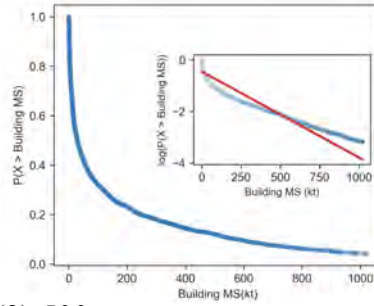
(32) Nanchang



(1) 250m

$R^2=0.96$

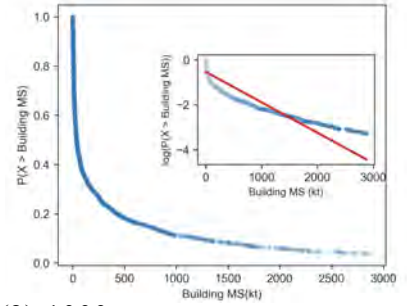
$\mu = 4.44 \times 10^4, \theta = 1.18 \times 10^5$



(2) 500m

$R^2=0.87$

$\mu = 1.36 \times 10^5, \theta = 3.01 \times 10^5$

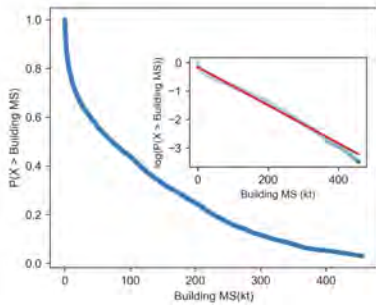


(3) 1000m

$R^2=0.82$

$\mu = 6.93 \times 10^5, \theta = 1.11 \times 10^6$

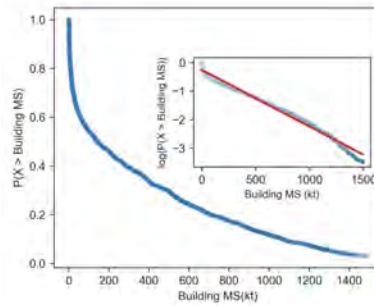
(33) Taiyuan



(1) 250m

$R^2=0.99$

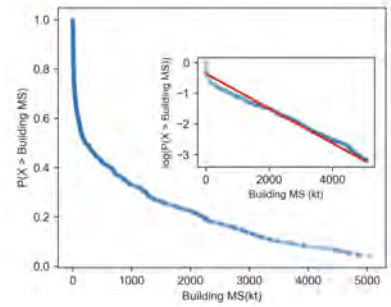
$\mu = 1.88 \times 10^4, \theta = 1.42 \times 10^5$



(2) 500m

$R^2=0.98$

$\mu = 1.30 \times 10^5, \theta = 5.04 \times 10^5$

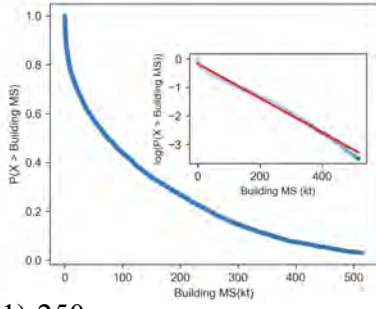


(3) 1000m

$R^2=0.96$

$\mu = 5.55 \times 10^5, \theta = 1.66 \times 10^6$

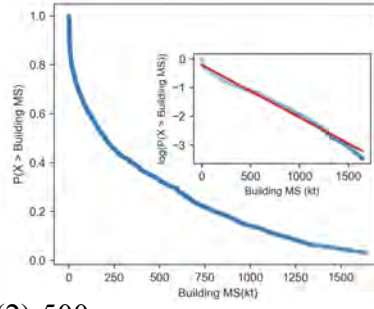
(34) Xiamen



(1) 250m

$R^2=0.99$

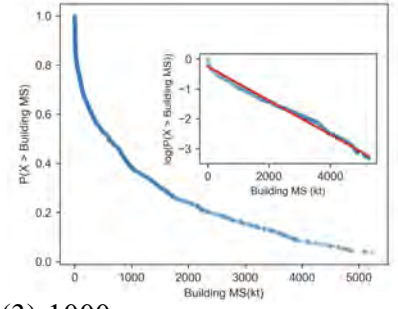
$\mu = 2.44 \times 10^4, \theta = 1.60 \times 10^5$



(2) 500m

$R^2=0.99$

$\mu = 1.16 \times 10^5, \theta = 5.47 \times 10^5$

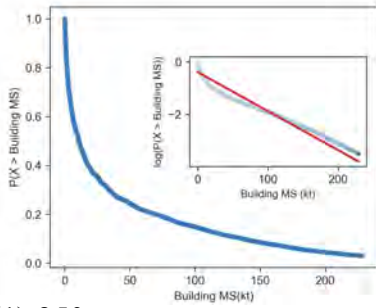


(3) 1000m

$R^2=0.98$

$\mu = 4.02 \times 10^5, \theta = 1.70 \times 10^6$

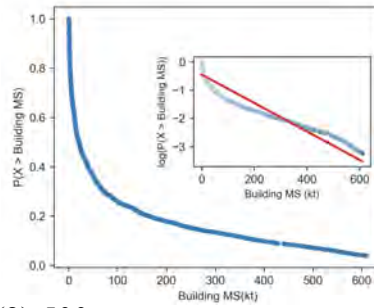
(35) Quanzhou



(1) 250m

$R^2=0.92$

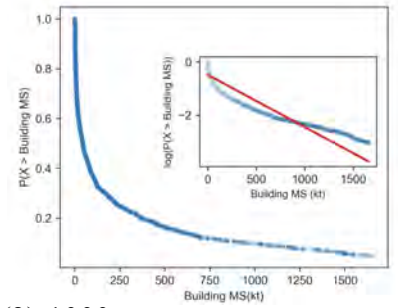
$\mu = 3.75 \times 10^4, \theta = 8.06 \times 10^4$



(2) 500m

$R^2=0.87$

$\mu = 8.96 \times 10^4, \theta = 1.99 \times 10^5$

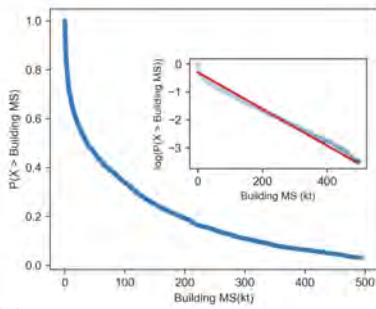


(3) 1000m

$R^2=0.90$

$\mu = 3.03 \times 10^5, \theta = 5.88 \times 10^5$

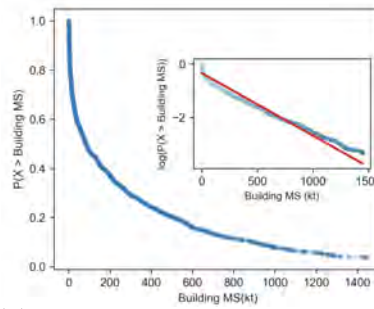
(36) Guiyang



(1) 250m

$R^2=0.98$

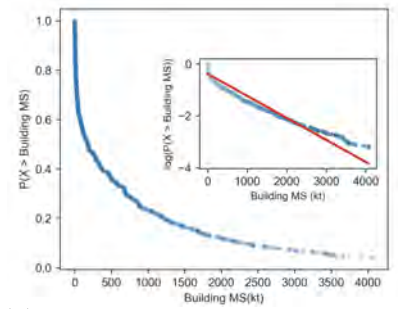
$\mu = 5.08 \times 10^4, \theta = 1.58 \times 10^5$



(2) 500m

$R^2=0.95$

$\mu = 1.48 \times 10^5, \theta = 4.30 \times 10^5$

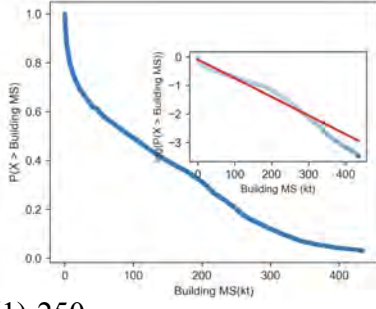


(3) 1000m

$R^2=0.93$

$\mu = 6.63 \times 10^5, \theta = 1.45 \times 10^6$

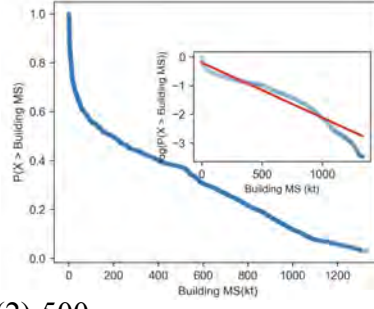
(37) Hohhot



(1) 250m

$R^2=0.96$

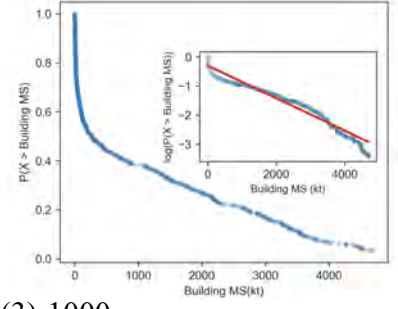
$\mu = 7.49 \times 10^3, \theta = 1.43 \times 10^5$



(2) 500m

$R^2=0.95$

$\mu = 1.05 \times 10^5, \theta = 5.21 \times 10^5$

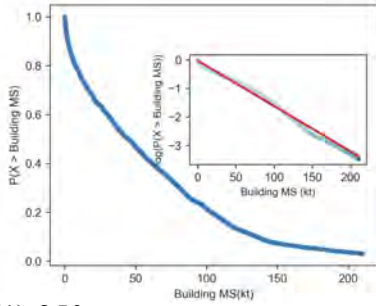


(3) 1000m

$R^2=0.94$

$\mu = 4.24 \times 10^5, \theta = 1.62 \times 10^6$

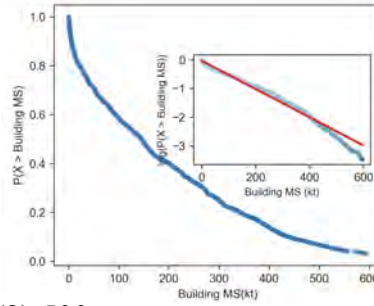
(38) Changsha



(1) 250m

$R^2=0.98$

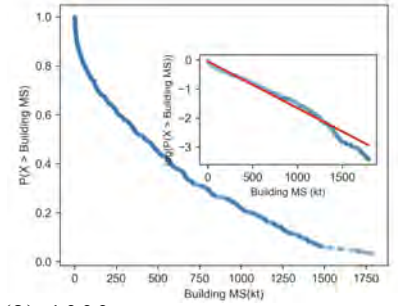
$\mu = 4.90 \times 10^3, \theta = 6.63 \times 10^4$



(2) 500m

$R^2=0.98$

$\mu = 6.70 \times 10^3, \theta = 2.03 \times 10^5$

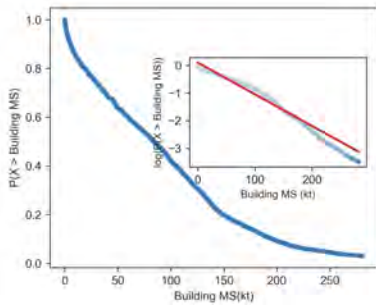


(3) 1000m

$R^2=0.96$

$\mu = -7.42 \times 10^3, \theta = 5.62 \times 10^5$

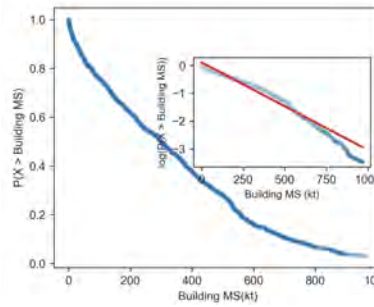
(39) Tangshan



(1) 250m

$R^2=0.98$

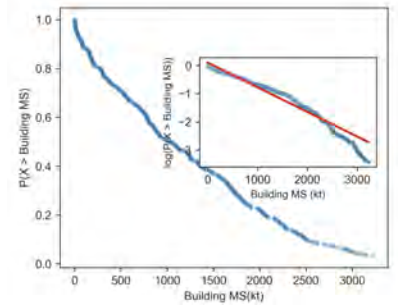
$\mu = -8.63 \times 10^3, \theta = 8.70 \times 10^4$



(2) 500m

$R^2=0.96$

$\mu = -3.34 \times 10^4, \theta = 3.18 \times 10^5$

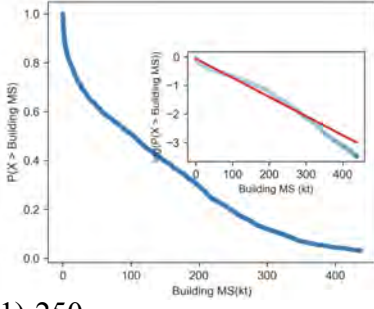


(3) 1000m

$R^2=0.93$

$\mu = -2.03 \times 10^5, \theta = 1.01 \times 10^6$

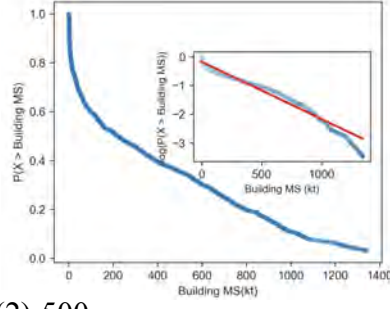
(40) Yinchuan



(1) 250m

$R^2=0.96$

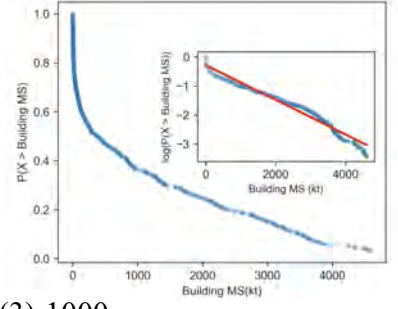
$\mu = 3.42 \times 10^2, \theta = 1.36 \times 10^5$



(2) 500m

$R^2=0.97$

$\mu = 8.58 \times 10^4, \theta = 5.01 \times 10^5$

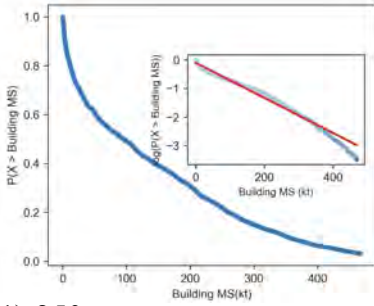


(3) 1000m

$R^2=0.94$

$\mu = 3.75 \times 10^5, \theta = 1.52 \times 10^6$

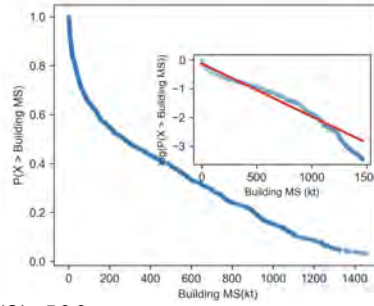
(41) Linyi



(1) 250m

$R^2=0.97$

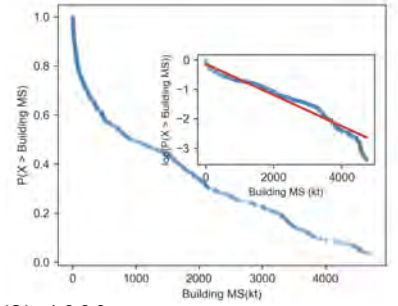
$\mu = 6.49 \times 10^3, \theta = 1.48 \times 10^5$



(2) 500m

$R^2=0.97$

$\mu = 7.06 \times 10^4, \theta = 5.43 \times 10^5$

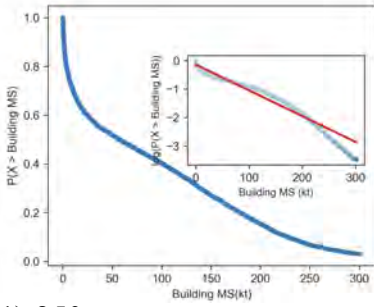


(3) 1000m

$R^2=0.93$

$\mu = 1.30 \times 10^5, \theta = 1.68 \times 10^6$

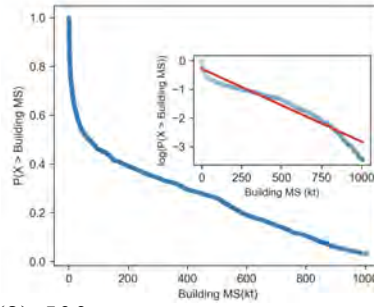
(42) Luoyang



(1) 250m

$R^2=0.97$

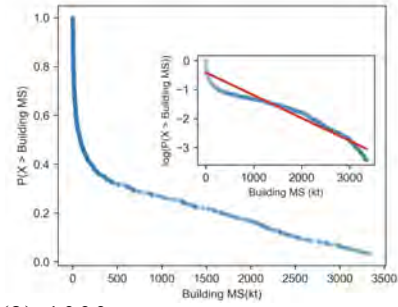
$\mu = 1.04 \times 10^4, \theta = 1.03 \times 10^5$



(2) 500m

$R^2=0.95$

$\mu = 1.14 \times 10^5, \theta = 3.94 \times 10^5$

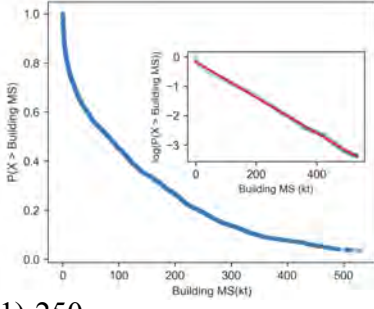


(3) 1000m

$R^2=0.93$

$\mu = 4.60 \times 10^5, \theta = 1.18 \times 10^6$

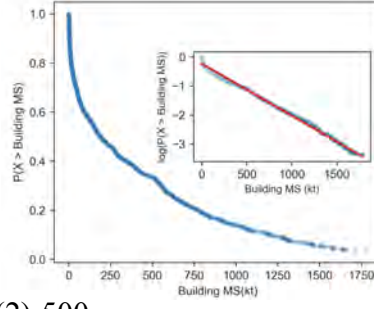
(43) Lanzhou



(1) 250m

$R^2=0.99$

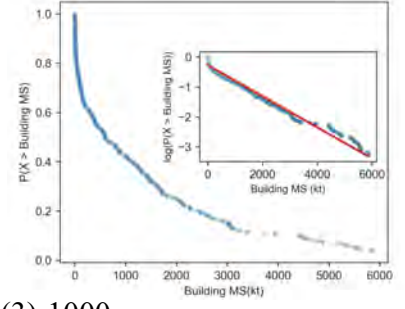
$\mu = 2.41 \times 10^4, \theta = 1.60 \times 10^5$



(2) 500m

$R^2=0.99$

$\mu = 1.31 \times 10^5, \theta = 5.59 \times 10^5$

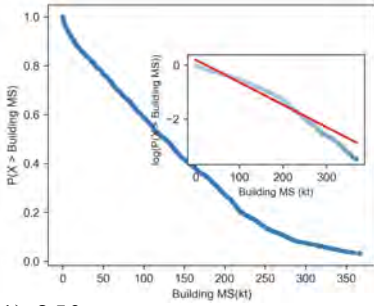


(3) 1000m

$R^2=0.97$

$\mu = 5.78 \times 10^5, \theta = 2.00 \times 10^6$

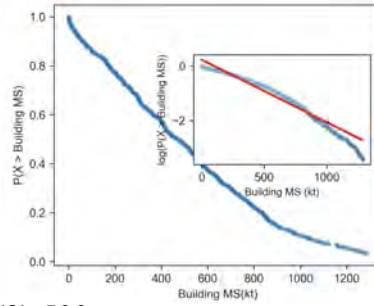
(44) Urumqi



(1) 250m

$R^2=0.95$

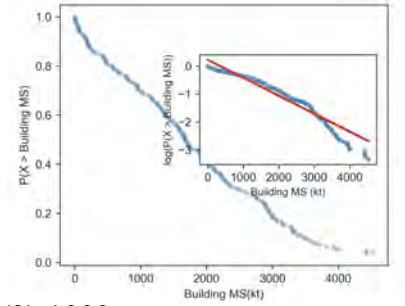
$\mu = -3.05 \times 10^4, \theta = 1.10 \times 10^5$



(2) 500m

$R^2=0.95$

$\mu = -9.80 \times 10^4, \theta = 4.37 \times 10^5$

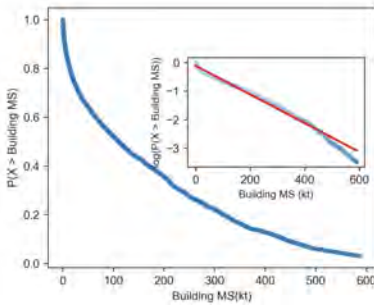


(3) 1000m

$R^2=0.92$

$\mu = -4.53 \times 10^5, \theta = 1.39 \times 10^6$

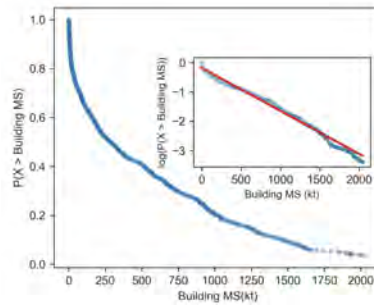
(45) Xining



(1) 250m

$R^2=0.97$

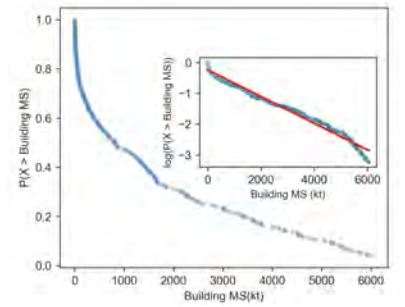
$\mu = 1.07 \times 10^4, \theta = 1.82 \times 10^5$



(2) 500m

$R^2=0.99$

$\mu = 1.23 \times 10^5, \theta = 6.81 \times 10^5$

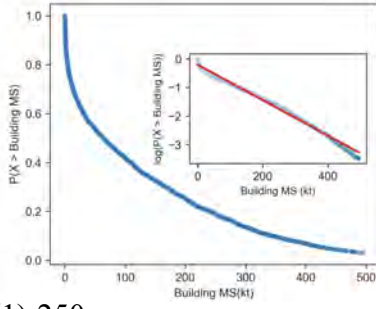


(3) 1000m

$R^2=0.97$

$\mu = 4.52 \times 10^5, \theta = 2.18 \times 10^6$

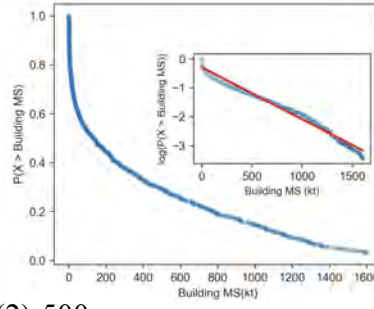
(46) Haikou



(1) 250m

$R^2=0.98$

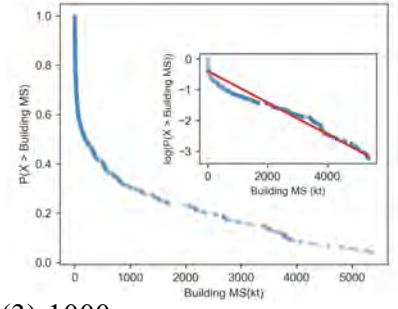
$\mu = 2.65 \times 10^4, \theta = 1.52 \times 10^5$



(2) 500m

$R^2=0.97$

$\mu = 1.64 \times 10^5, \theta = 5.59 \times 10^5$

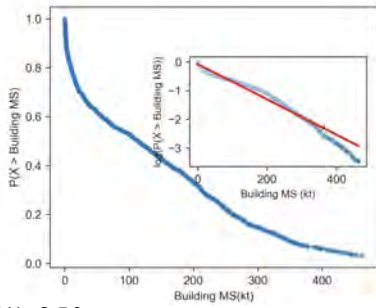


(3) 1000m

$R^2=0.95$

$\mu = 6.85 \times 10^5, \theta = 1.83 \times 10^6$

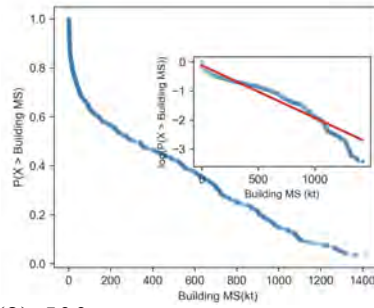
(47) Handan



(1) 250m

$R^2=0.96$

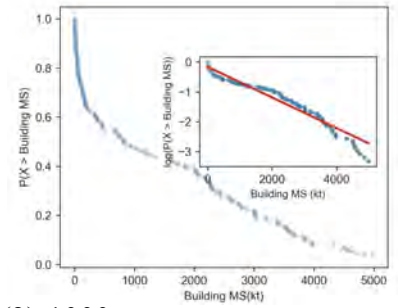
$\mu = 2.97 \times 10^3, \theta = 1.48 \times 10^5$



(2) 500m

$R^2=0.95$

$\mu = 6.74 \times 10^4, \theta = 5.53 \times 10^5$

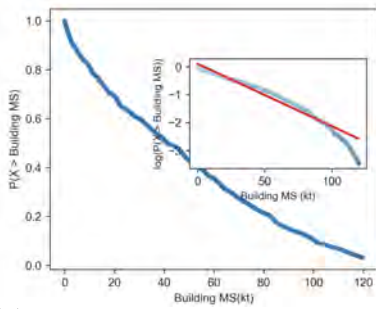


(3) 1000m

$R^2=0.92$

$\mu = 2.04 \times 10^5, \theta = 1.75 \times 10^6$

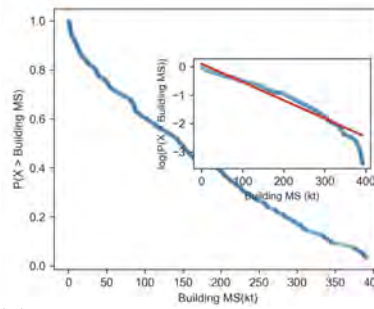
(48) Nanyang



(1) 250m

$R^2=0.92$

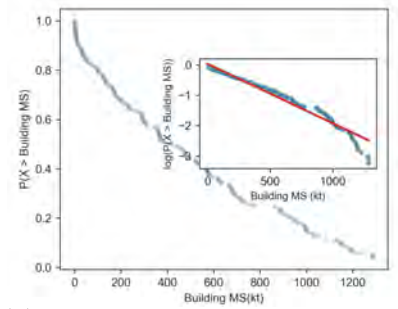
$\mu = -8.15 \times 10^3, \theta = 3.95 \times 10^4$



(2) 500m

$R^2=0.94$

$\mu = -1.62 \times 10^4, \theta = 1.55 \times 10^5$

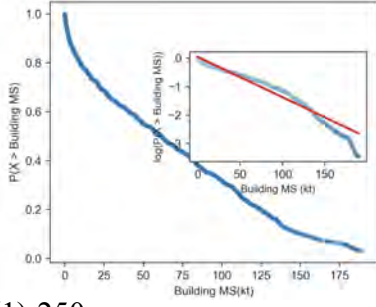


(3) 1000m

$R^2=0.91$

$\mu = -5.38 \times 10^4, \theta = 4.52 \times 10^5$

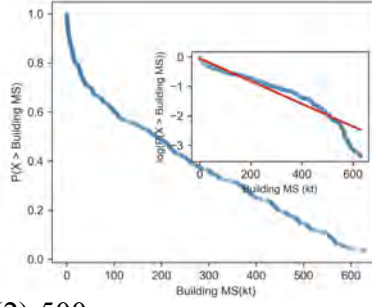
(49) Lhasa



(1) 250m

$R^2=0.92$

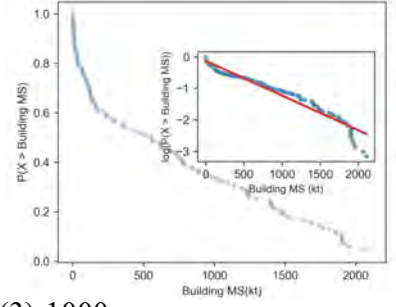
$\mu = -8.23 \times 10^3, \theta = 6.23 \times 10^4$



(2) 500m

$R^2=0.94$

$\mu = 1.43 \times 10^4, \theta = 2.60 \times 10^5$

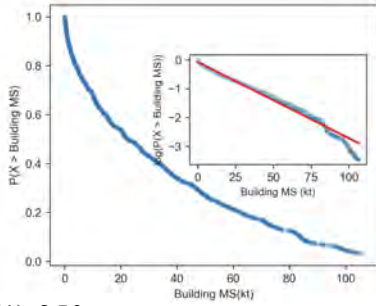


(3) 1000m

$R^2=0.91$

$\mu = 5.61 \times 10^4, \theta = 8.04 \times 10^5$

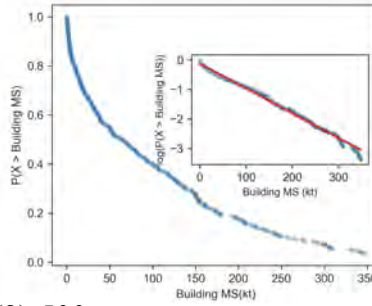
(50) Zhoukou



(1) 250m

$R^2=0.95$

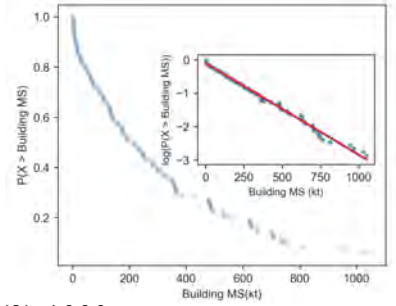
$\mu = 1.00 \times 10^2, \theta = 3.36 \times 10^4$



(2) 500m

$R^2=0.99$

$\mu = 1.48 \times 10^4, \theta = 1.19 \times 10^5$



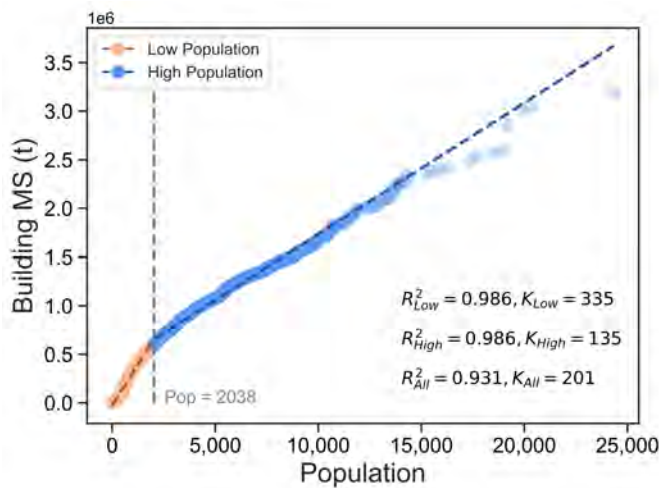
(3) 1000m

$R^2=0.98$

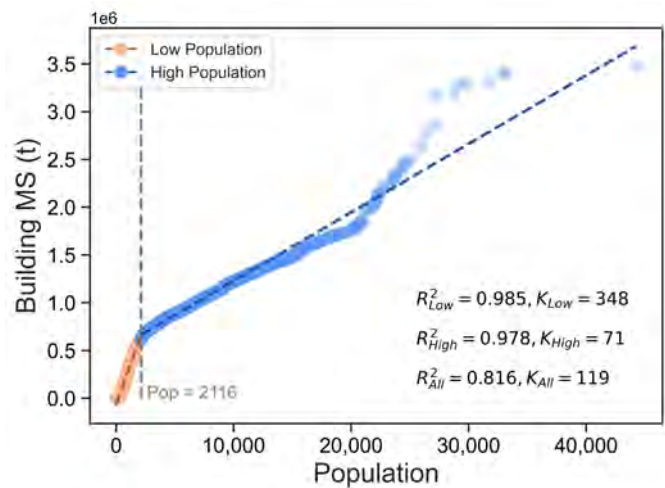
$\mu = 2.40 \times 10^4, \theta = 3.47 \times 10^5$

Supplementary Figure A6: CCDF curves for building stocks in the 50 Chinese cities

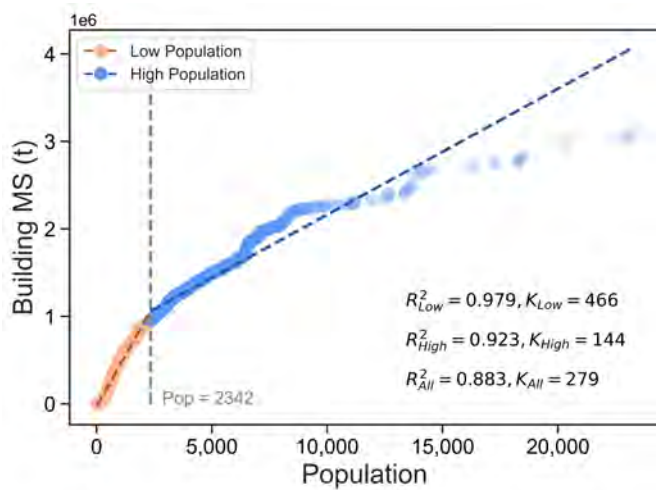
A.7 Correlations between population and building stocks at grid level in the 50 Chinese cities



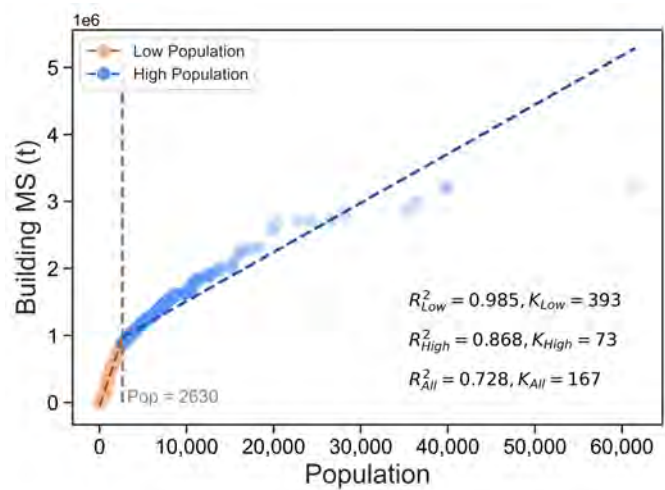
(1) Beijing



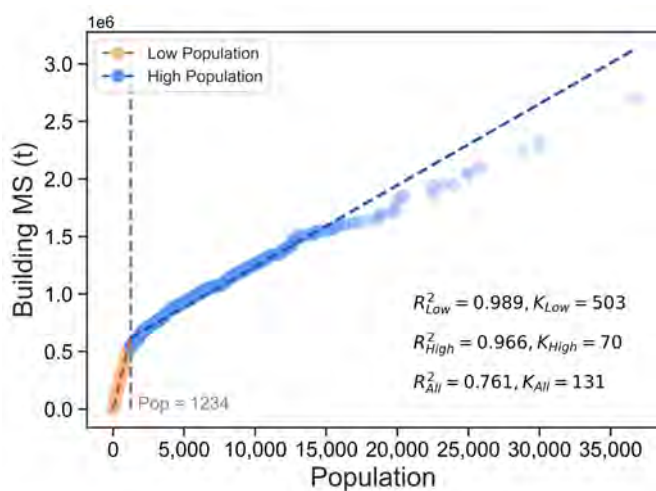
(2) Shanghai



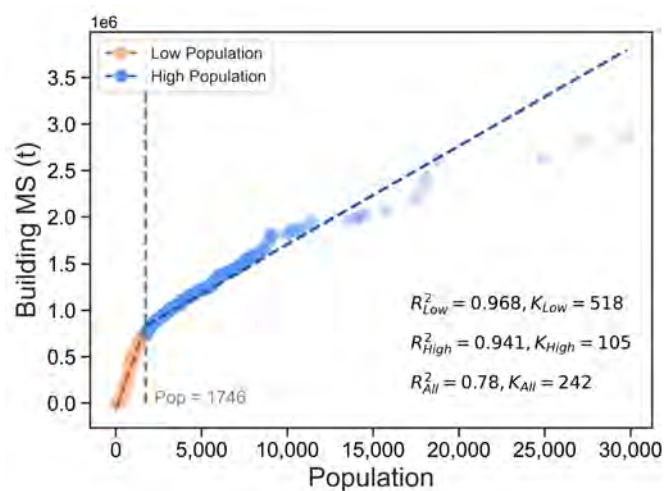
(3) Chongqing



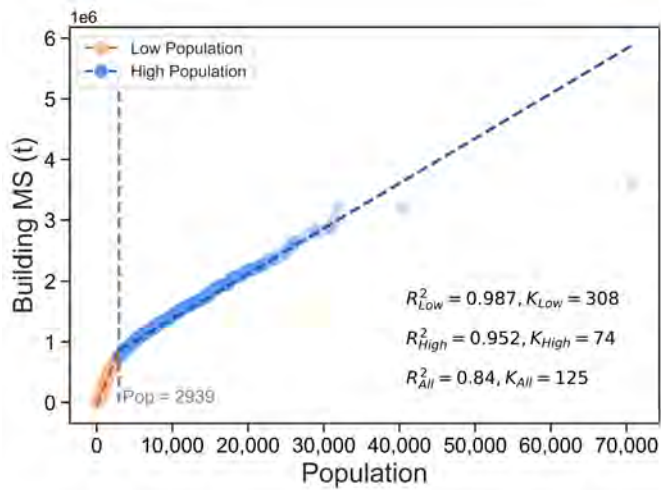
(4) Chengdu



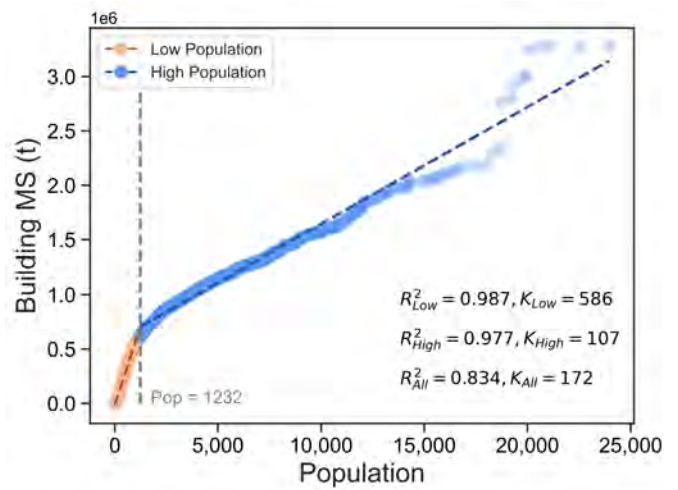
(5) Tianjin



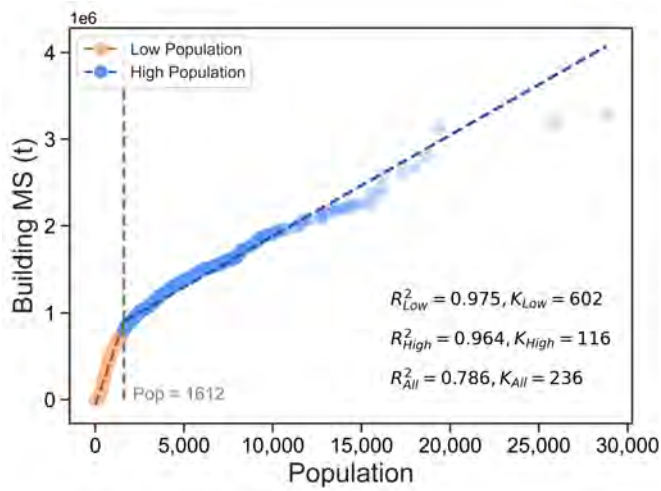
(6) Suzhou



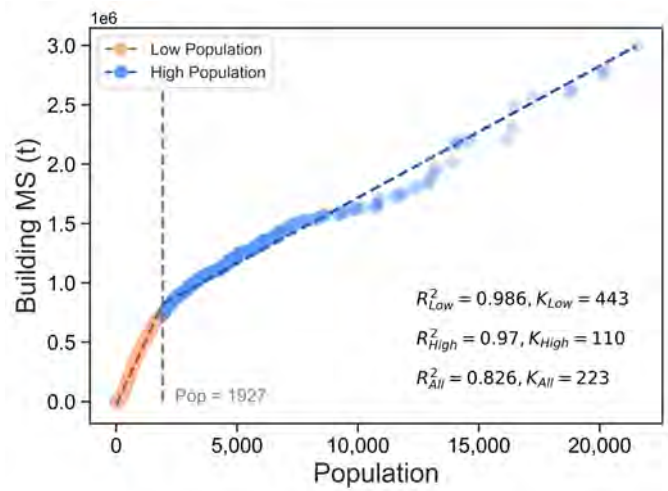
(7) Guangzhou



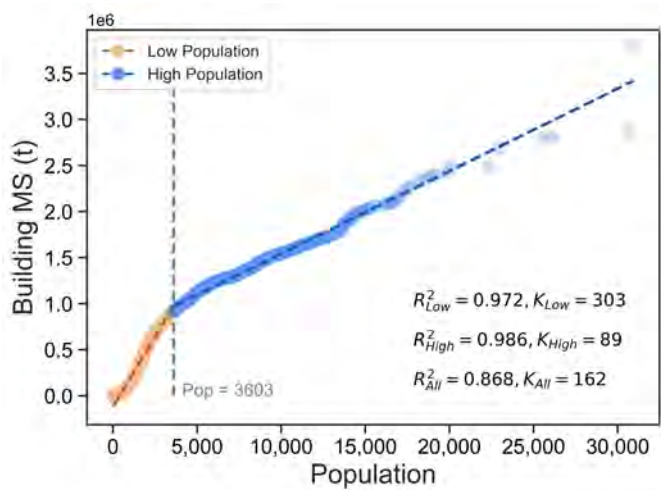
(8) Wuhan



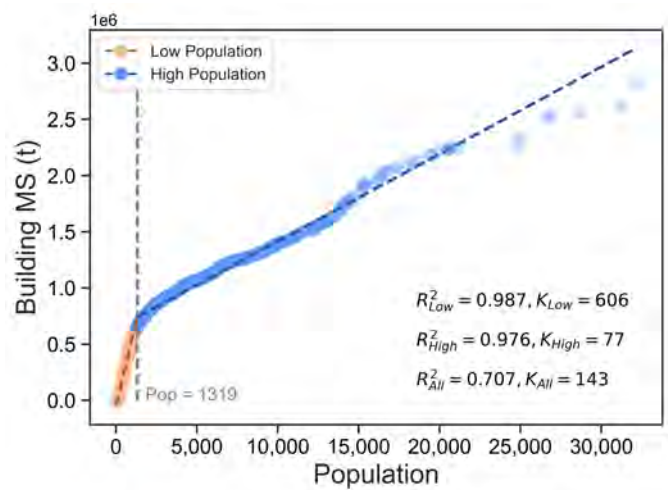
(9) Zhengzhou



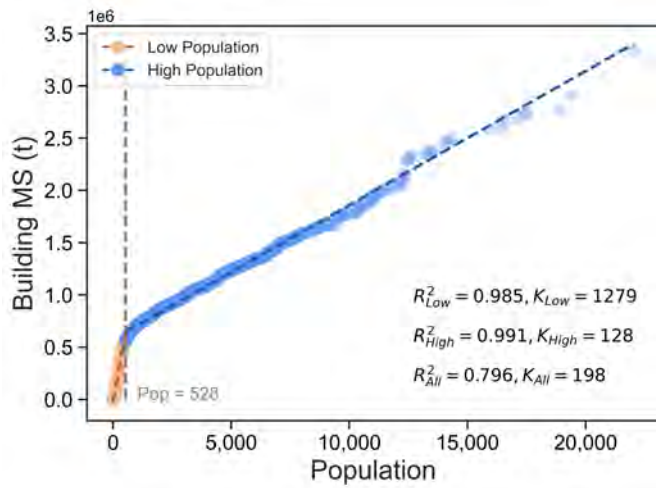
(10) Hangzhou



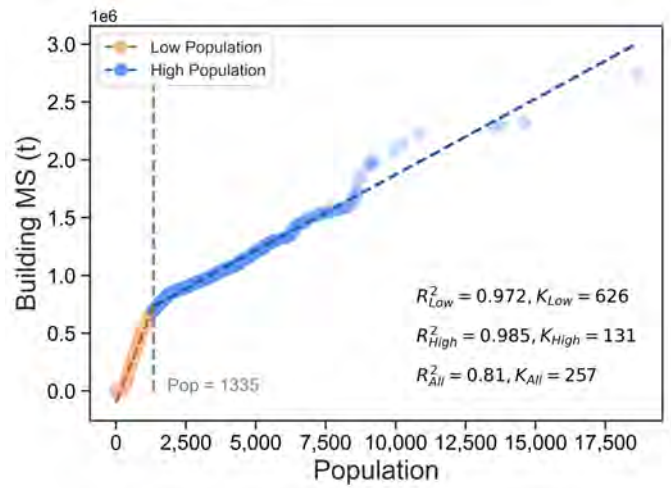
(11) Shenzhen



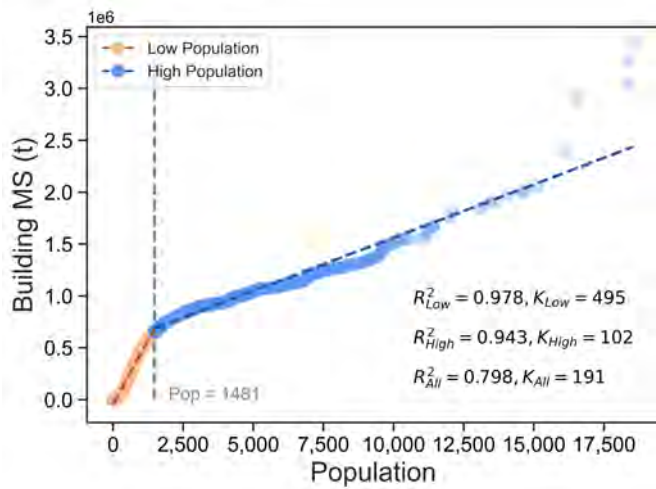
(12) Nanjing



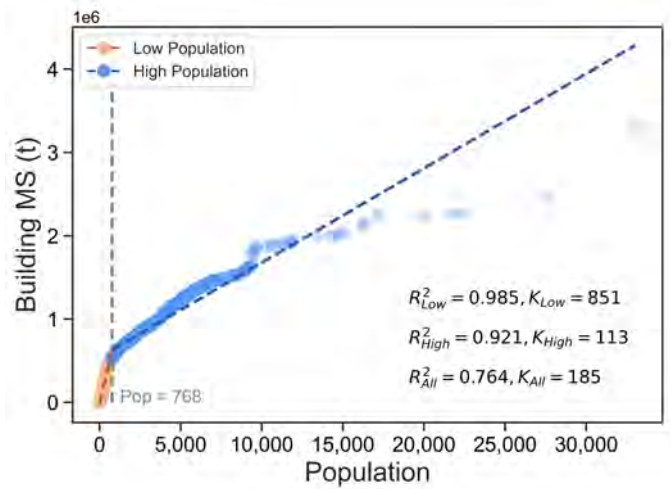
(13) Shenyang



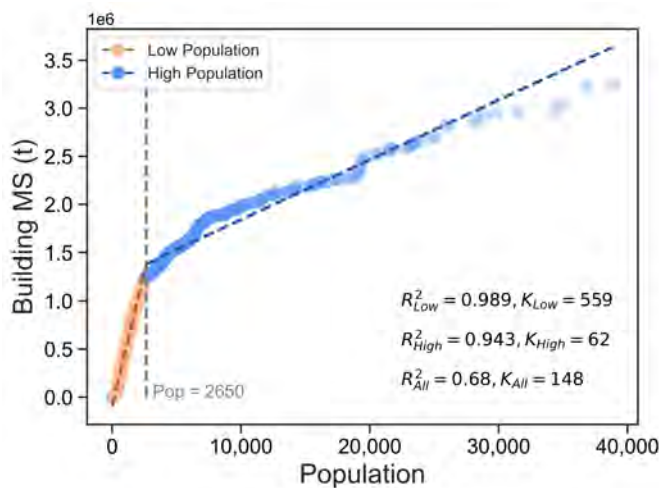
(14) Shijiazhuang



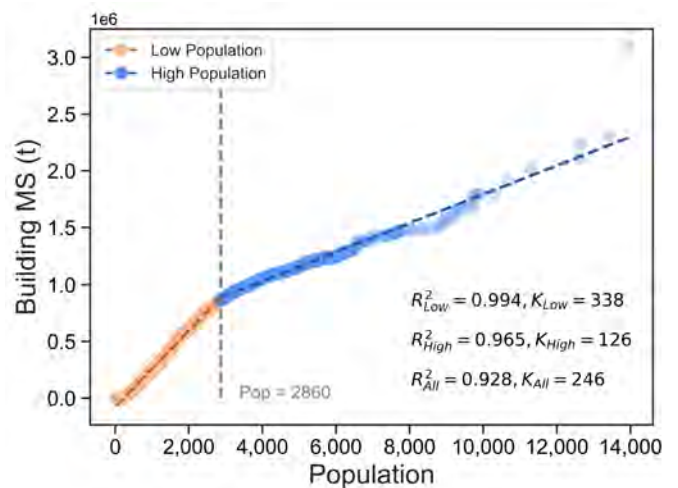
(15) Qingdao



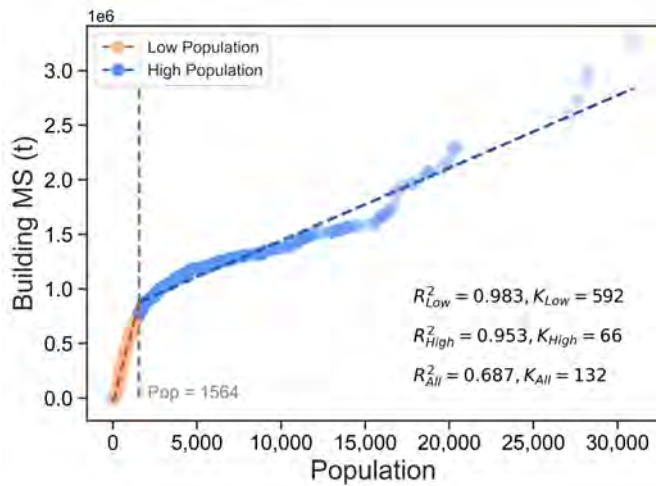
(16) Dalian



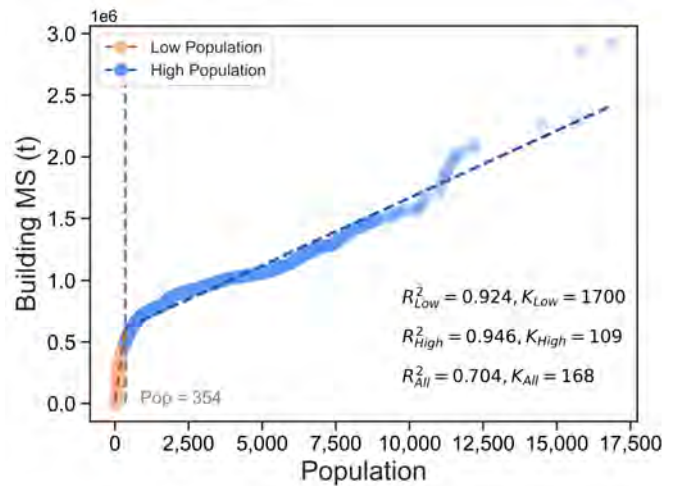
(17) Xi'an



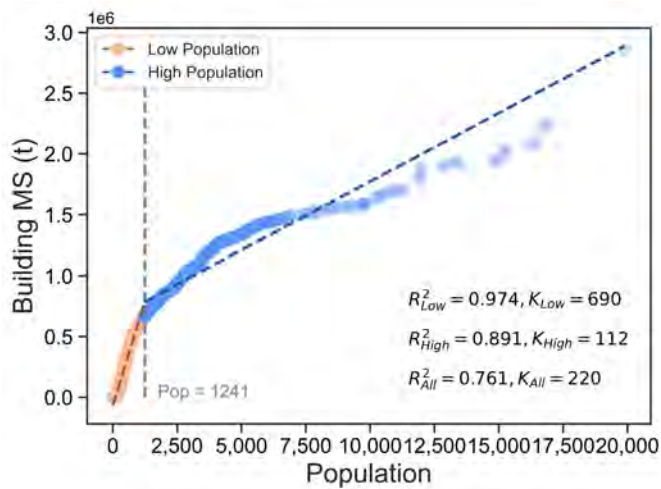
(18) Foshan



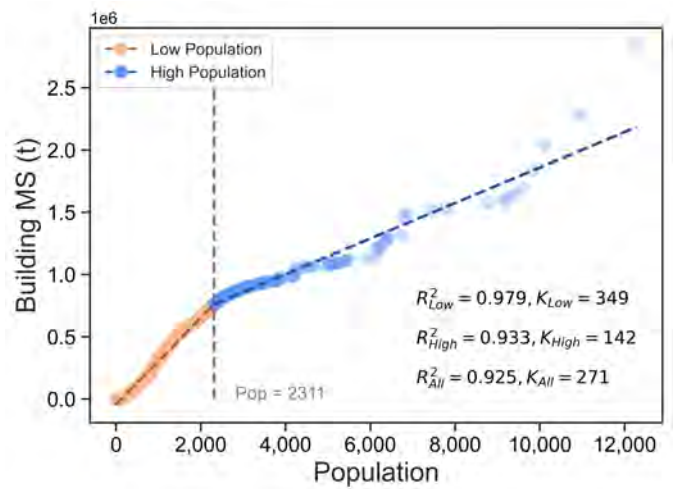
(19) Hefei



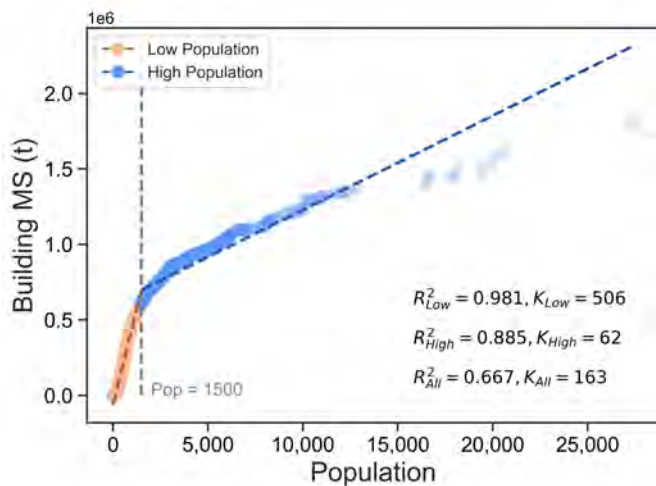
(20) Changchun



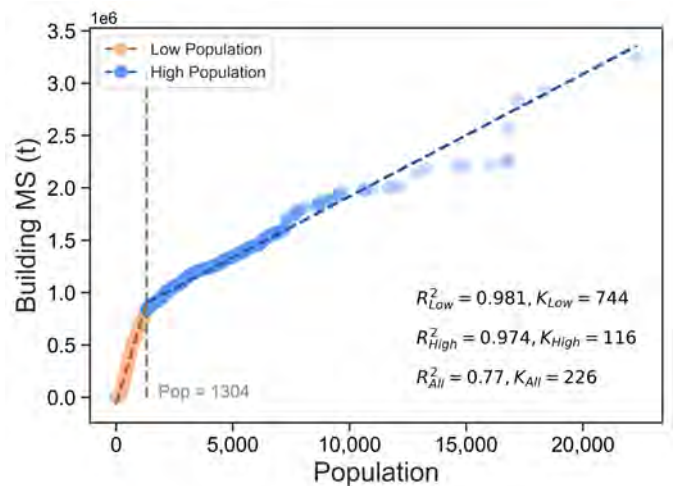
(21) Jinan



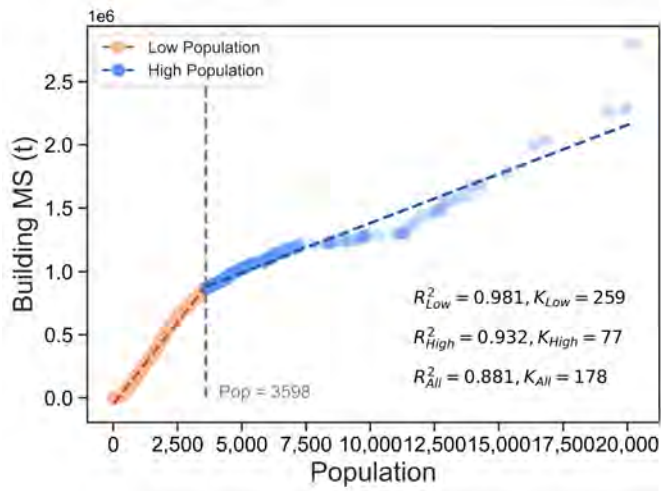
(22) Weifang



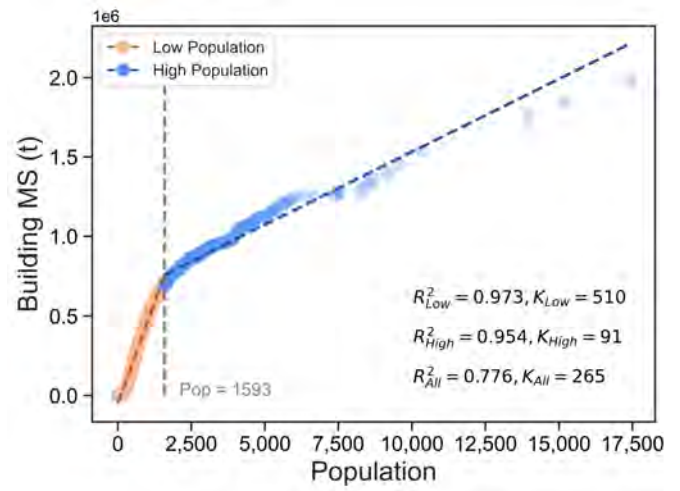
(23) Wuxi



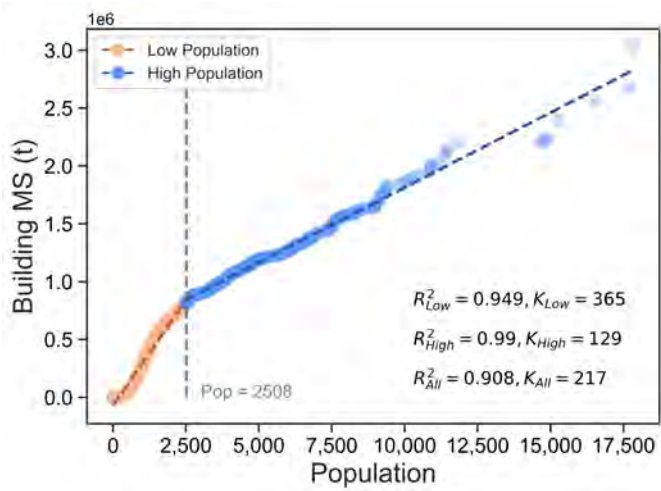
(24) Ha'erbin



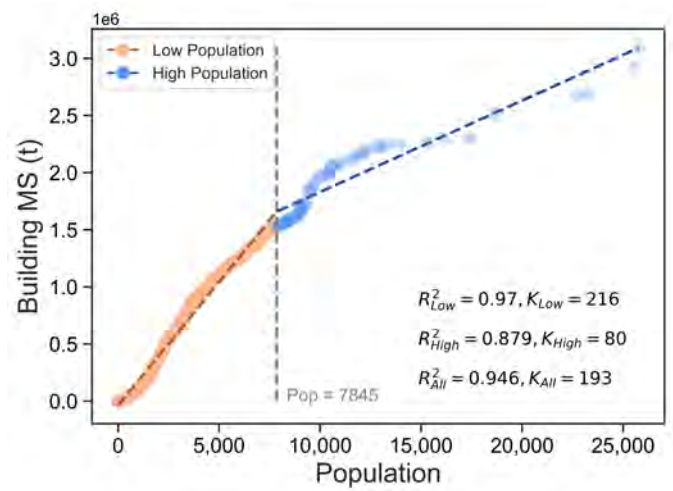
(25) Ningbo



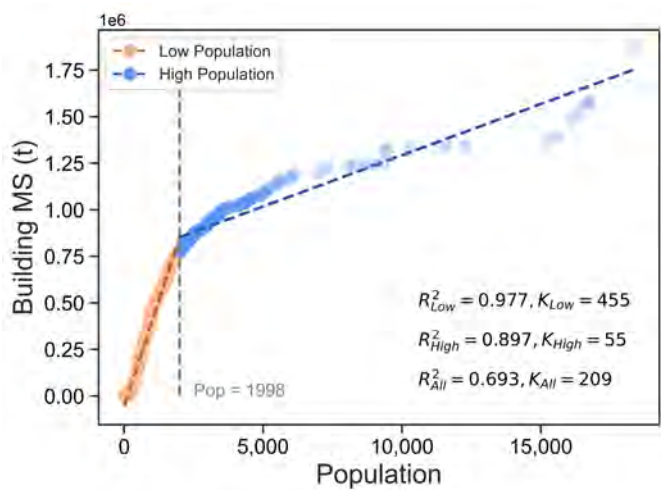
(26) Baoding



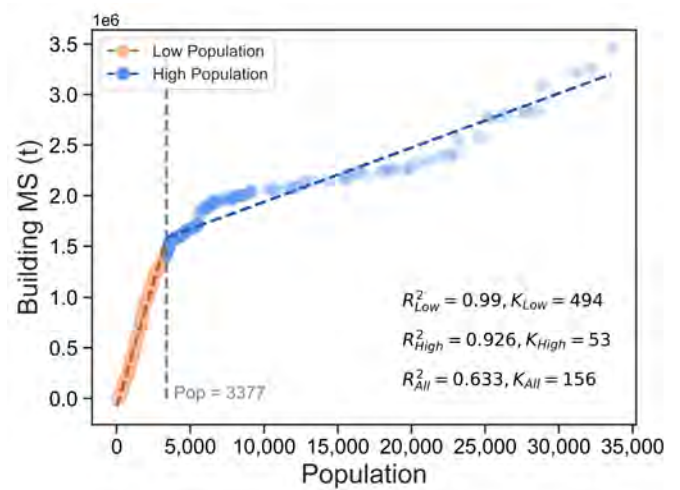
(27) Fuzhou



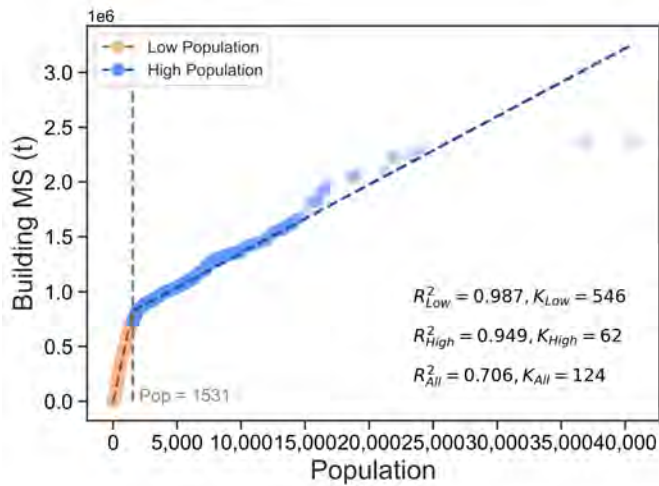
(28) Wenzhou



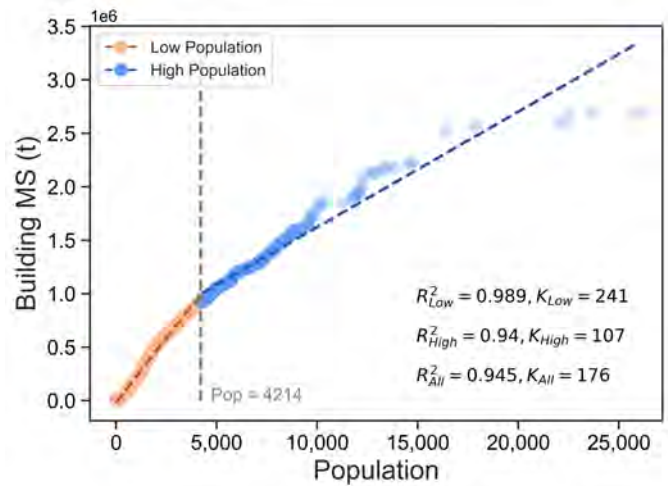
(29) Nantong



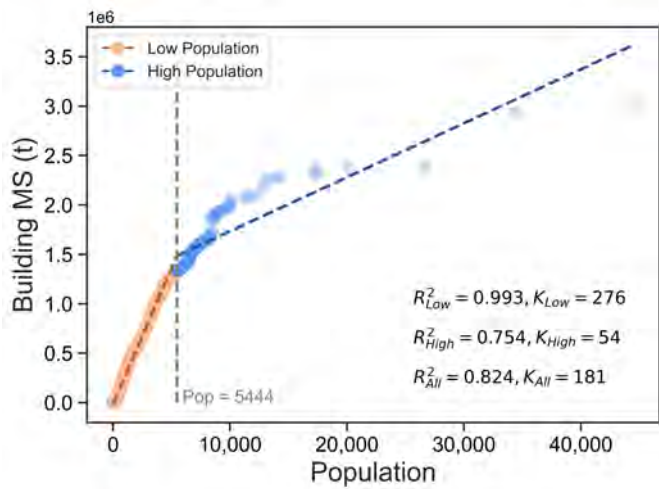
(30) Kunming



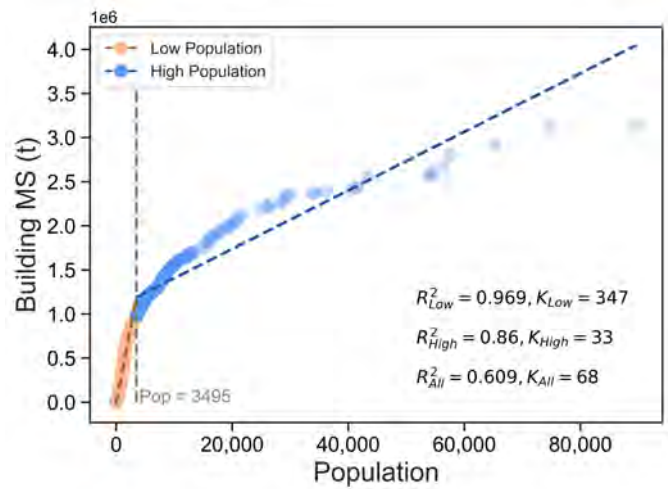
(31) Nanning



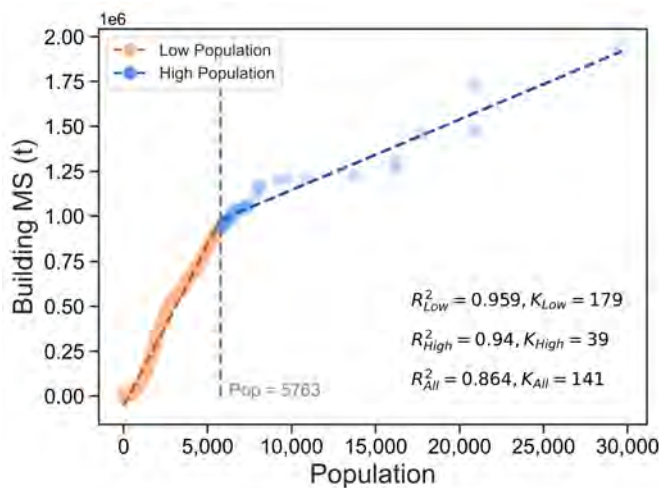
(32) Nanchang



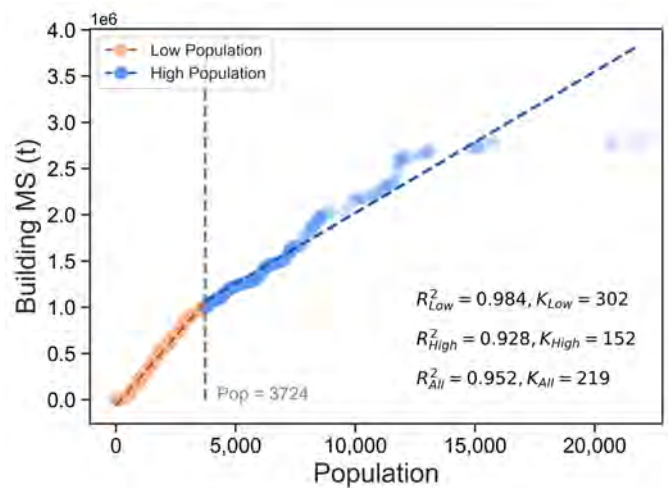
(33) Taiyuan



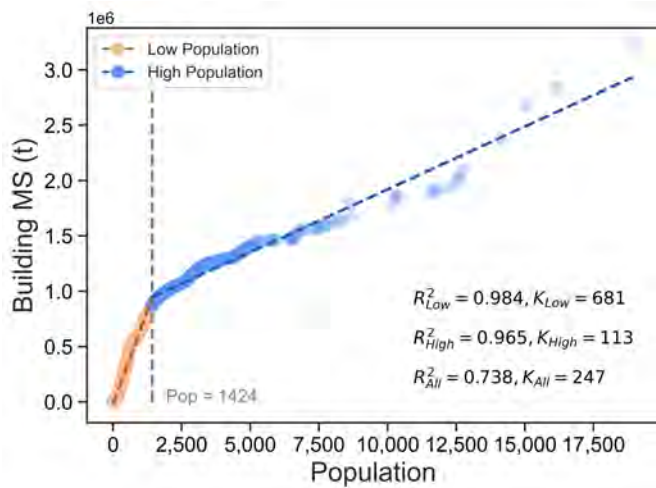
(34) Xiamen



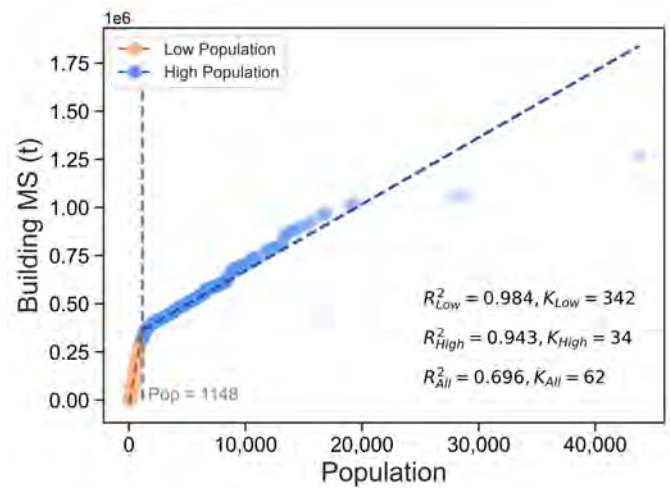
(35) Quanzhou



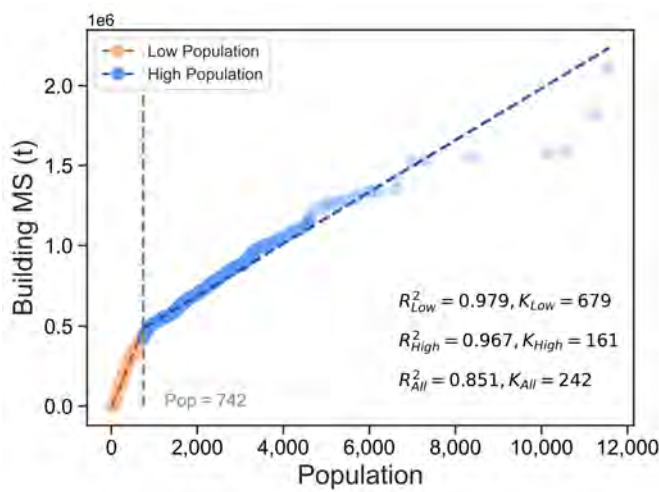
(36) Guiyang



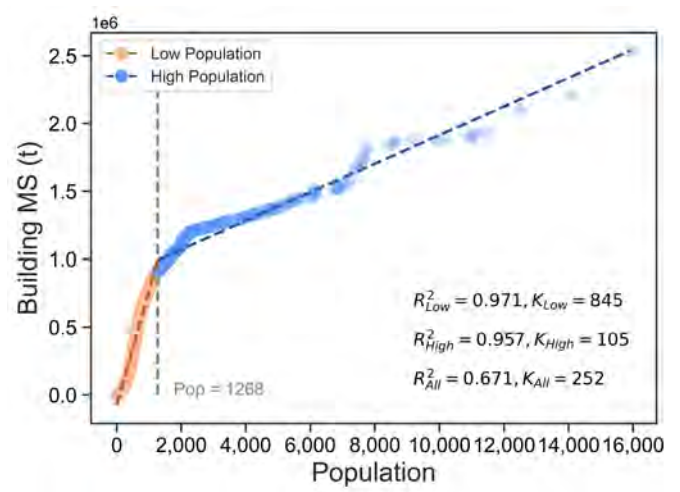
(37) Hohhot



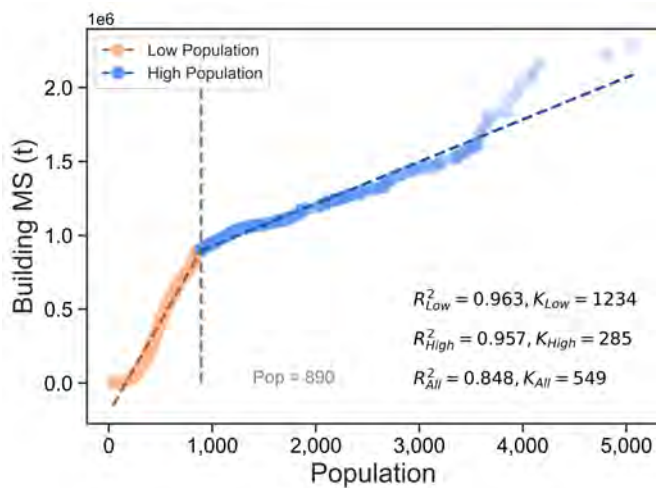
(38) Changsha



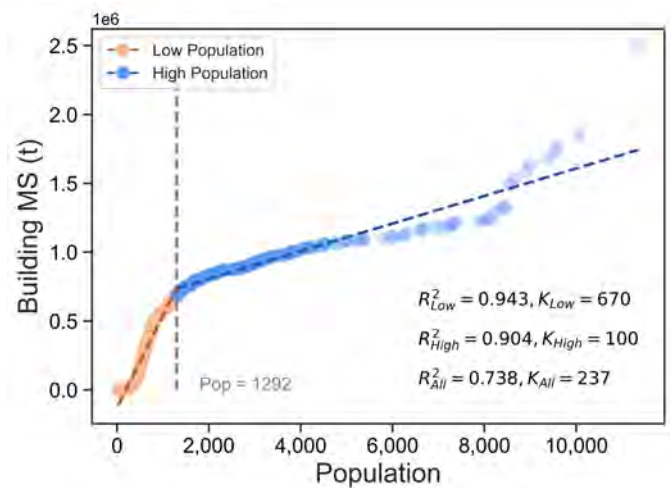
(39) Tangshan



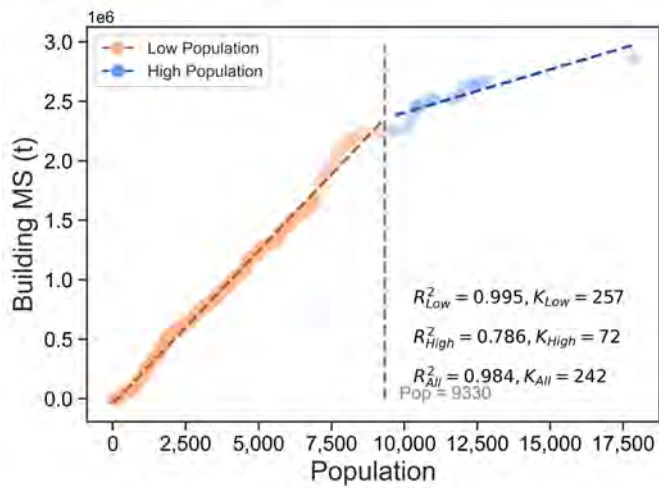
(40) Yinchuan



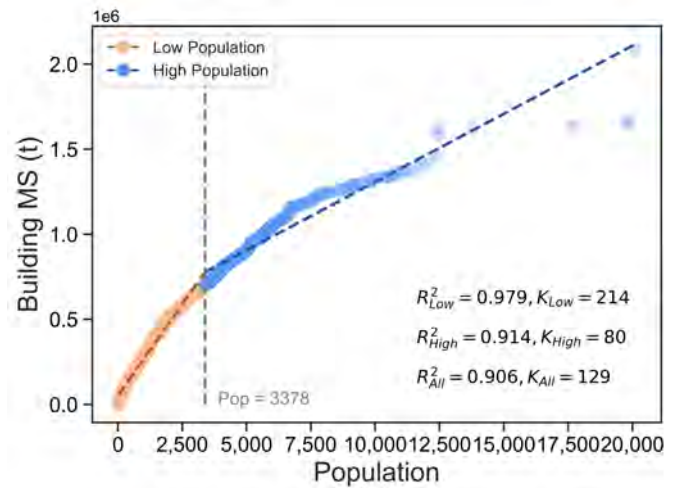
(41) Linyi



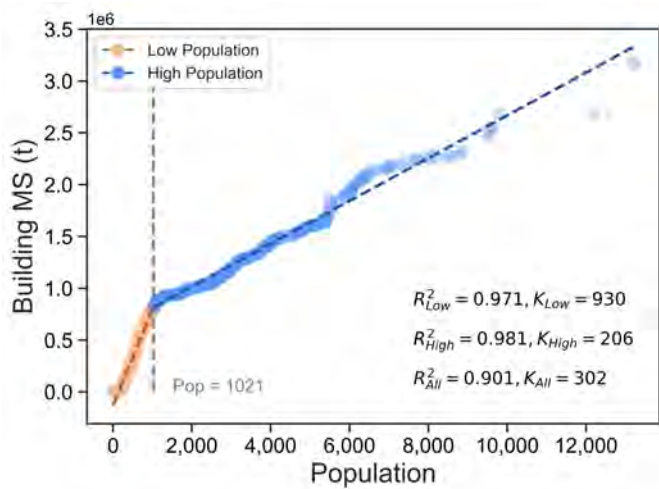
(42) Luoyang



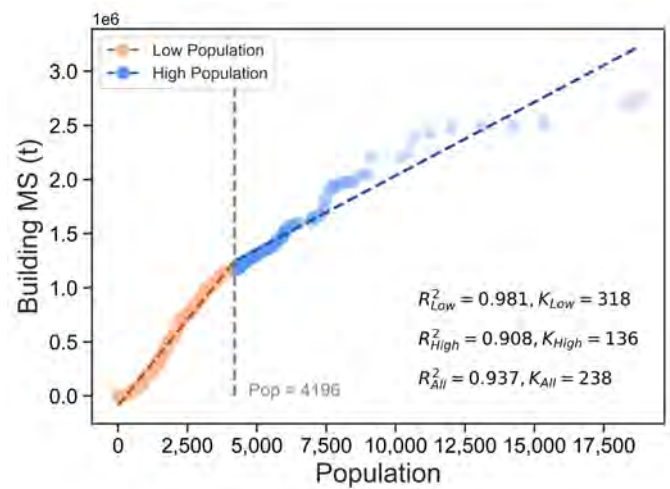
(43) Lanzhou



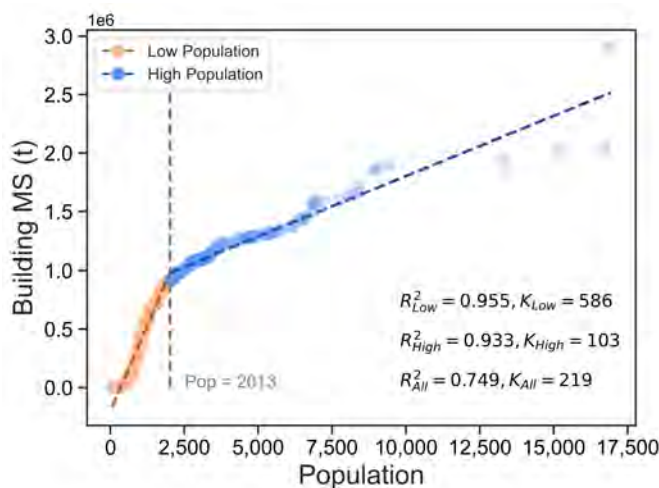
(44) Urumqi



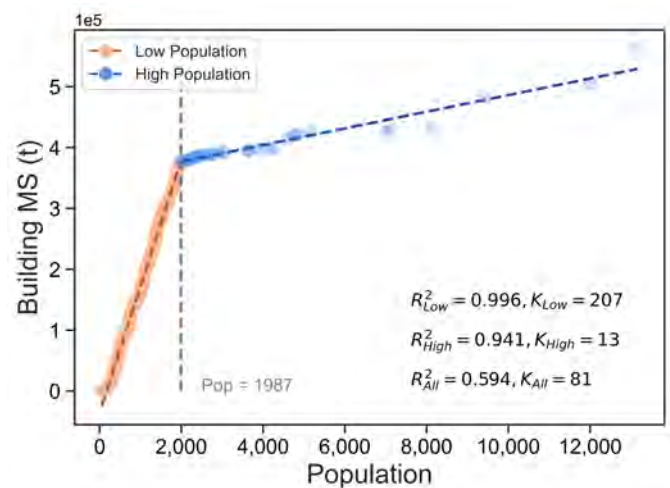
(45) Xining



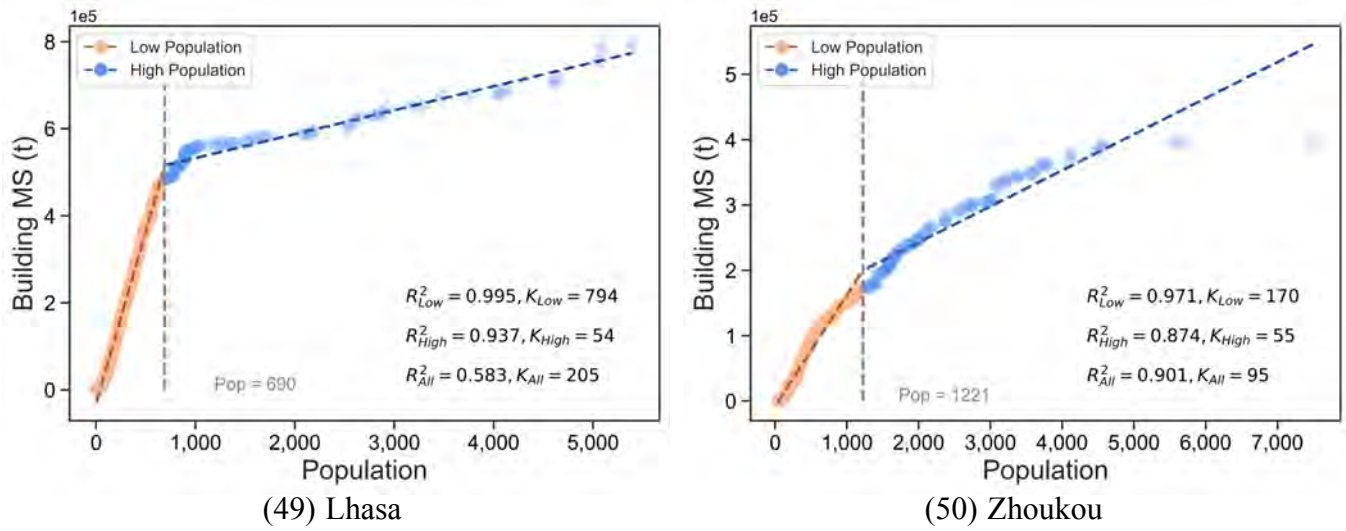
(46) Haikou



(47) Handan

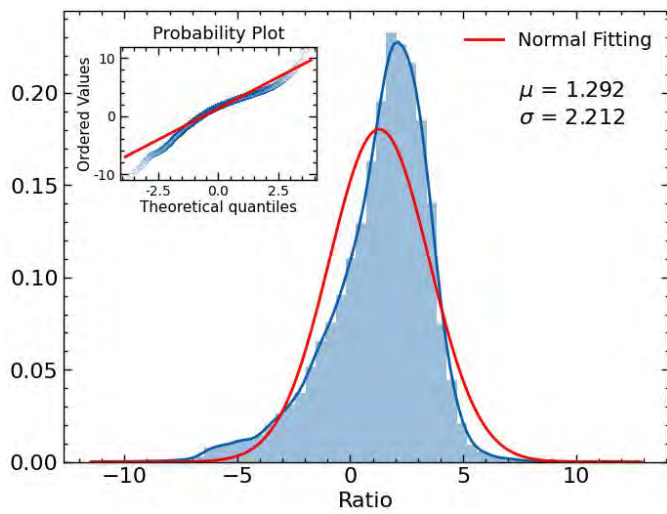


(48) Nanyang

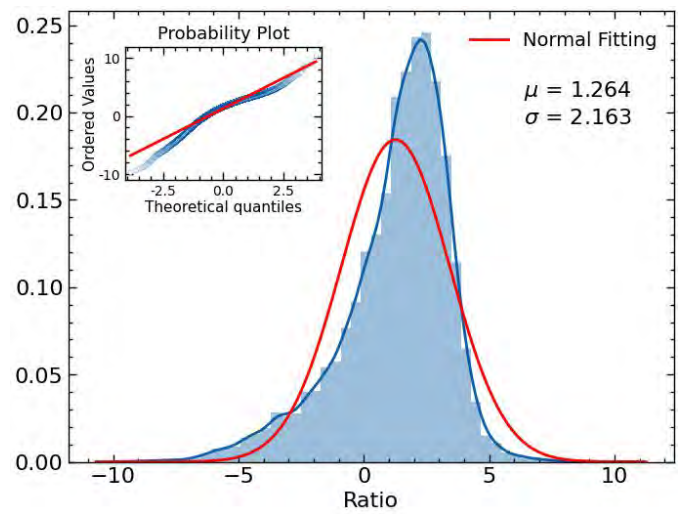


Supplementary Figure A7: Correlations between population and building stocks in the 50 Chinese cities

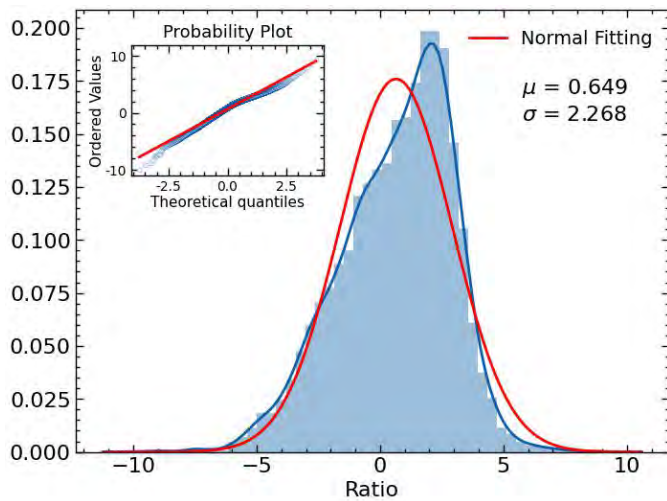
A.8 Log-normal distribution of BtR ratio at grid level in the 50 Chinese Cities



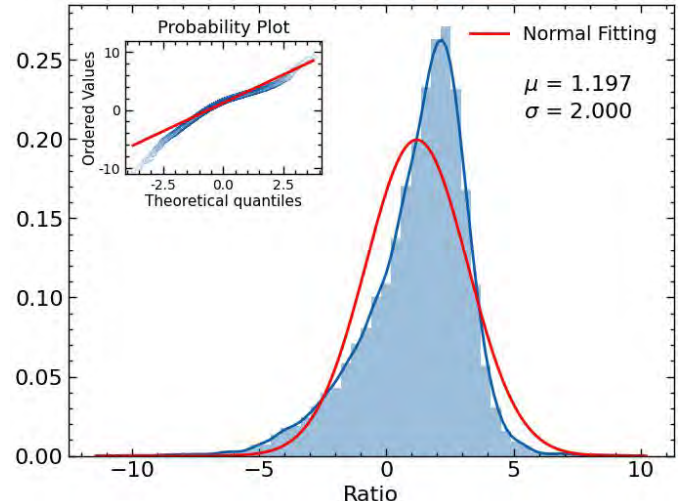
(1) Beijing



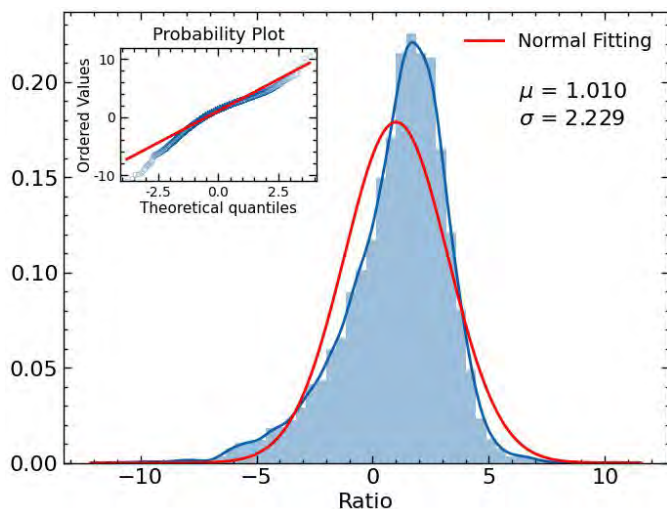
(2) Shanghai



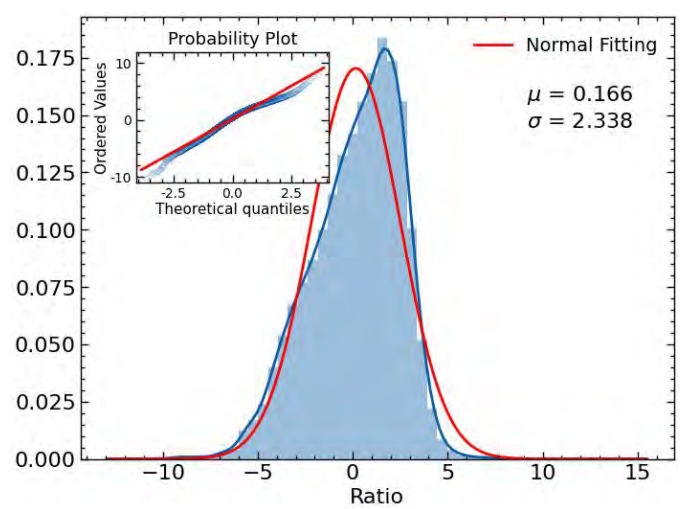
(3) Chongqing



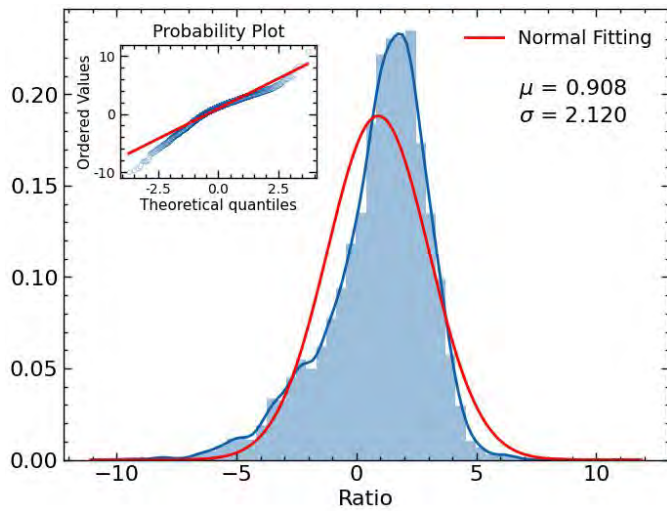
(4) Chengdu



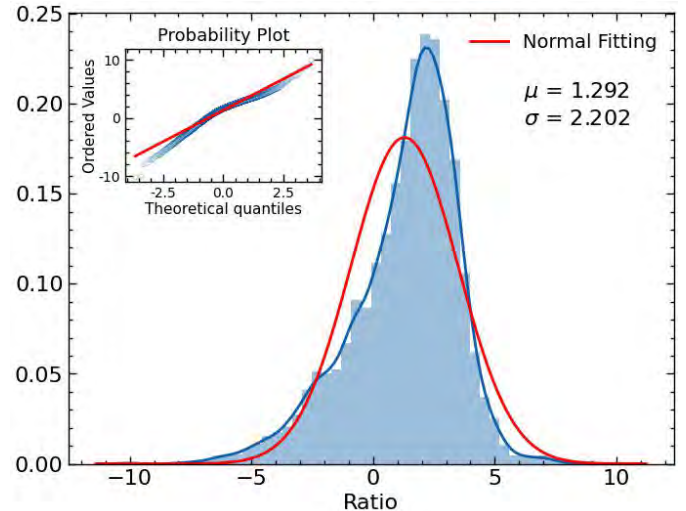
(5) Tianjin



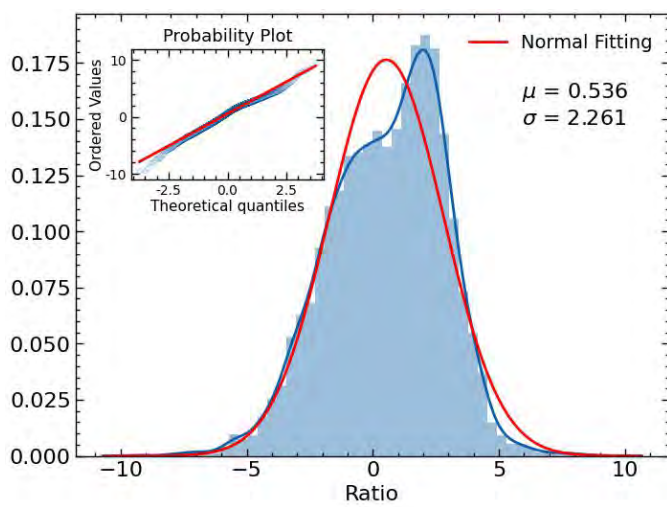
(6) Suzhou



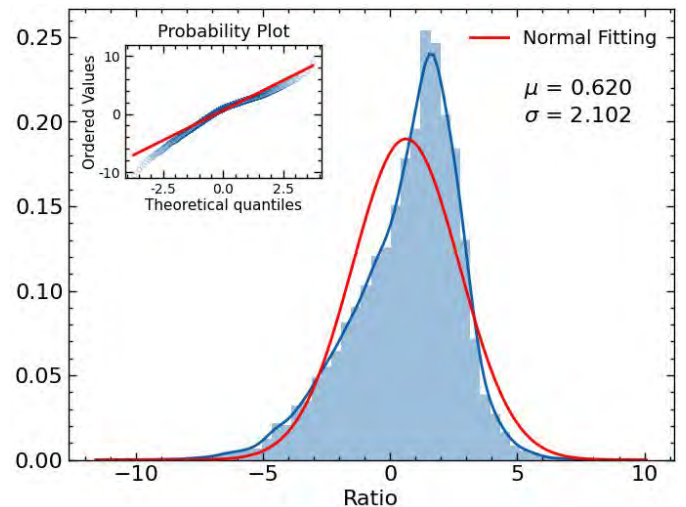
(7) Guangzhou



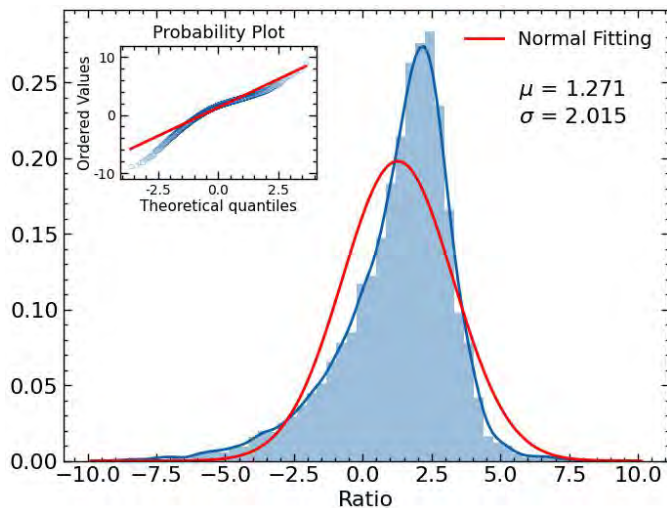
(8) Wuhan



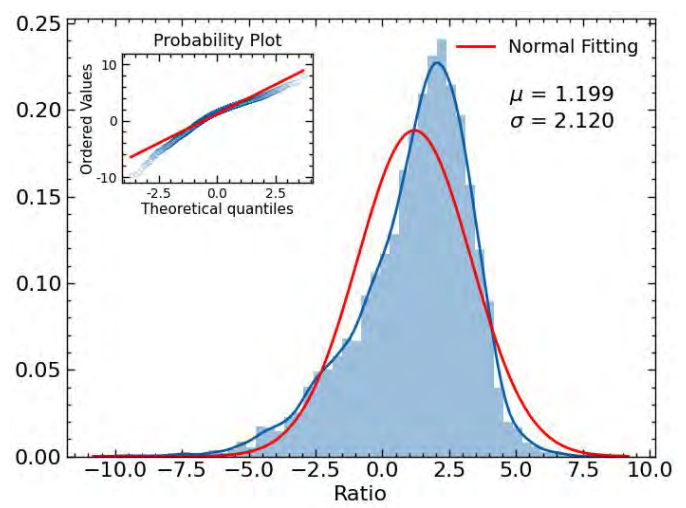
(9) Zhengzhou



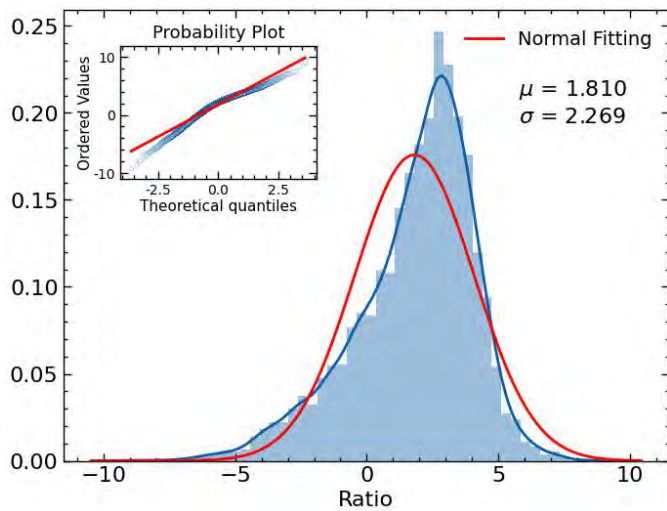
(10) Hangzhou



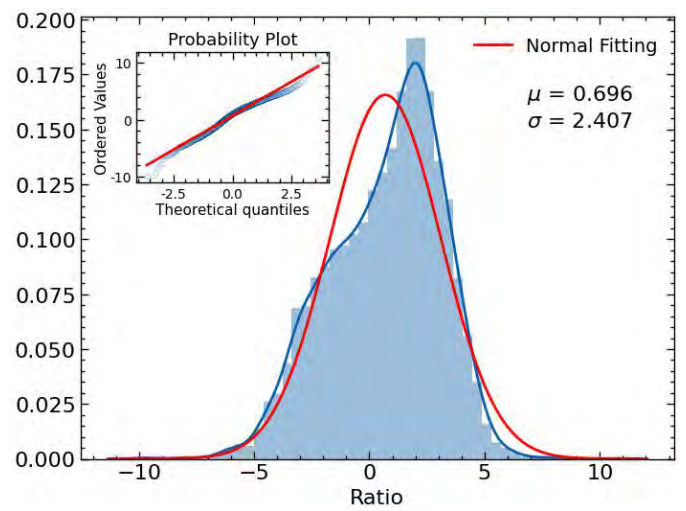
(11) Shenzhen



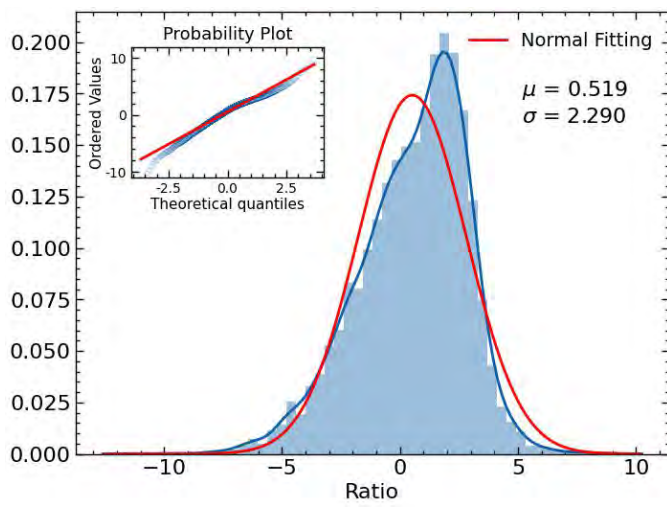
(12) Nanjing



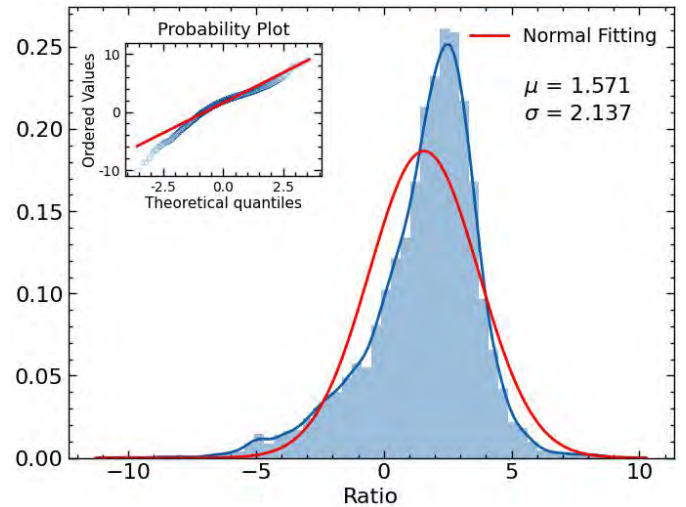
(13) Shenyang



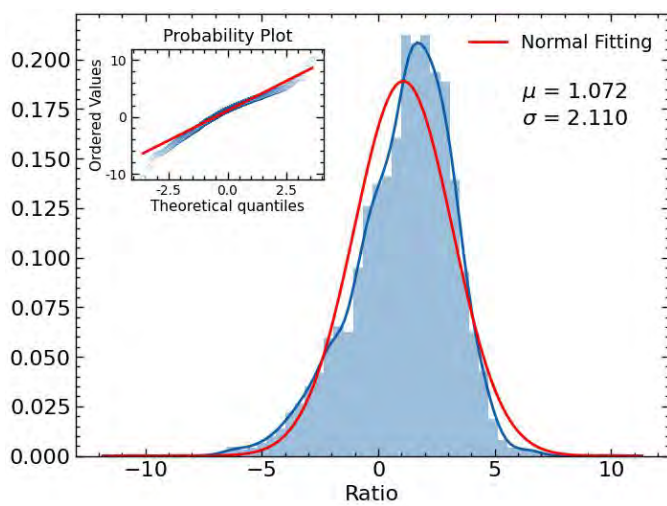
(14) Shijiazhuang



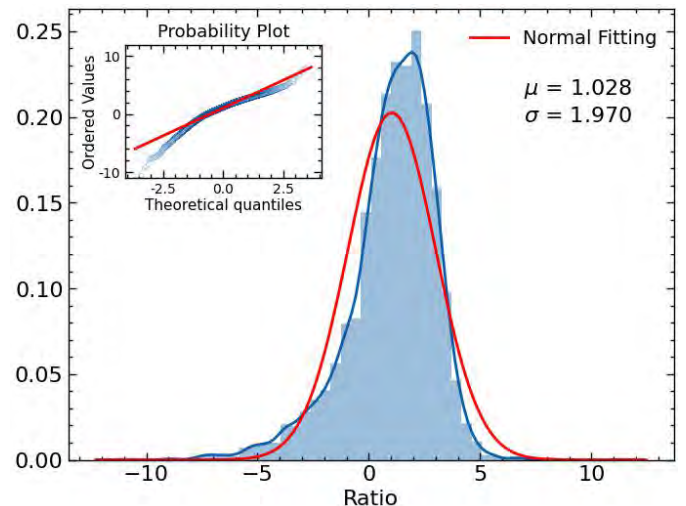
(15) Qingdao



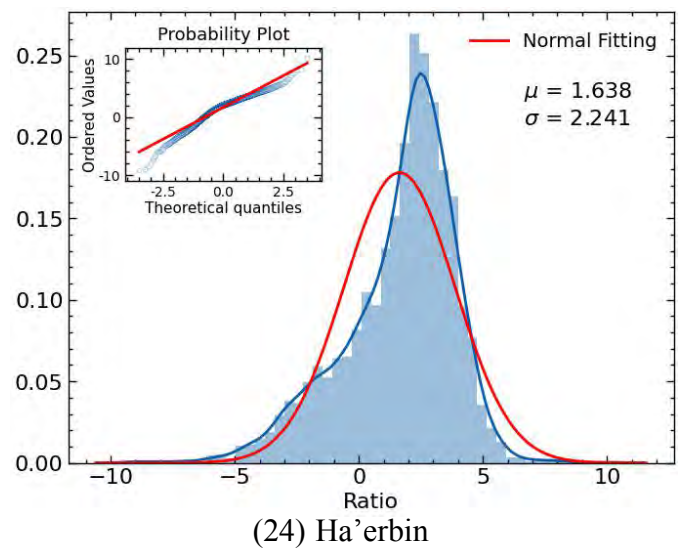
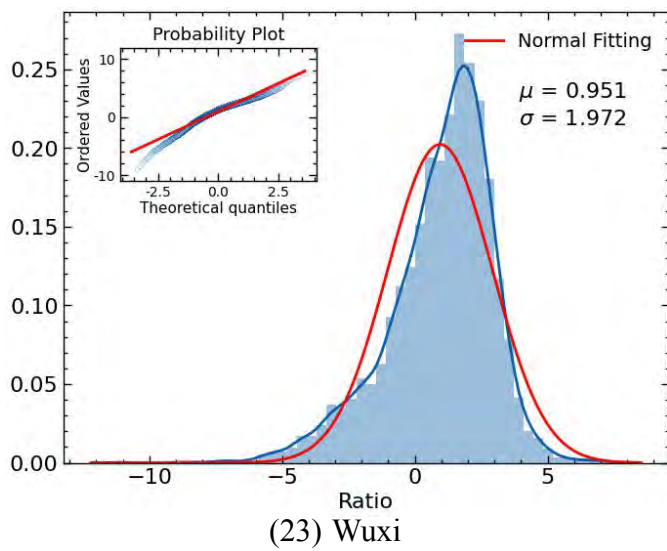
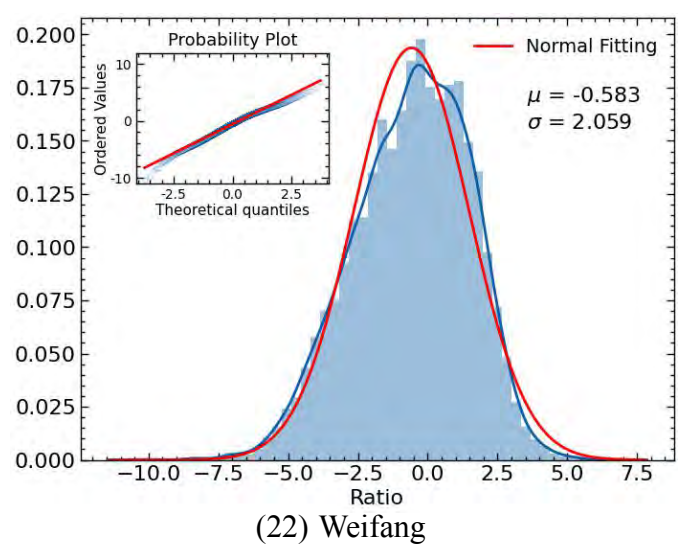
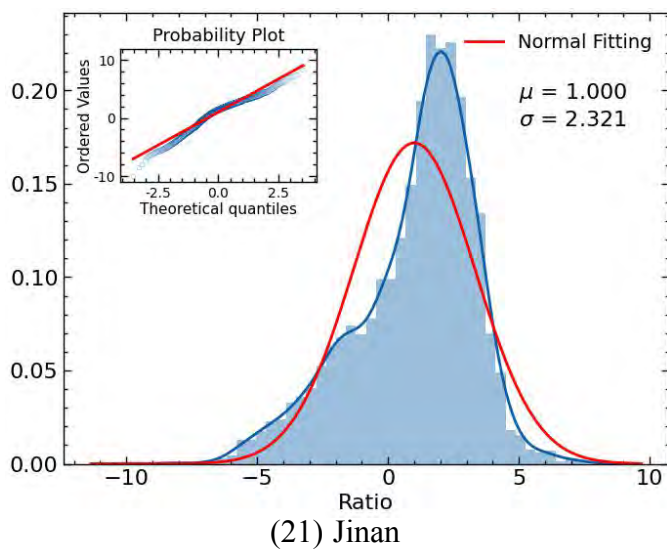
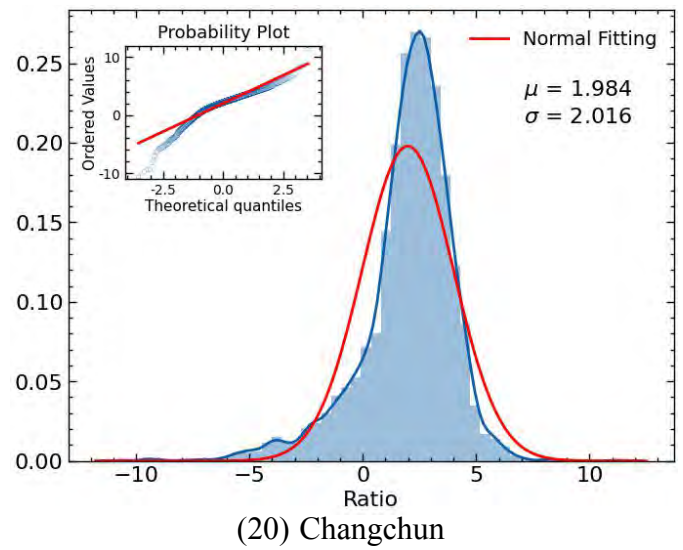
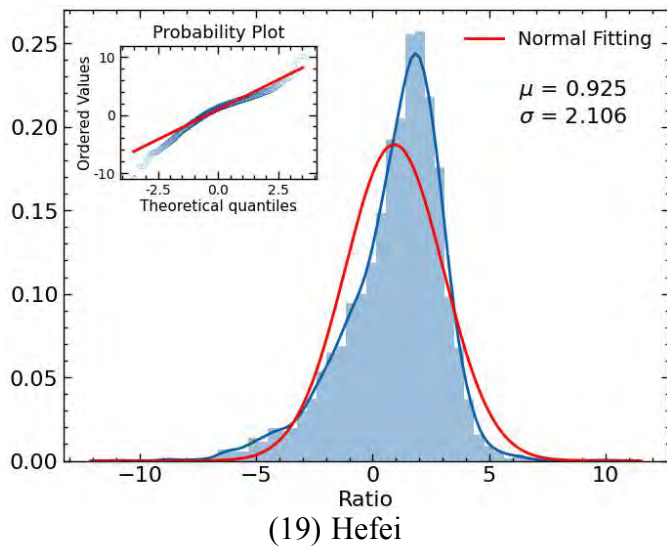
(16) Dalian

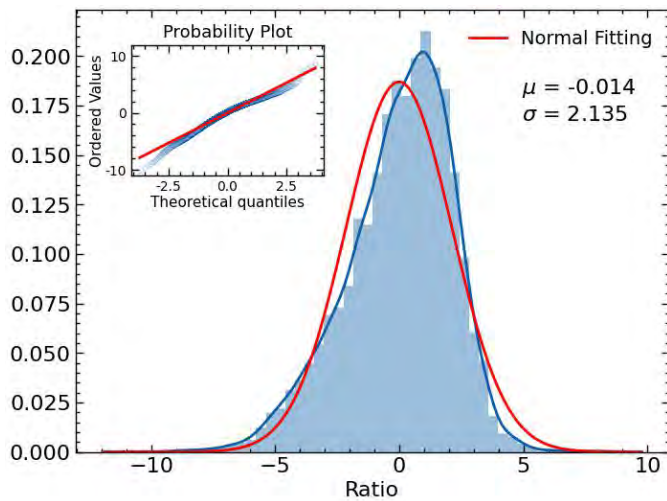


(17) Xi'an

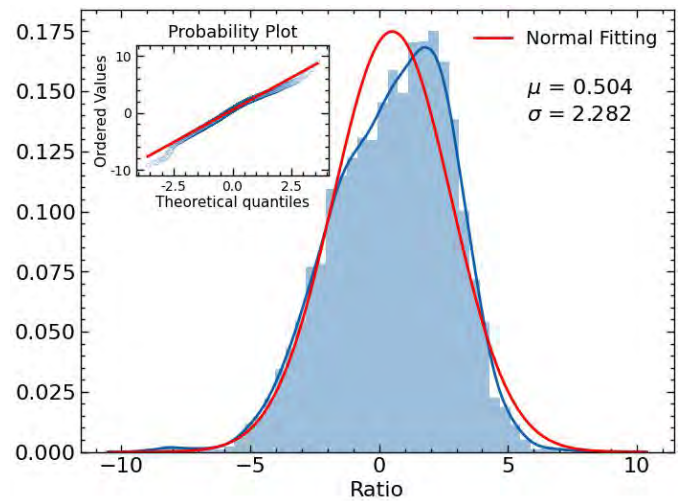


(18) Foshan

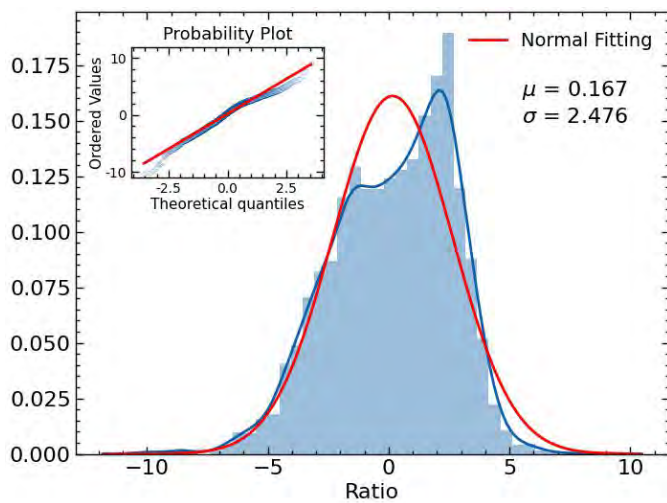




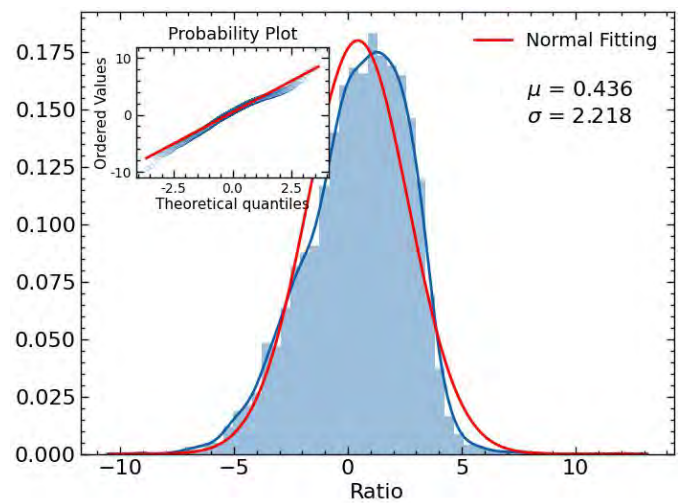
(25) Ningbo



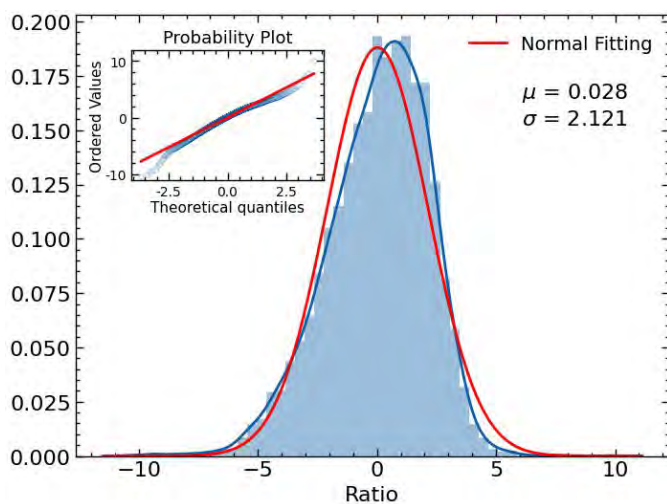
(26) Baoding



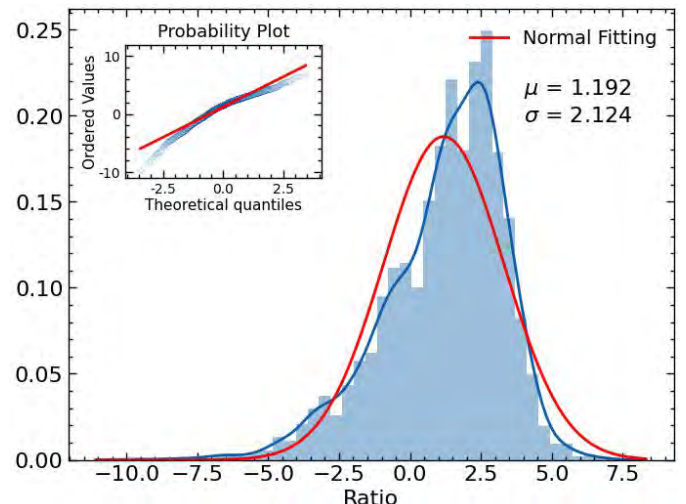
(27) Fuzhou



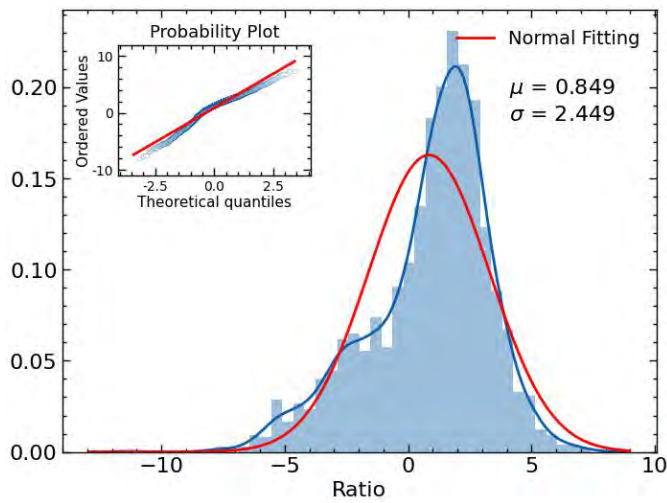
(28) Wenzhou



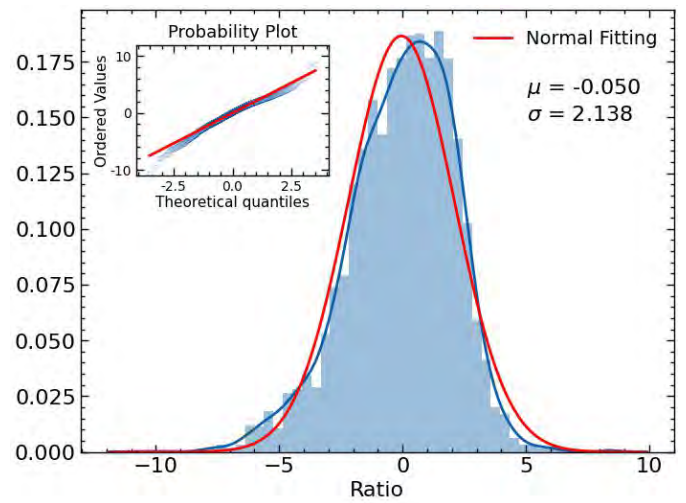
(29) Nantong



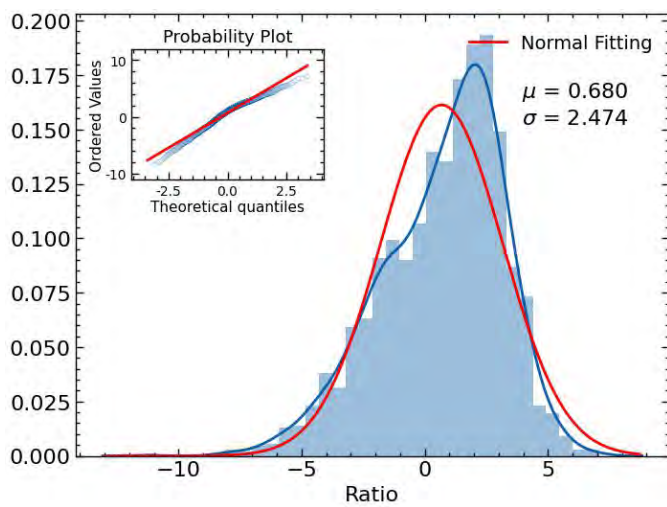
(30) Kunming



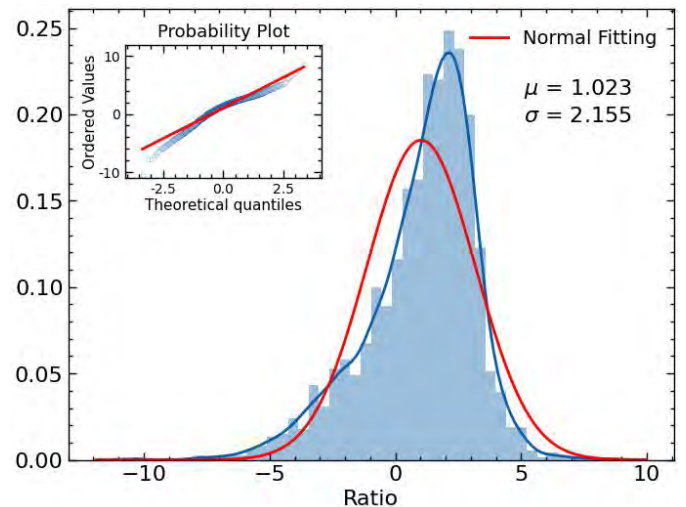
(31) Nanning



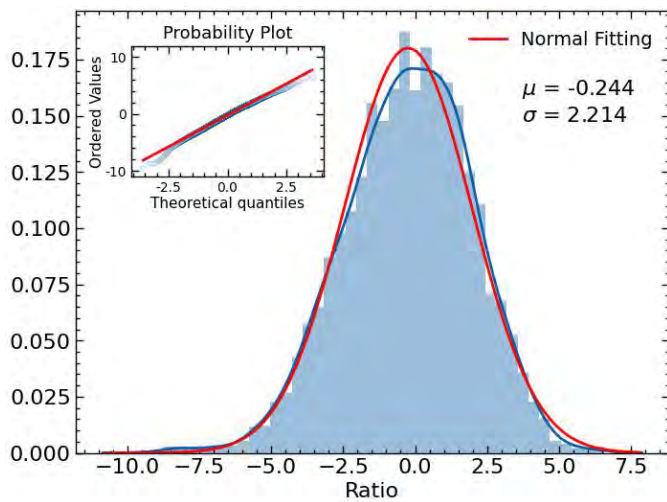
(32) Nanchang



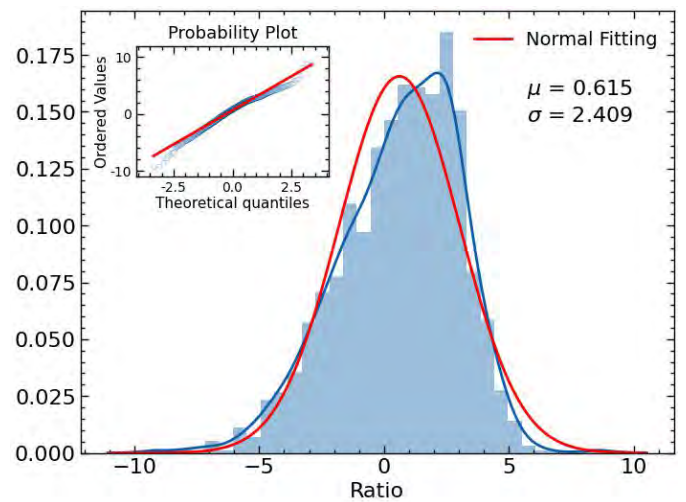
(33) Taiyuan



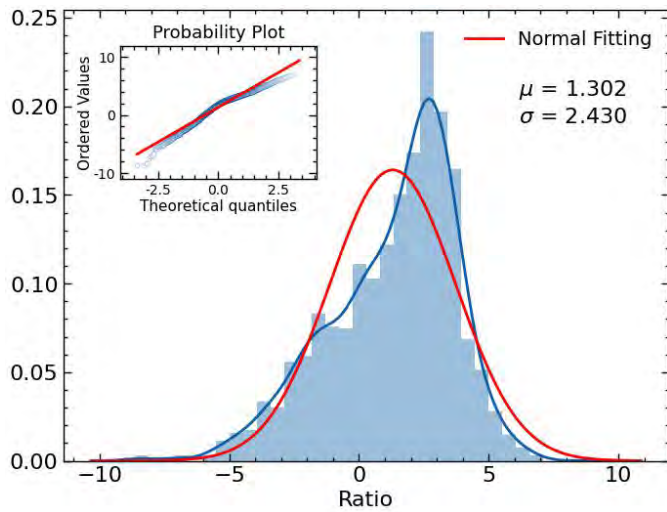
(34) Xiamen



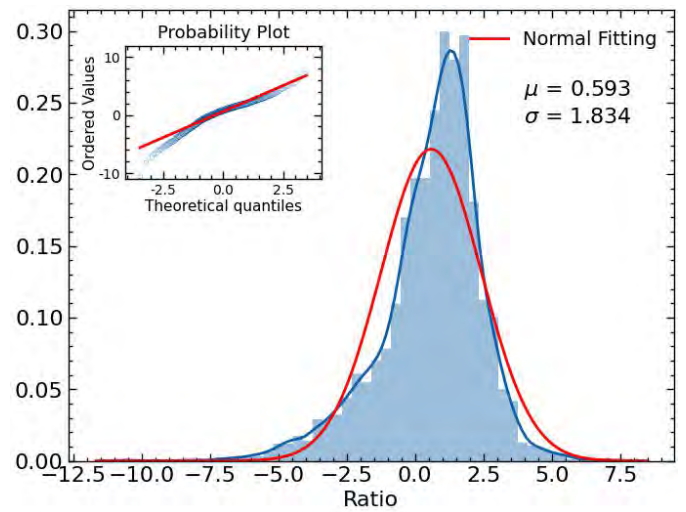
(35) Quanzhou



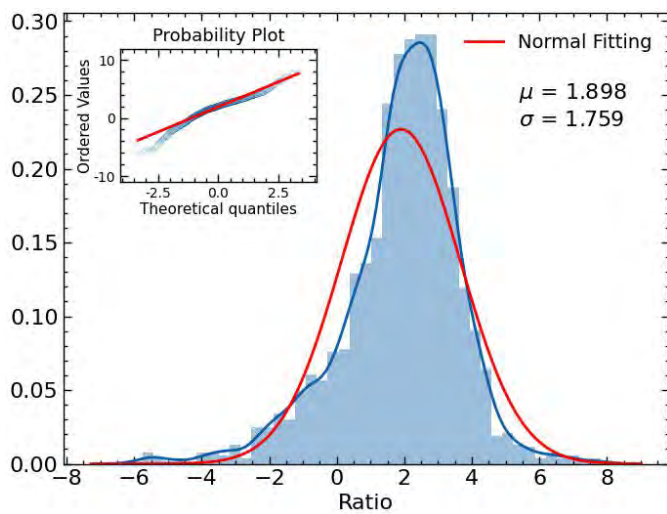
(36) Guiyang



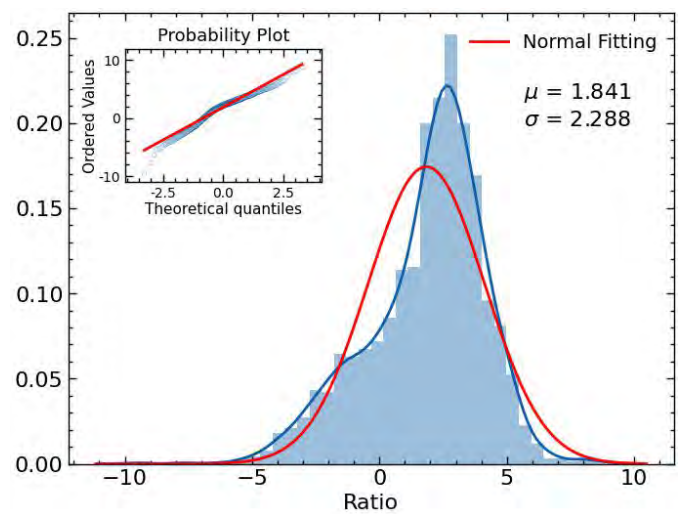
(37) Hohhot



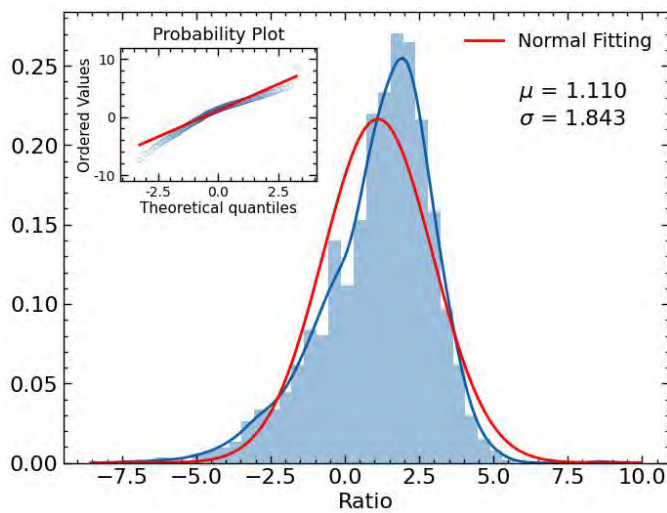
(38) Changsha



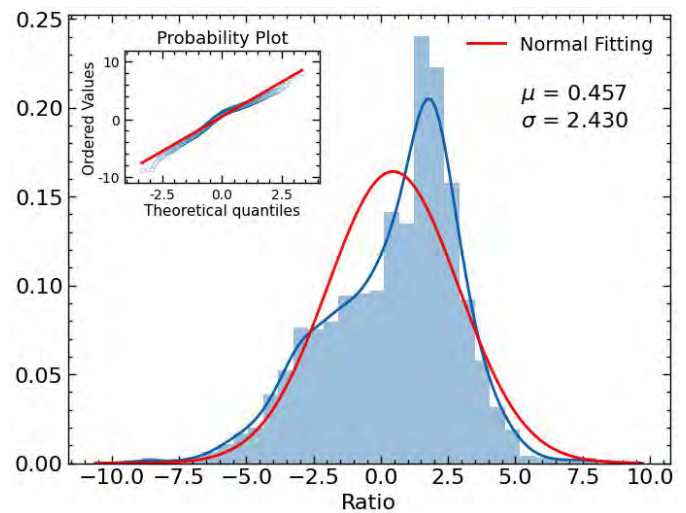
(39) Tangshan



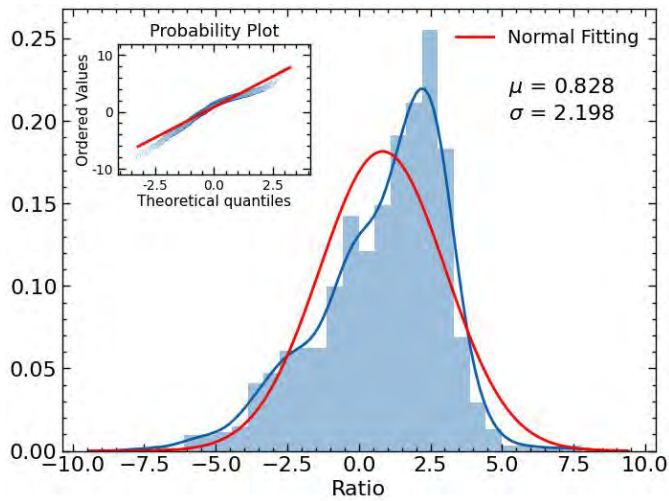
(40) Yinchuan



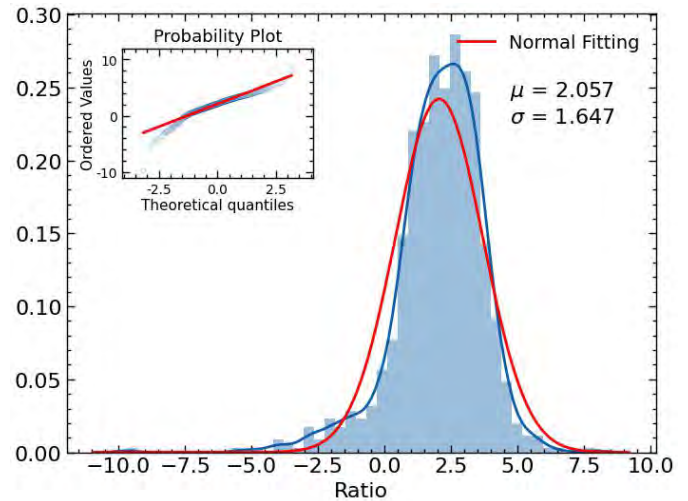
(41) Linyi



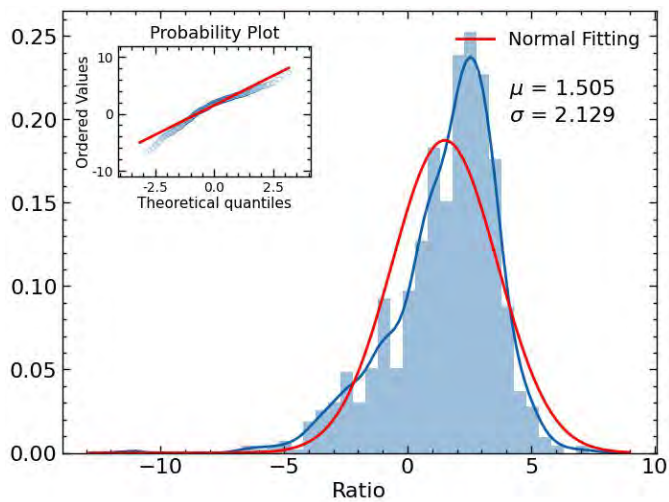
(42) Luoyang



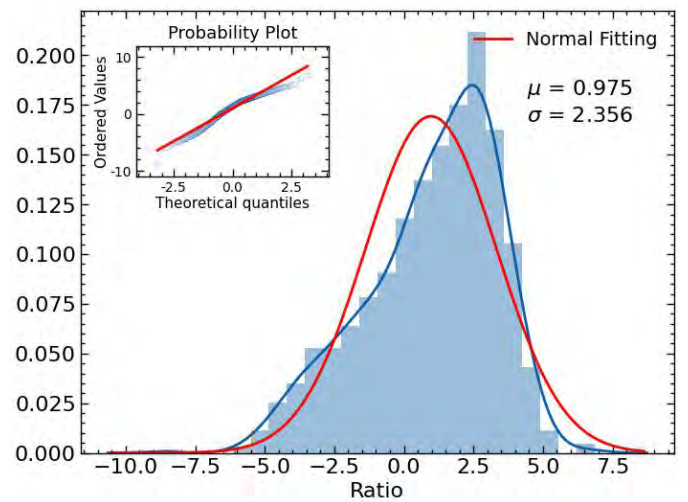
(43) Lanzhou



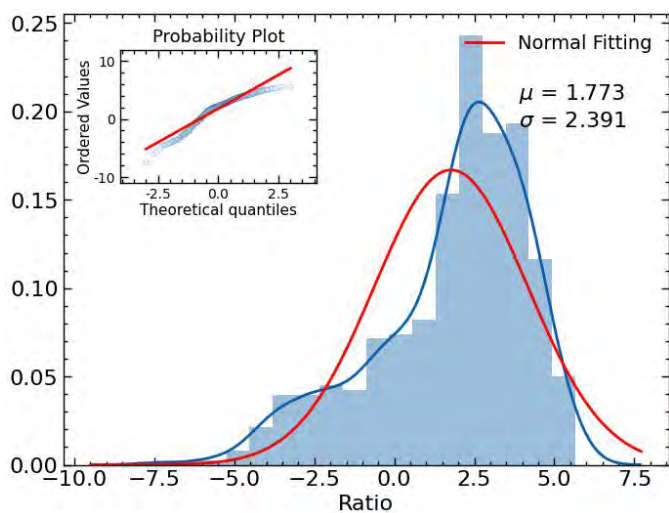
(44) Urumqi



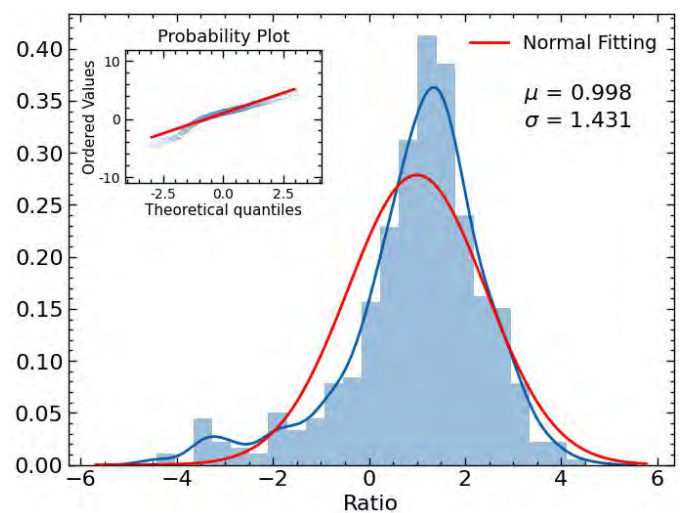
(45) Xining



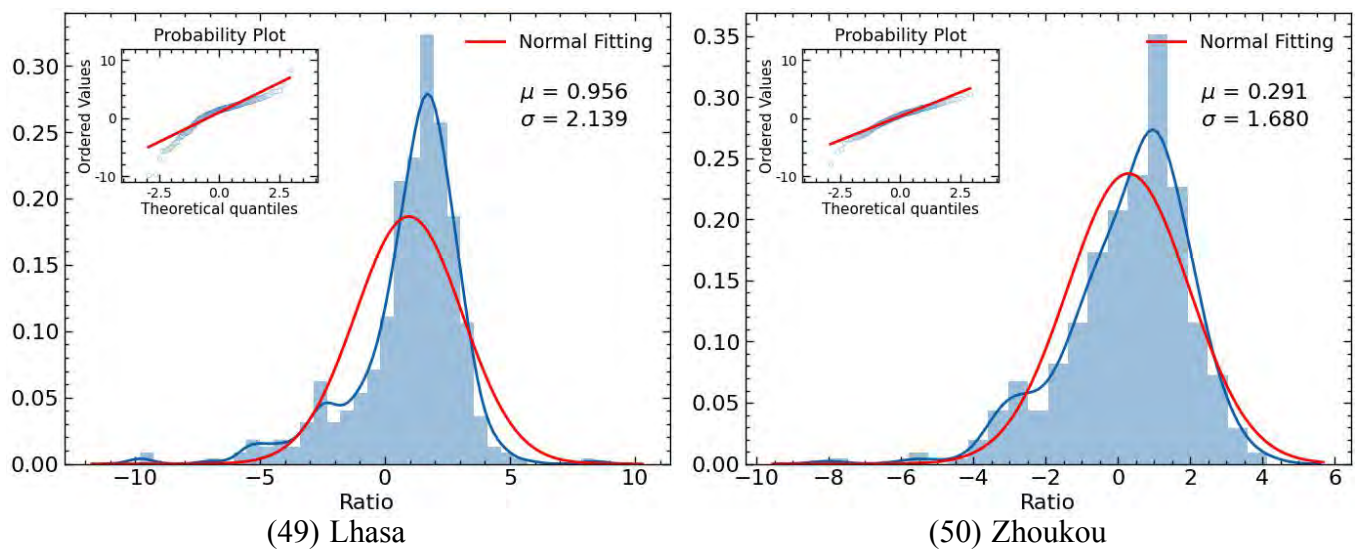
(46) Haikou



(47) Handan



(48) Nanyang



Supplementary Figure A8: The pdf curves and P-P plot for BtR ratio in the 50 Chinese cities