
''' A city's physical structures, once established, may remain in place for more than 150 years '''

Cities' Fingerprints: A Complex Network Approach

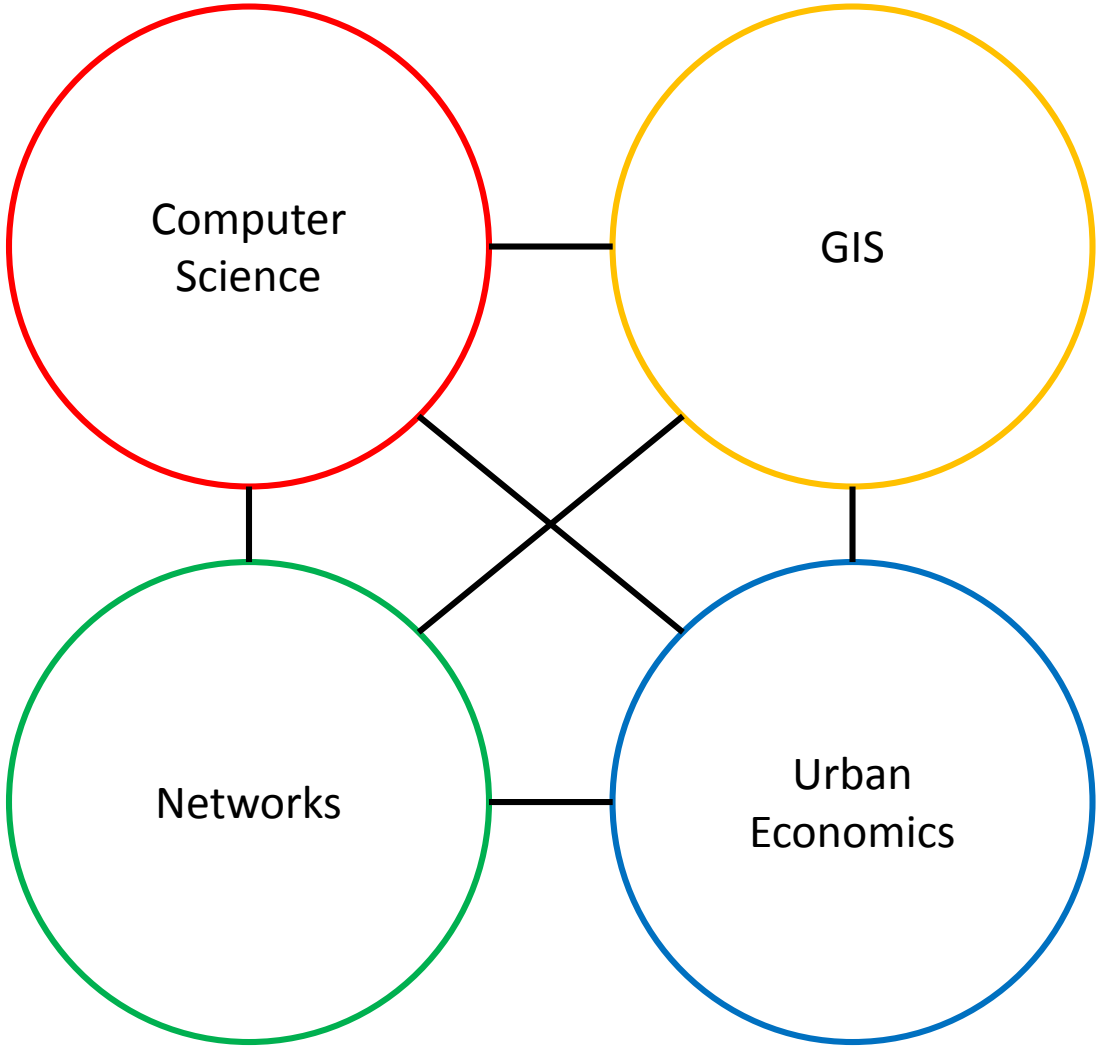
Andres PDLR

Outline

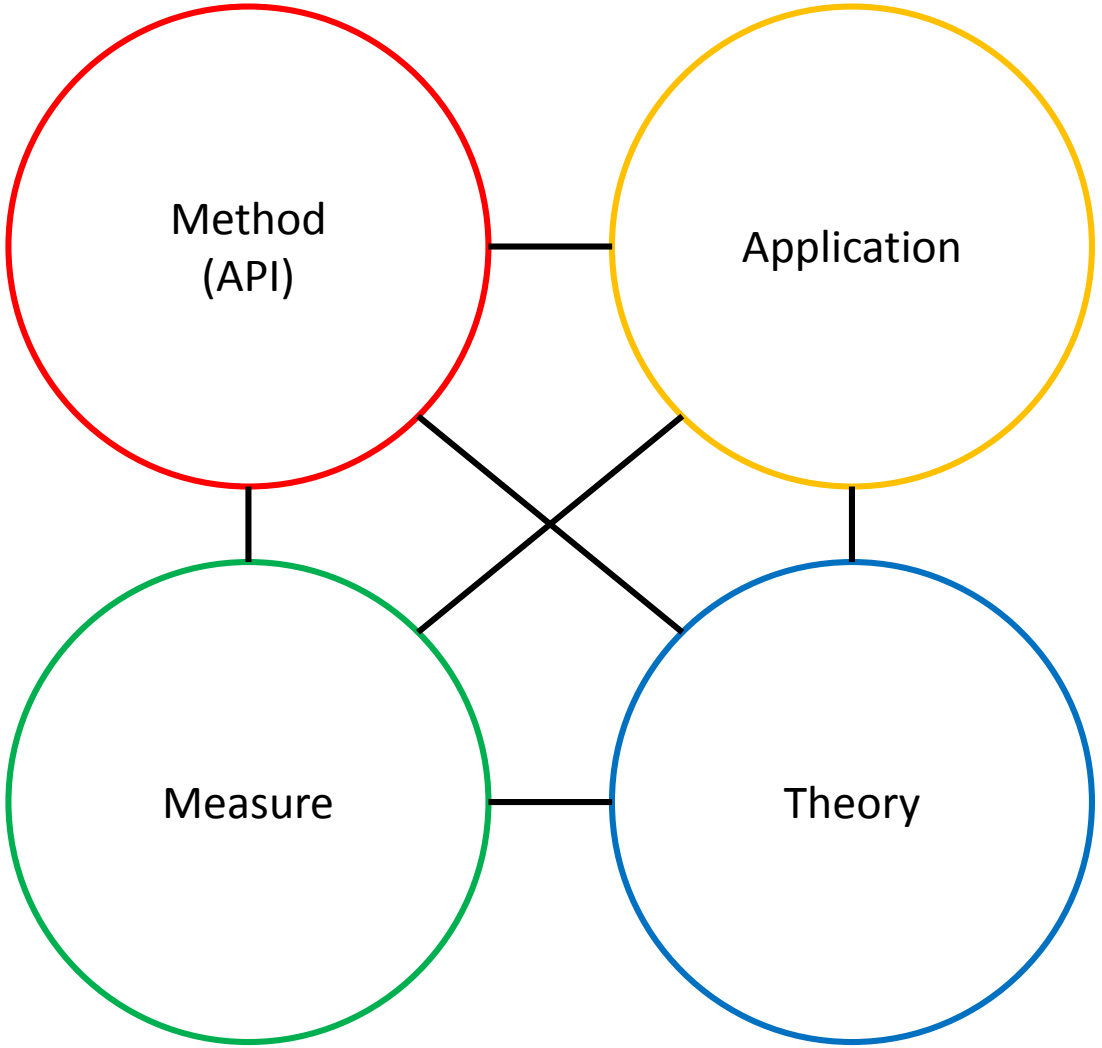
- The Problem
- The Contribution of this Paper
- Relation to the Literature
- Methods
  - Algorithm I
  - Algorithm II
- Simulations
- Main Results
- Conclusions

Motivation

This paper was inspired by:



This paper attempts to develop:



Problem

The problem:

1. How the street network and street patterns are correlated with measurements of mobility and commute
2. Is there a simple way to reduce the complexity contained in the street network that captures mobility patterns
3. Is there a way to measure the constraints that streets infrastructure inflict to the agents in a city
4. How to extend the intersection between network theory and urban analysis without loosing the spatial component of the street net

Urban Morphology in Literature

- “Economic geography today is often considered to be less about the `space of places', where the success of places is attributed to characteristics of locations, and more about the 'the space of flows' where places derive their success from their position in networks” ACNA_2006

- There is an increasing effort to build “nomothetic studies concerned with the formulation of generalizations about the forces behind the spatial aspects of urban growth” TDMUM_1972

- Urban morphology and morphogenesis, activity and residence location choice, urban sprawl and the evolution of urban networks, are just a few of the important processes that have been discussed for a long time but that we now hope to understand quantitatively TSP_2014

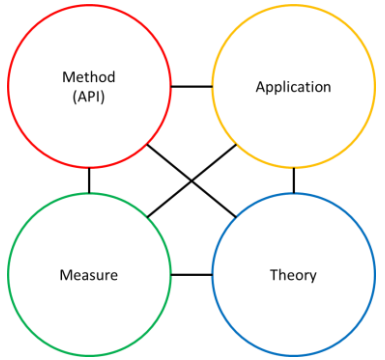
- “These works, although based on empirical observations, contain much subjectivity and our goal is to eliminate this subjective part to reach a non-ambiguous, scientific classification of these patterns. TSP_2014

Urban Morphology Implications

- Policy design
  - Hydrology
  - Facilities management
  - Transportation engineering
  - Business and service planning

- Economic Analysis and Urban Economics
  - Business locations
  - City competitiveness
  - Regional development

What to expect from this paper



- The use of computational tools to analyze urban morphology
  - GIS and Python
- A development of a potential measure to:
  - Evaluate complexity in street networks
  - Classify of cities
  - Develop theoretical measures of mobility
  - Analyze policy design in transportation and infrastructure
- Evidence of spatial concentration in cities fingerprint's:
  - Age of neighborhoods
  - Entropy of city planning
- A piece of theory on how cities' fingerprints relate with the street network

Computational Tools

https://github.com/andrespdlr/cities_fingerprints

Algorithm I

(an application)

JOURNAL OF THE ROYAL SOCIETY INTERFACE

A typology of street patterns

Rémi Louf, Marc Barthelemy

Published 8 October 2014. DOI: 10.1098/rsif.2014.0924

Abstract

We propose a quantitative method to classify cities according to their street pattern. We use the conditional probability distribution of shape factor of blocks with a given area and define what could constitute the 'fingerprint' of a city. Using a simple hierarchical clustering method, these fingerprints can then serve as a basis for a typology of cities. We apply this method to a set of 131 cities in the world, and at an intermediate level of the dendrogram, we observe four large families of cities characterized by different abundances of blocks of a certain area and shape. At a lower level of the classification, we find that most European cities and American cities in our sample fall in their own sub-category, highlighting quantitatively the differences between the typical layouts of cities in both regions. We also show with the example of New York and its different boroughs, that the fingerprint of a city can be seen as the sum of the ones characterizing the different neighbourhoods inside a city. This method provides a quantitative comparison of urban street patterns, which could be helpful for a better understanding of the causes and mechanisms behind their distinct shapes.

Classification method

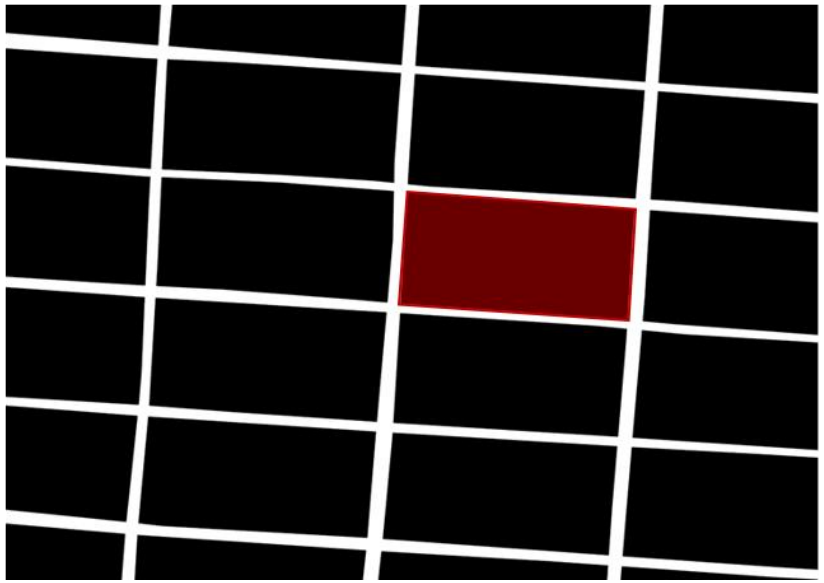
A = Area of the block

Ac = Area of the circumscribed circle C

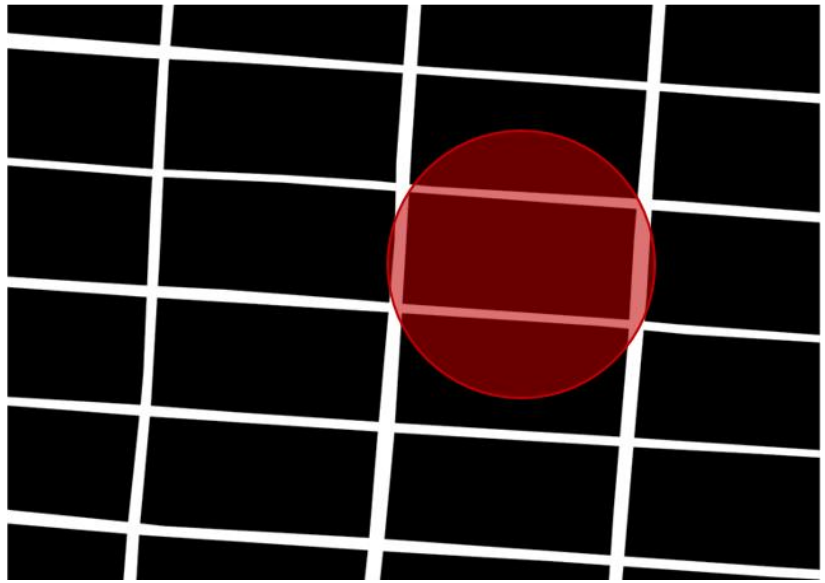
$\Phi = A/Ac$

$P(\Phi)$ = Distribution

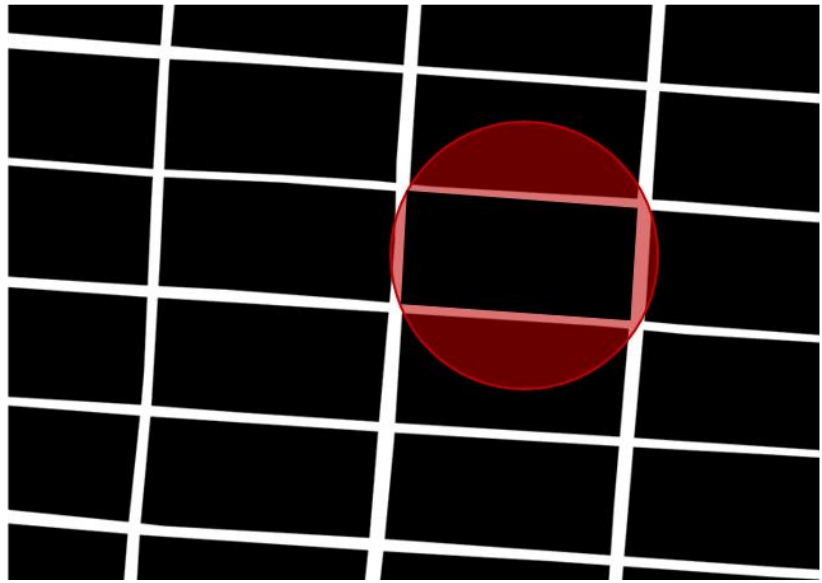
1 | A

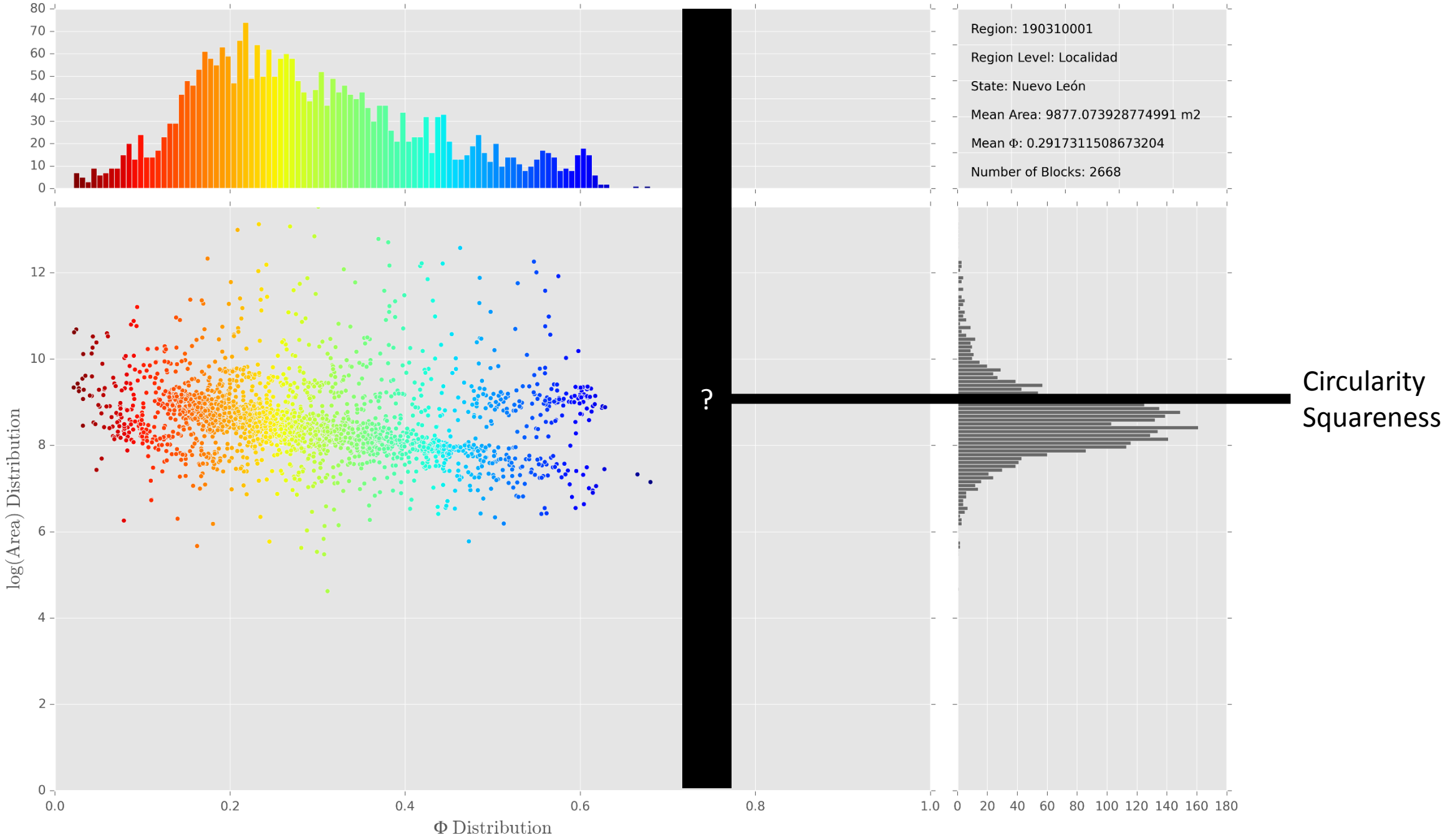


2 | AC



3 | Φ




Region: 190310001
Region Level: Localidad
State: Nuevo León
Mean Area: 9877.073928774991 m2
Mean Φ: 0.2917311508673204
Number of Blocks: 2668
log(Area) Distribution
Φ Distribution
?
Circularity
Squareness

an extension

- Is there evidence of spatial concentration in Φ?
- Moran's I
  - Measures spatial autocorrelation
  - Evaluates if spatial patterns are clustered, dispersed or randomly distributed.
- The fact that Φ is not randomly distributed implies certain patterns in urban planning and infrastructure design over time.

The Moran's I statistic for spatial autocorrelation is given as:

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2} \quad (1)$$

where z_i is the deviation of an attribute for feature i from its mean $(x_i - \bar{X})$, $w_{i,j}$ is the spatial weight between feature i and j, n is equal to the total number of features, and S_0 is the aggregate of all the spatial weights:

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} \quad (2)$$

The z_I-score for the statistic is computed as:

$$z_I = \frac{I - \mathrm{E}[I]}{\sqrt{\mathrm{V}[I]}} \quad (3)$$

where:

$$\mathrm{E}[I] = -1/(n-1) \quad (4)$$

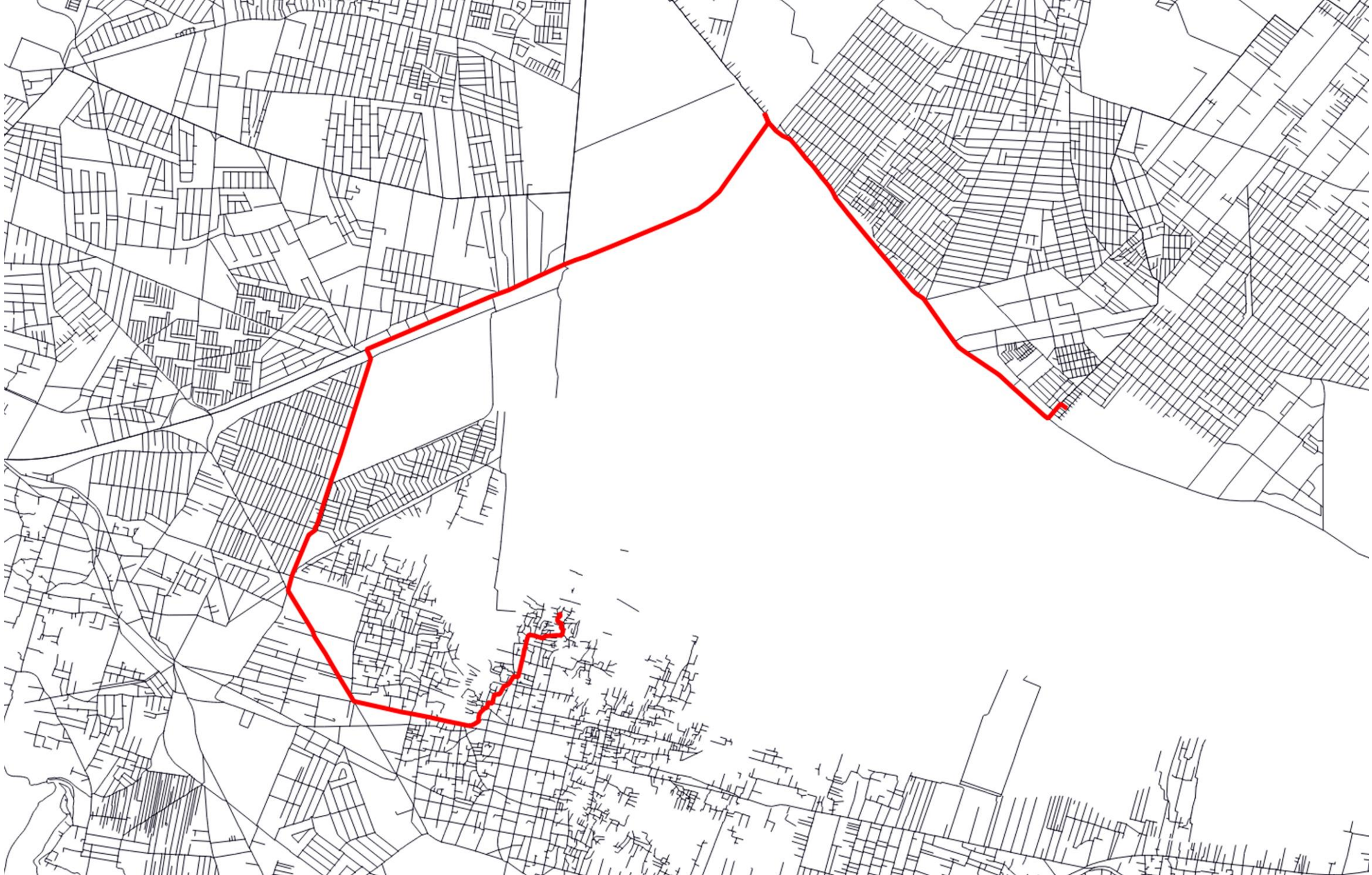
$$\mathrm{V}[I] = \mathrm{E}[I^2] - \mathrm{E}[I]^2 \quad (5)$$

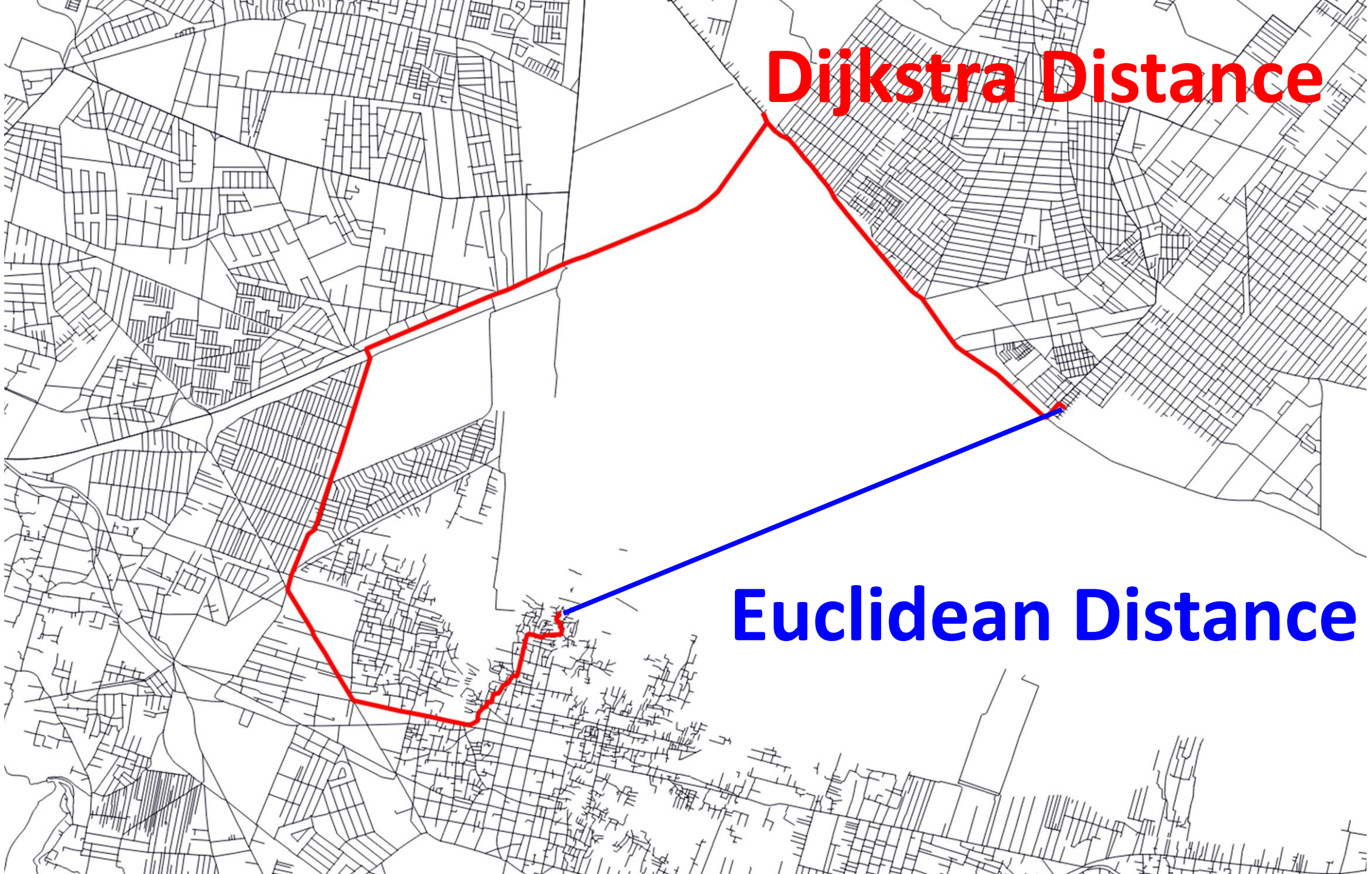
Source: http://arcg.is/1O9l8jF

Algorithm II

(a development)

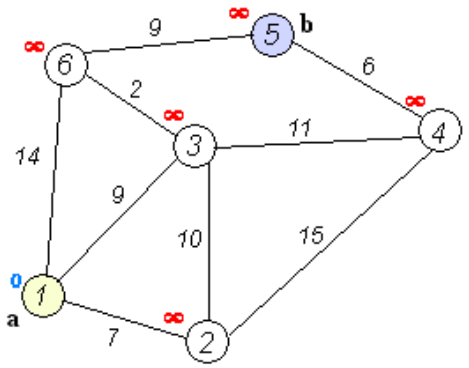
MSRN_2006 “The connection and arrangement of a road network is usually abstracted in network analysis as a directed planar graph G = {V, E}, where V is a collection of nodes (vertices) connected by directional links (edges) E (links are directional when a link from node R to node S is distinct from a link from S to R). Physically, a two-way road consists of two adjacent and opposite one-directional links.”



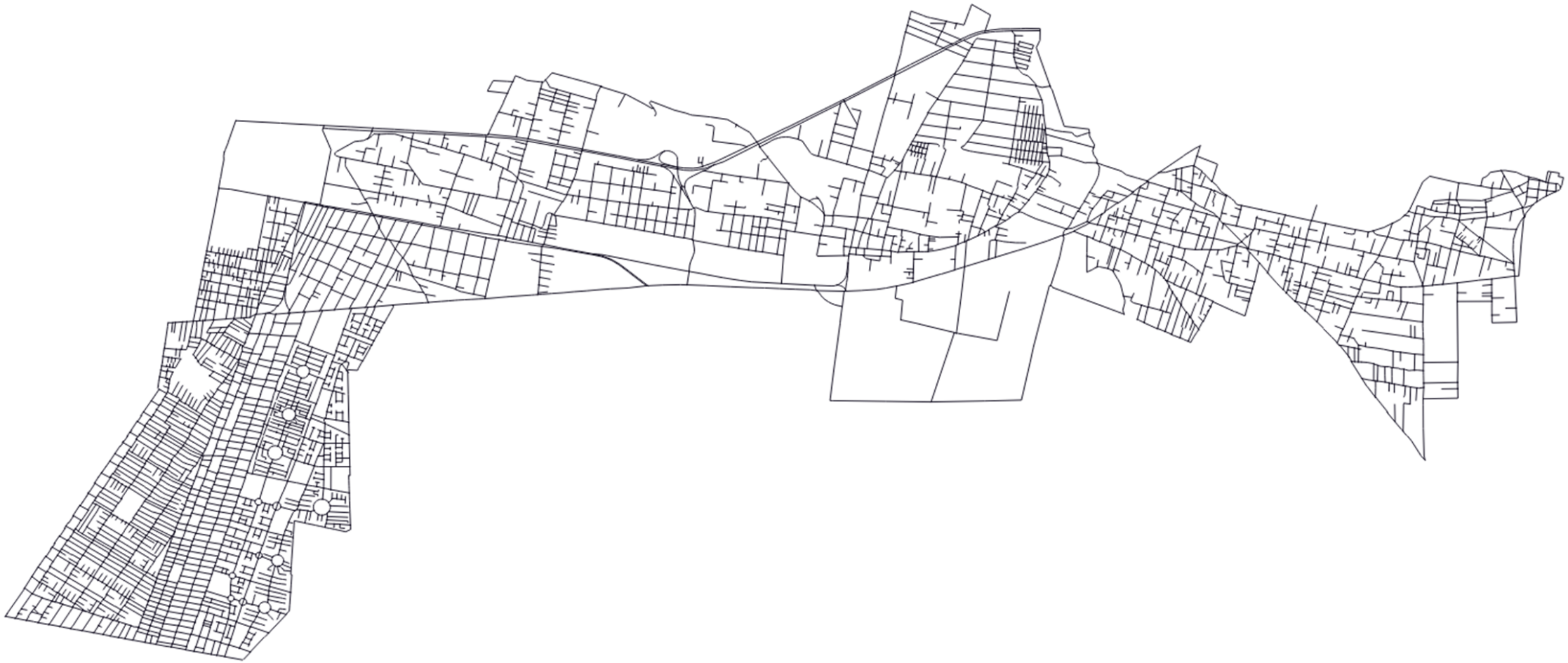

Dijkstra Distance
Euclidean Distance

Algorithm II = OLS estimation of:

Dijkstra = β*Euclidean



Shortest Path Algorithm
Image source: Wikipedia



$$C(n,r) = n! / (r! (n - r)!)$$

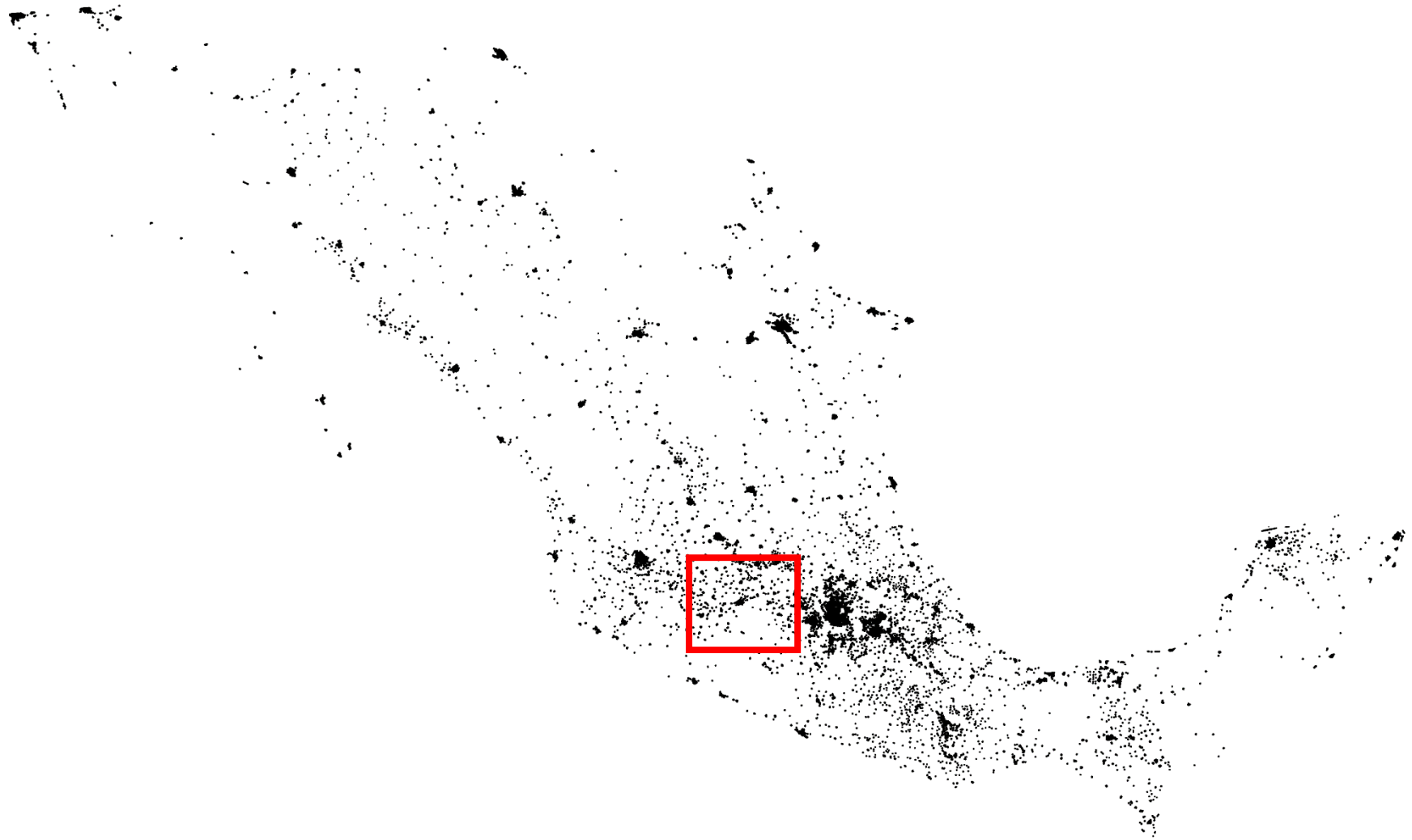
$$C(100,2) = 100! / (2! (100 - 2)!) = 4,950$$

$$C(57,2) = 1,596 \text{ distances}$$

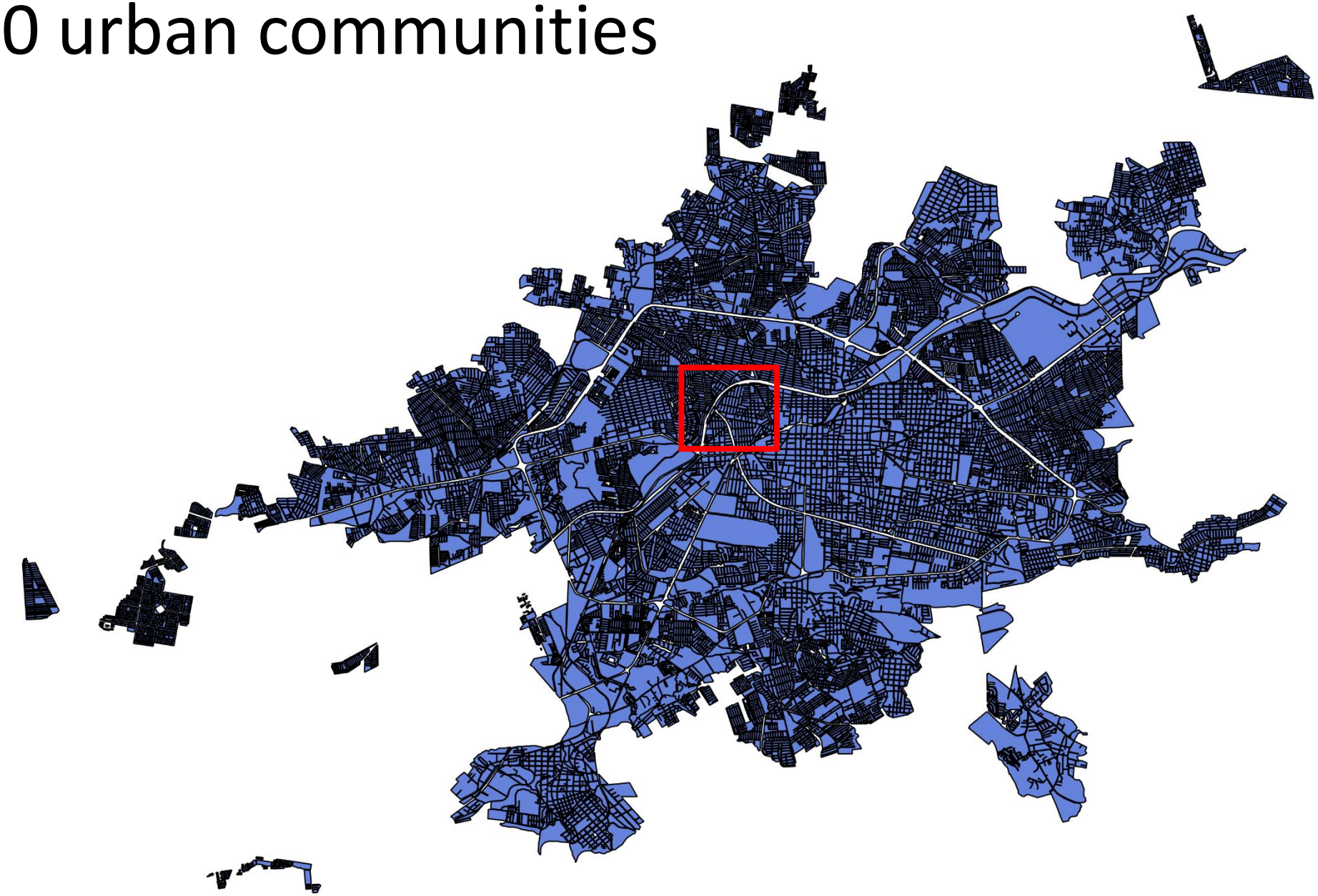
Simulations

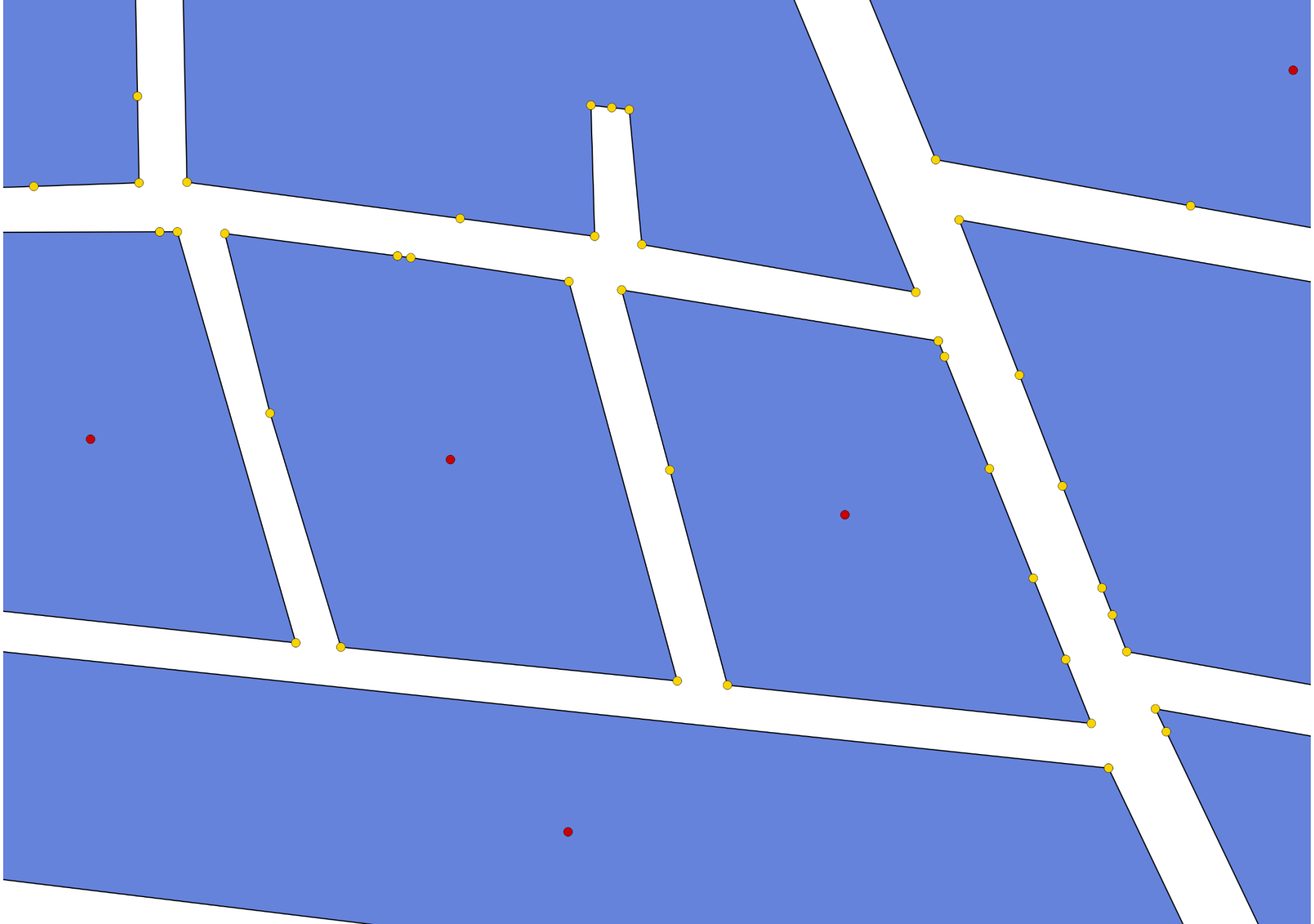
Algorithm I

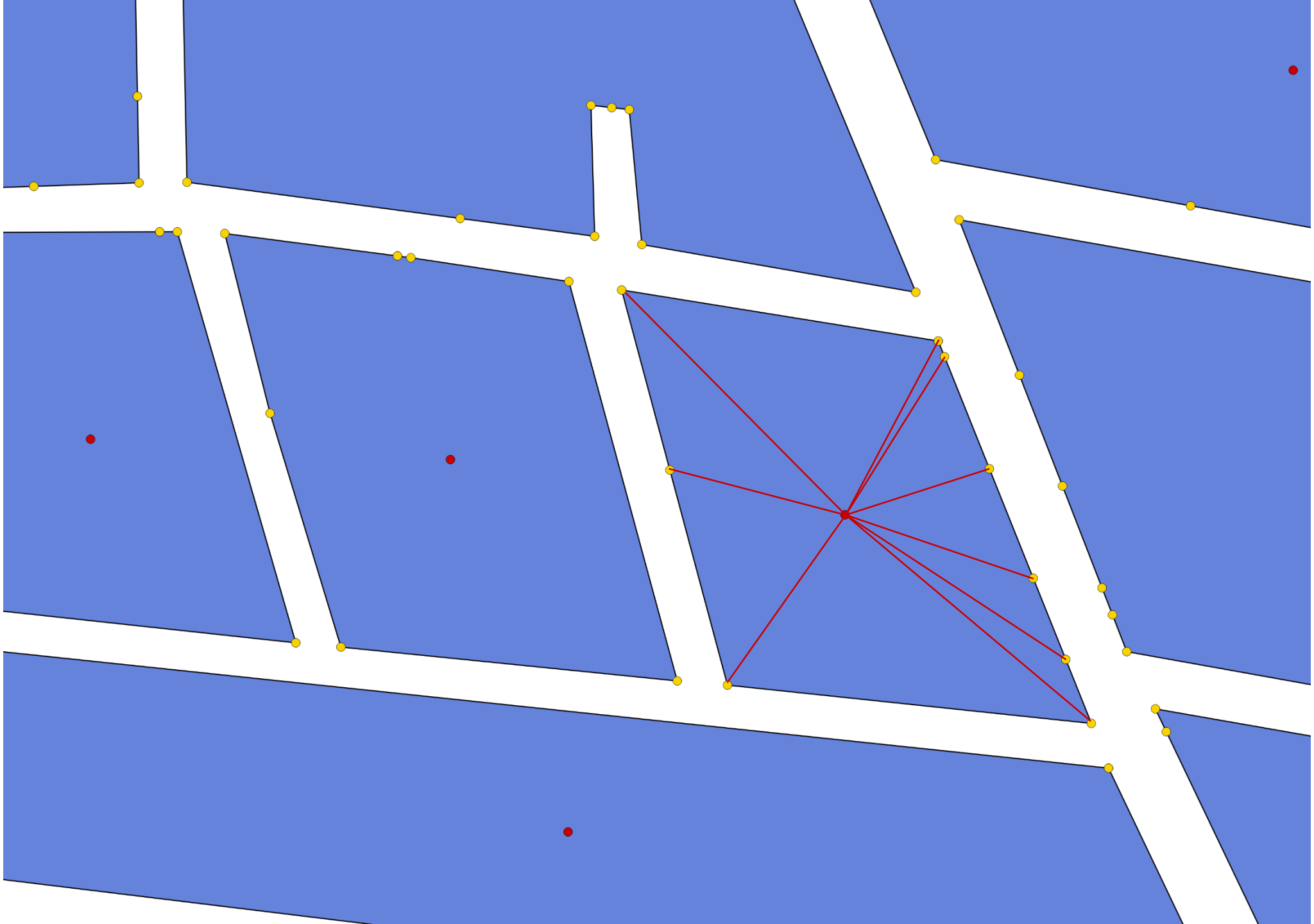
1,456,596 urban blocks

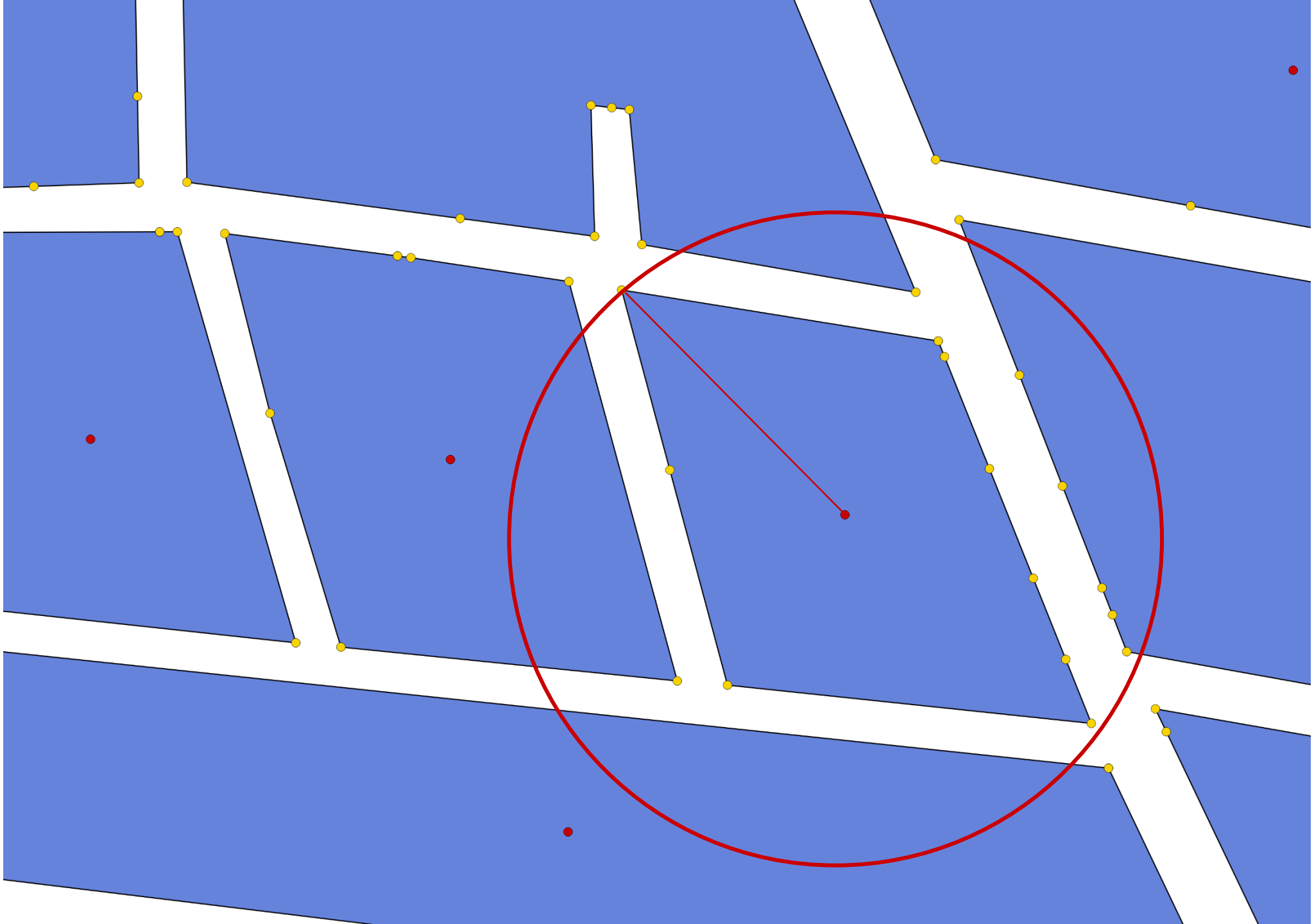


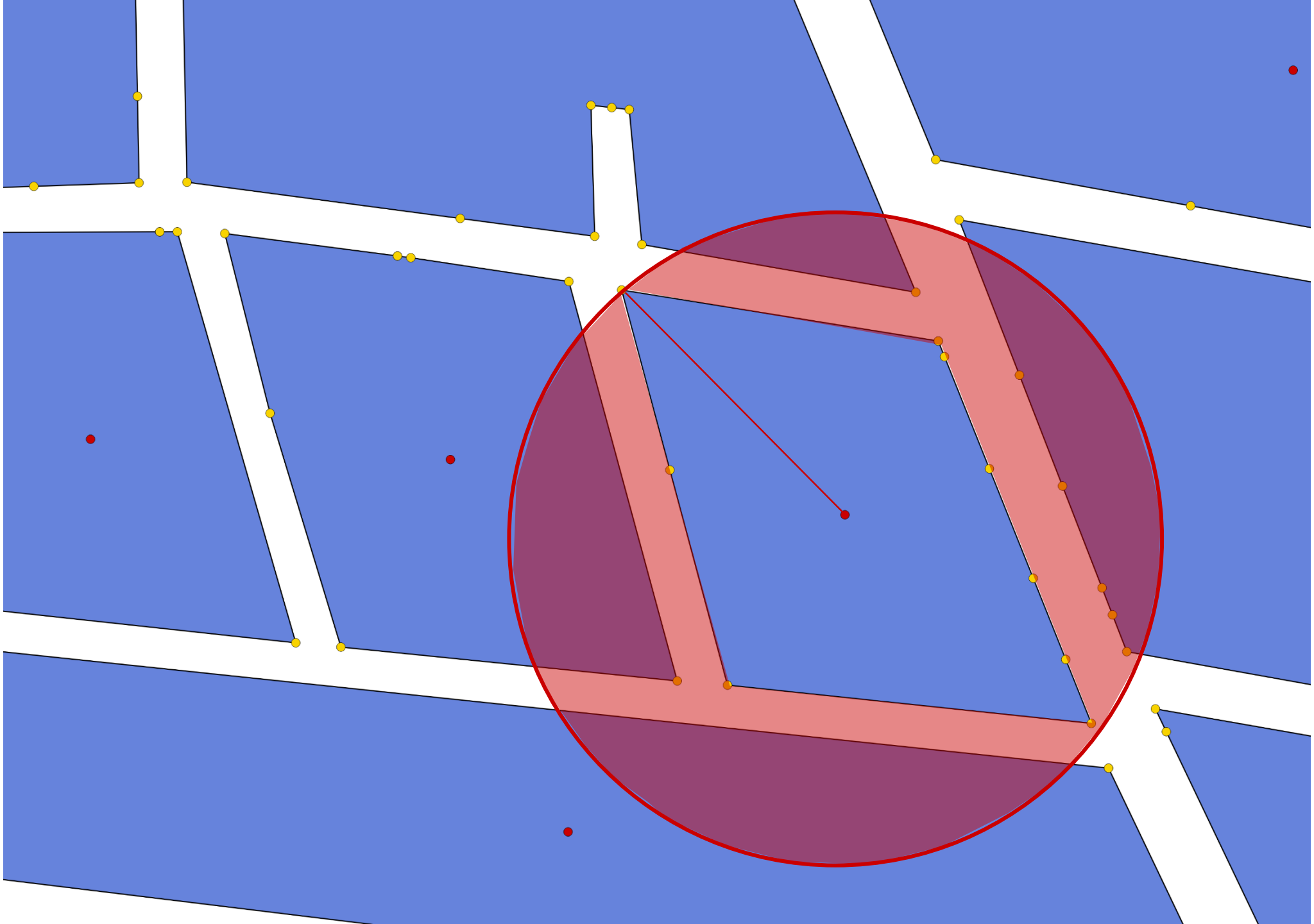
+ 4,500 urban communities

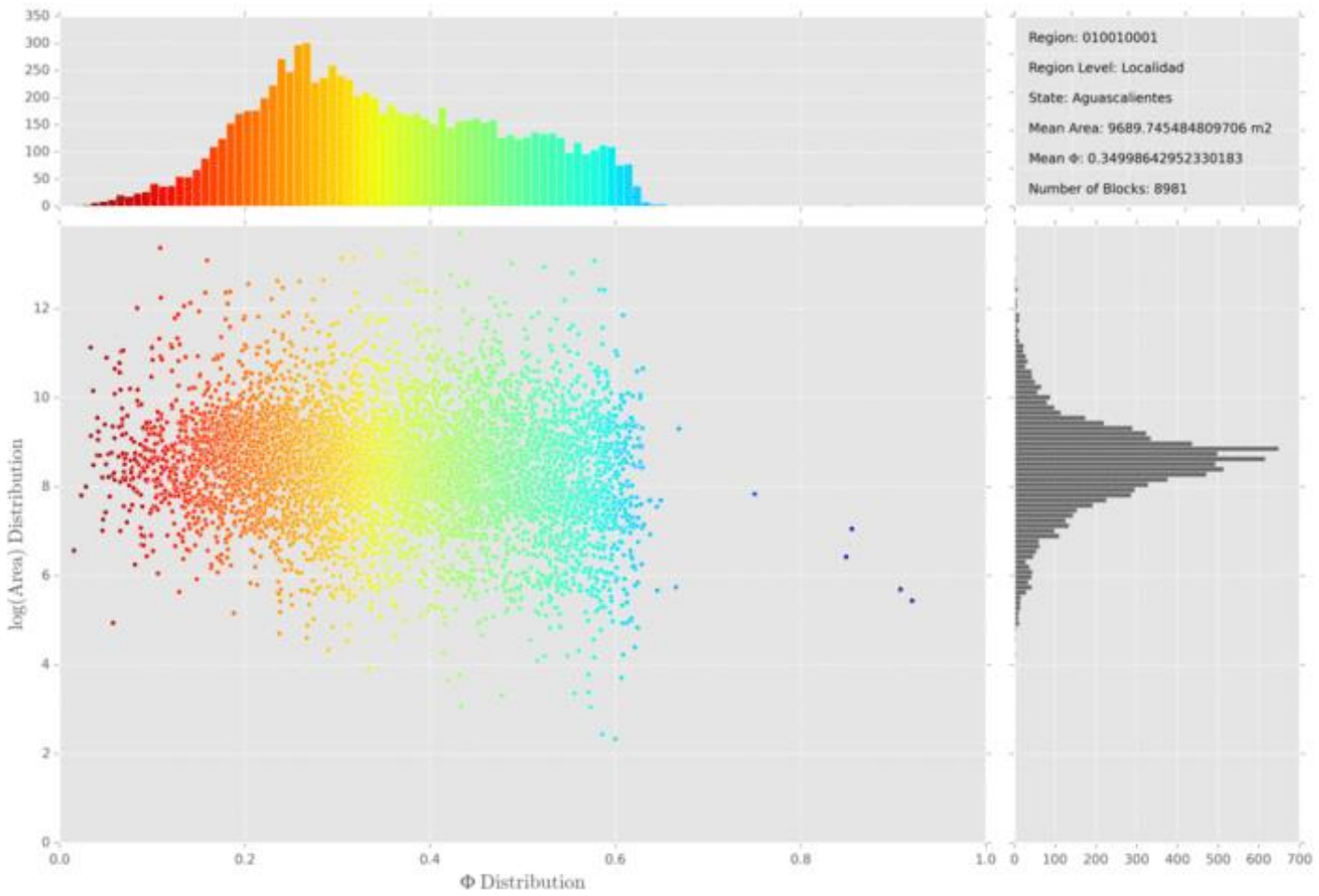




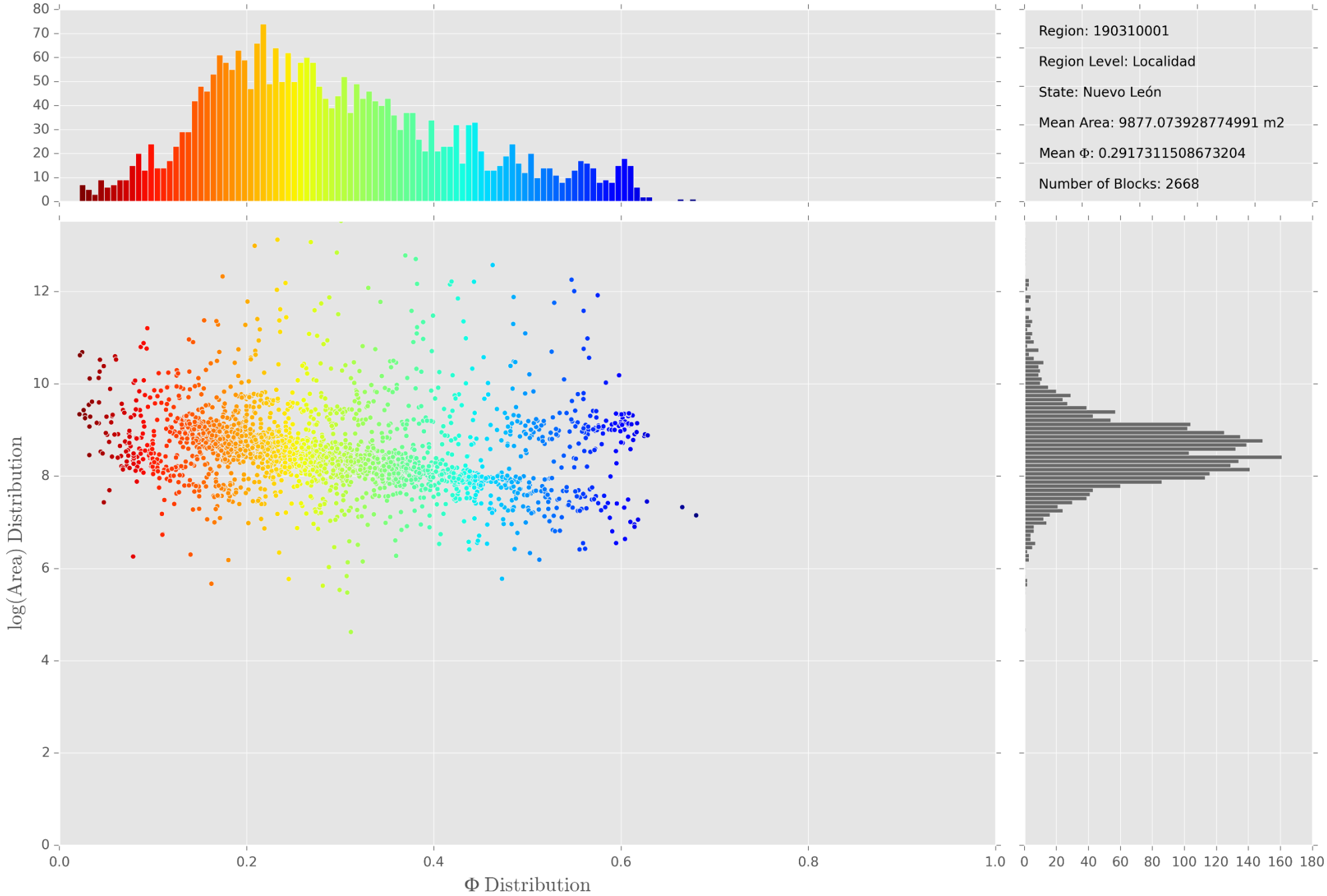




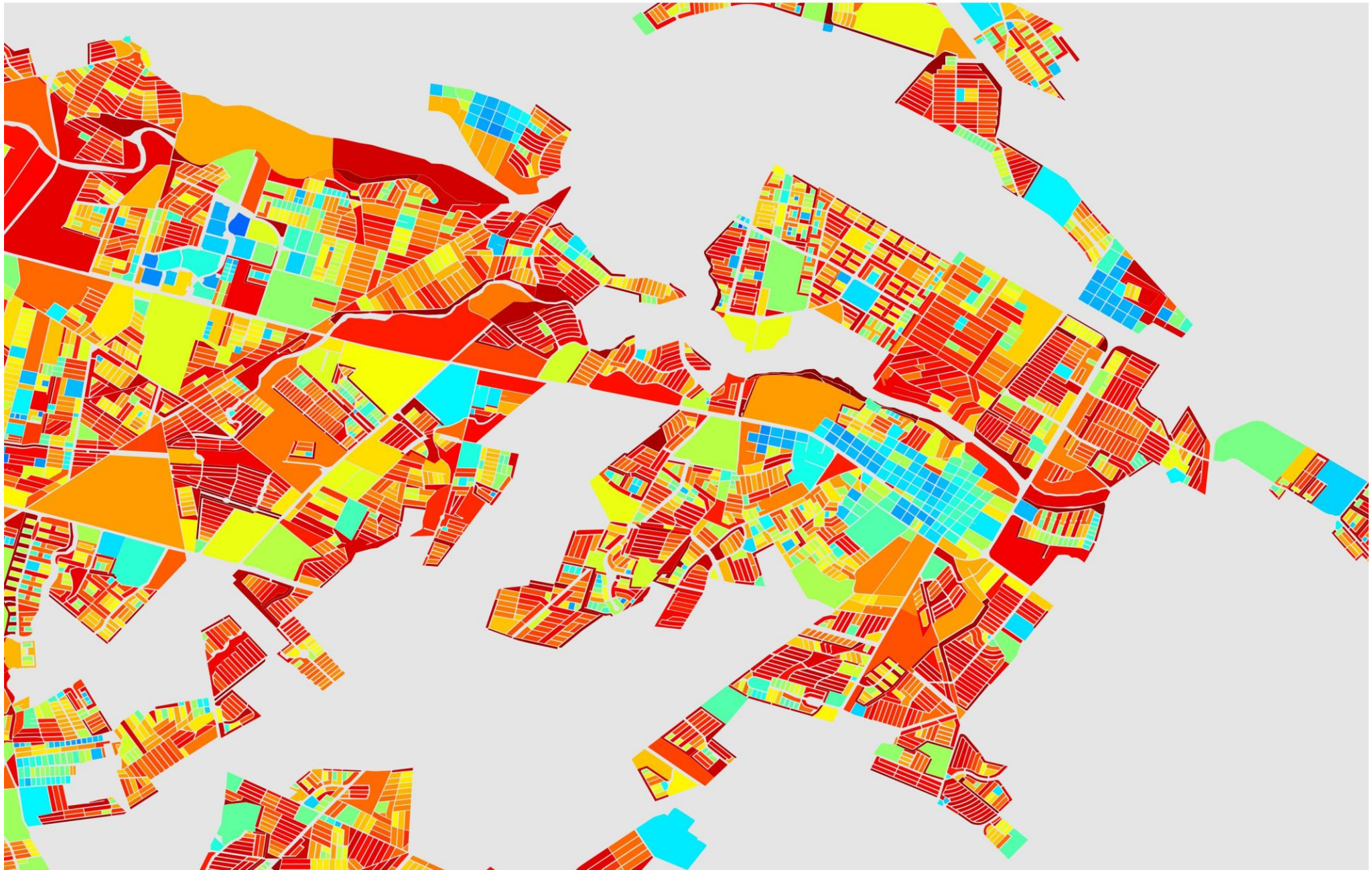




Examples		
	Φ	β
5 Lowest	190310001	150020015
	190060001	080210001
	150250001	300390001
	150580001	201840001
	190210001	211560001
5 Highest	320100001	141010001
	090150001	090150001
	301180001	150130001
	310500001	270040001
	260420001	140670001

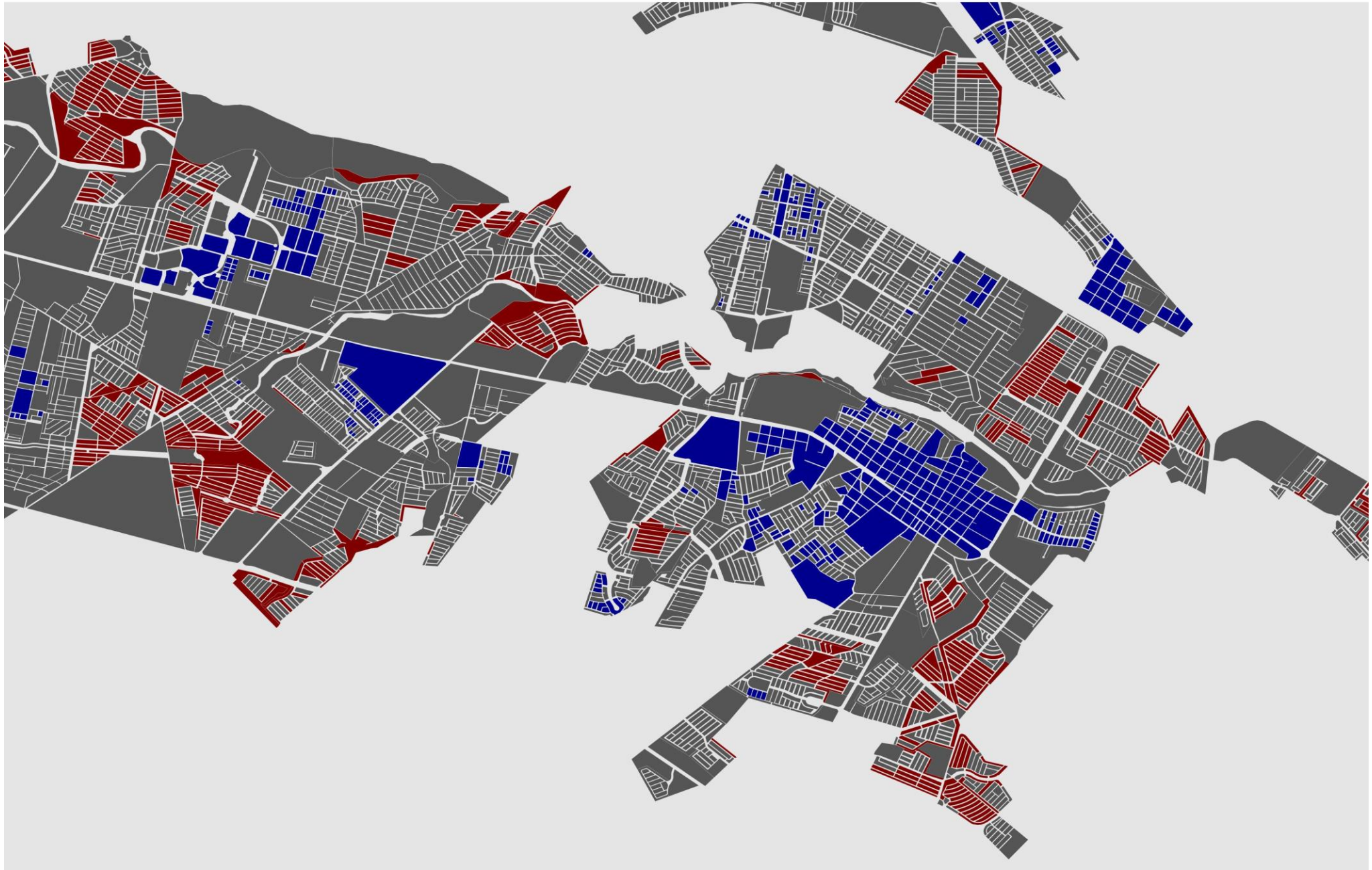

Region: 190310001
Region Level: Localidad
State: Nuevo León
Mean Area: 9877.073928774991 m2
Mean Φ: 0.2917311508673204
Number of Blocks: 2668
log(Area) Distribution
Φ Distribution
0
2
4
6
8
10
12
0.0
0.2
0.4
0.6
0.8
1.0
0
20
40
60
80
100
120
140
160
180

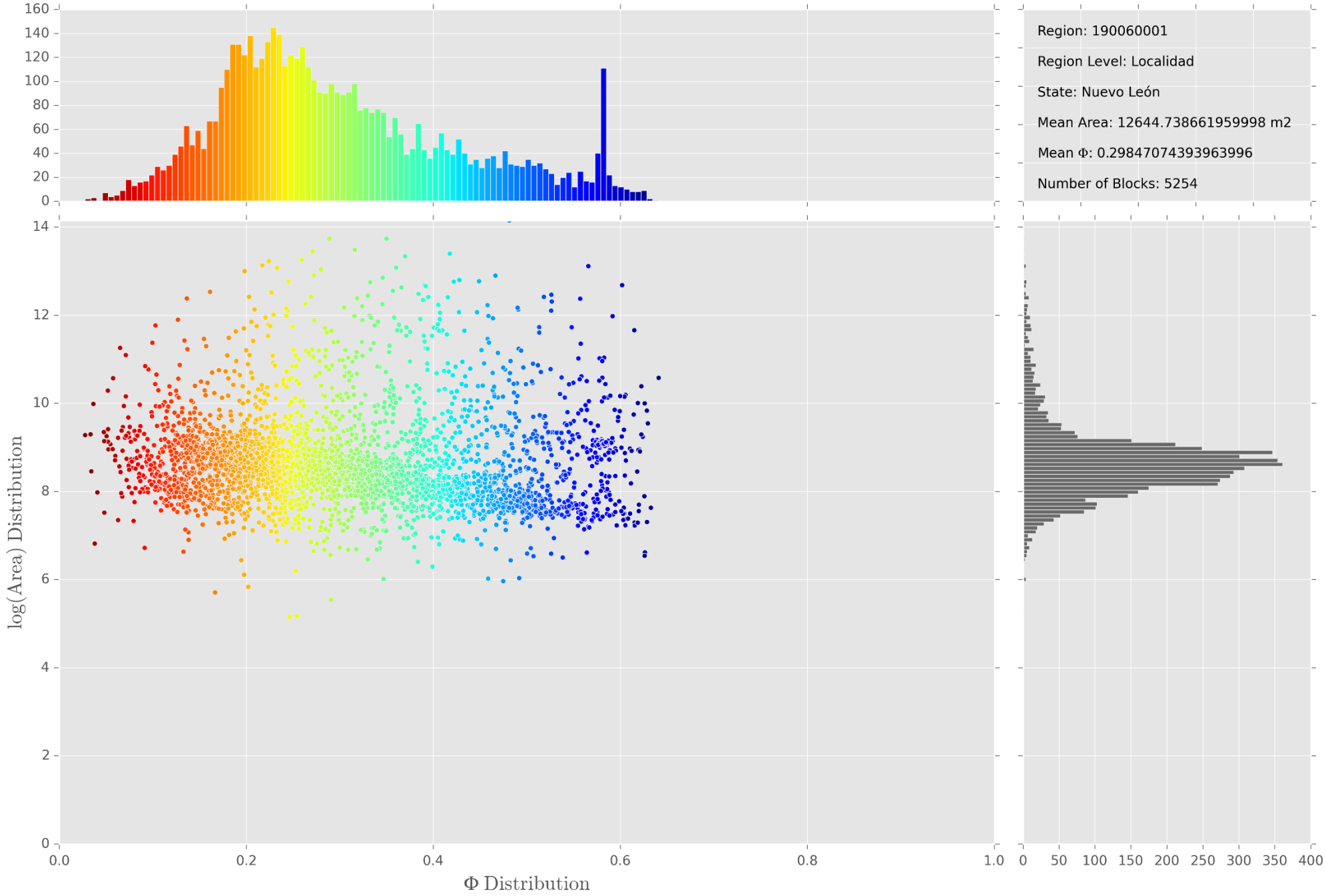
Region: 190310001 Juárez



Region: 190310001 Juárez

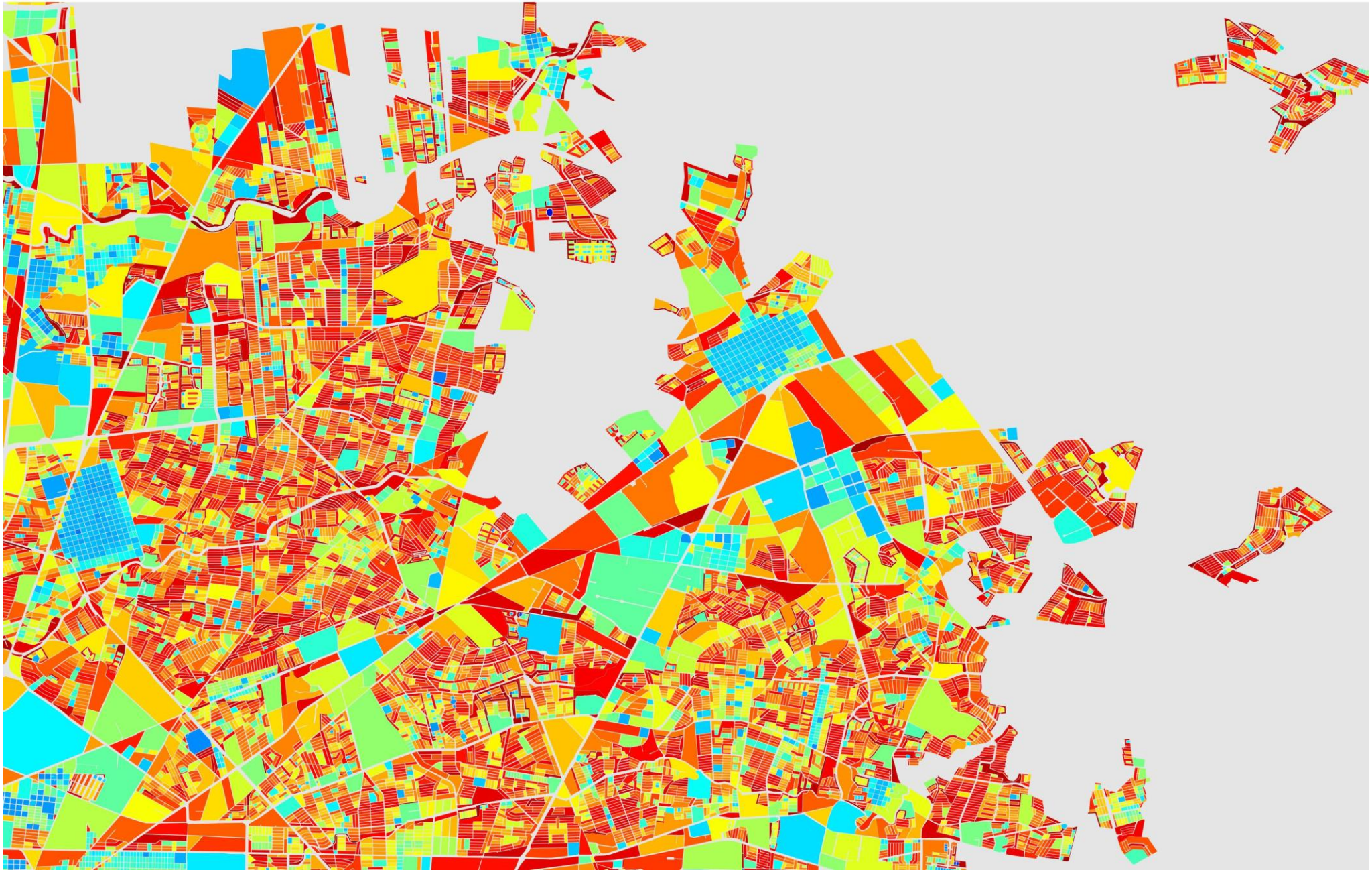
Spatial Concentration of Φ (Moran's I) HH LL




Region: 190060001
Region Level: Localidad
State: Nuevo León
Mean Area: 12644.738661959998 m2
Mean Φ: 0.29847074393963996
Number of Blocks: 5254
log(Area) Distribution
Φ Distribution
0
2
4
6
8
10
12
14
0.0
0.2
0.4
0.6
0.8
1.0
0
20
40
60
80
100
120
140
160
0
50
100
150
200
250
300
350
400

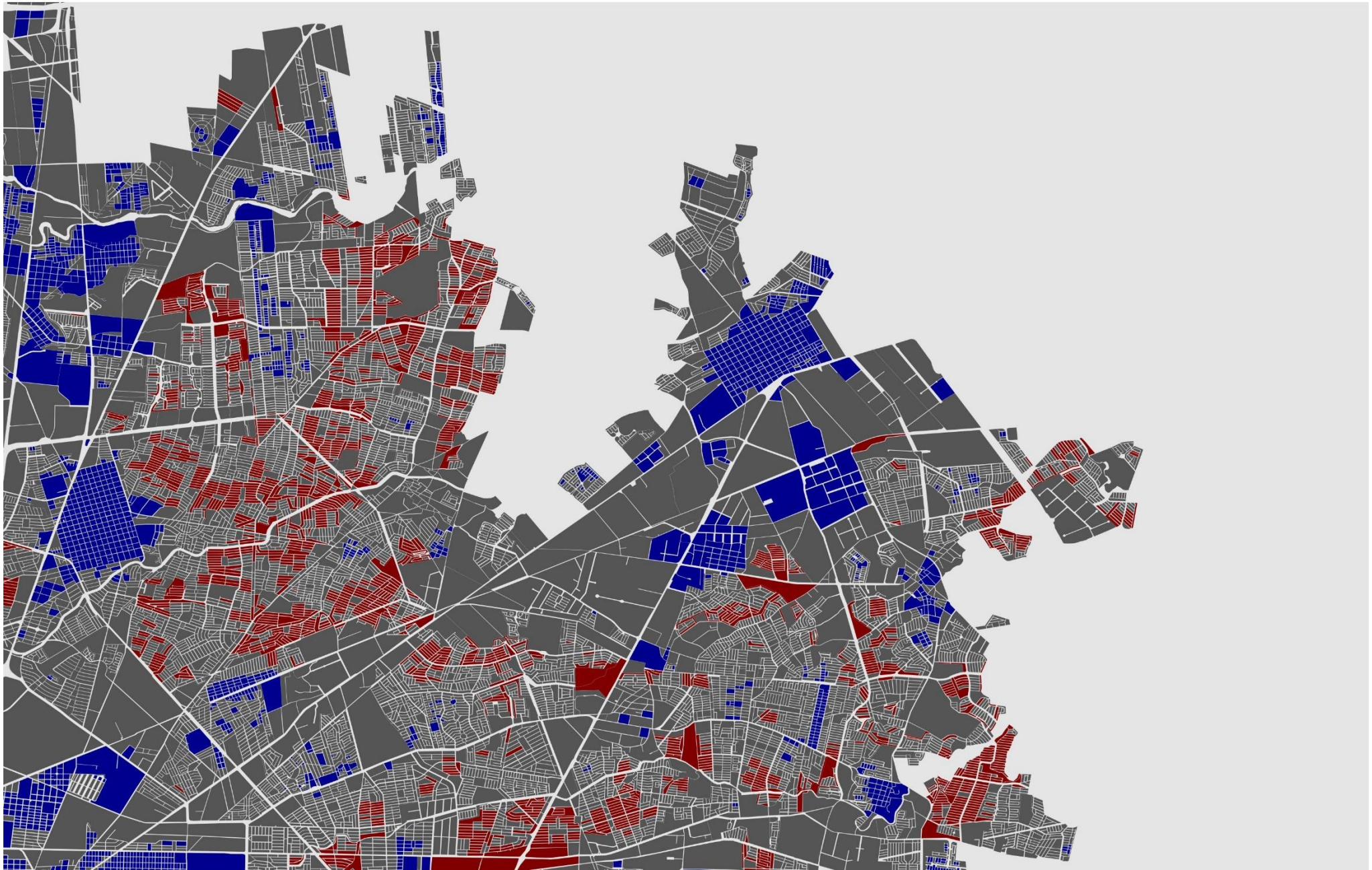
Region: 190060001 Apodaca

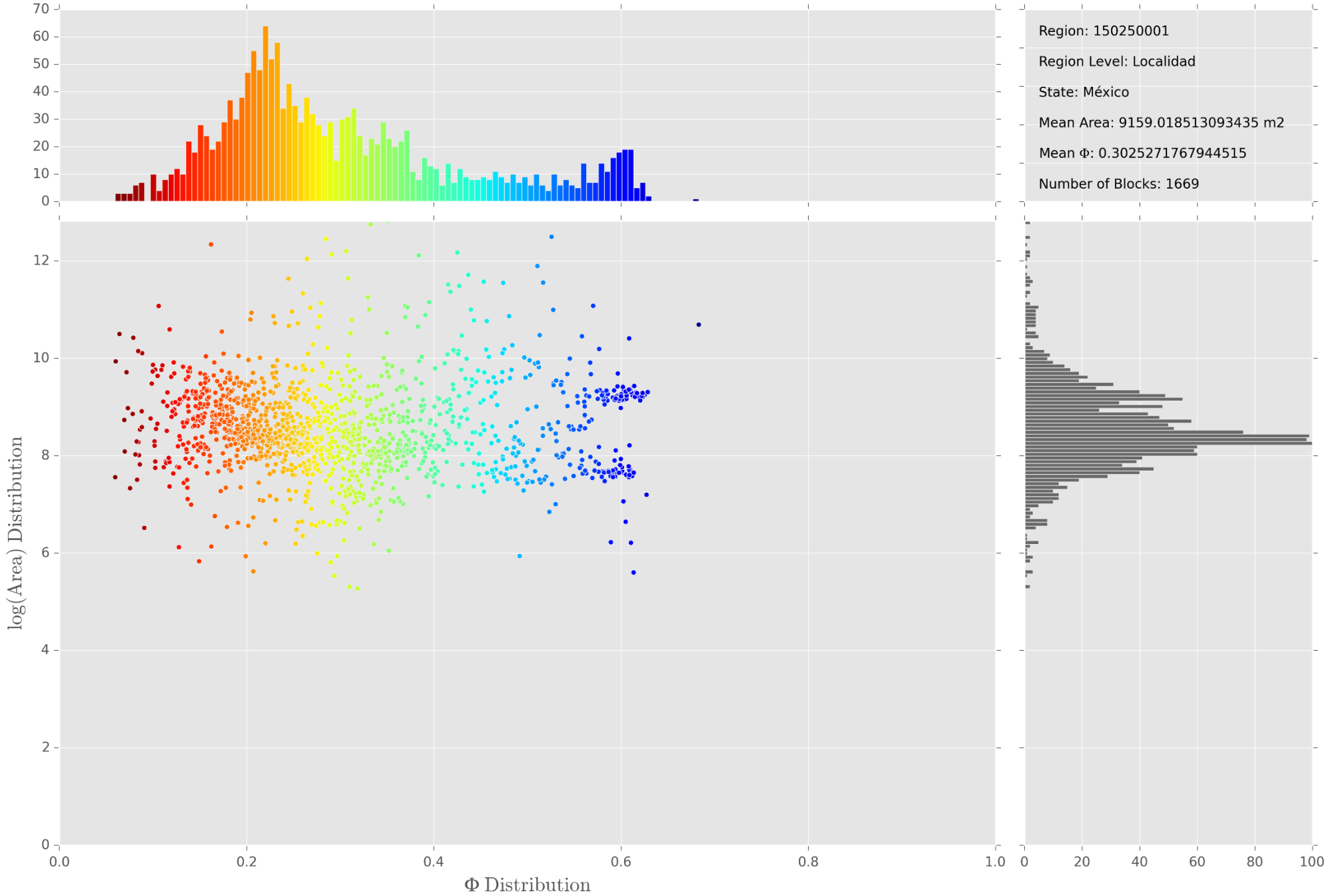
- Φ +



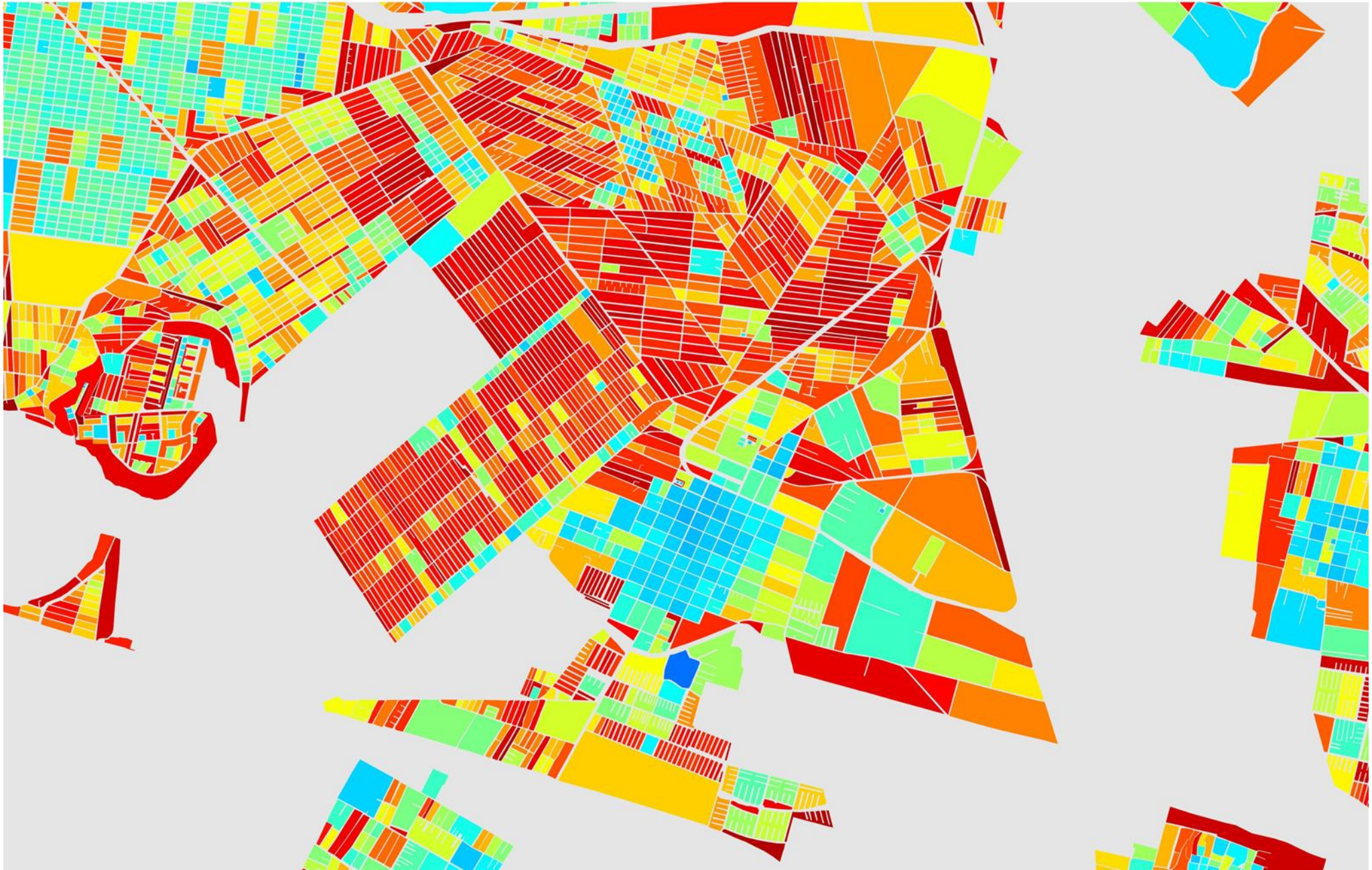
Region: 190060001 Apodaca

Spatial Concentration of Φ (Moran's I) HH LL



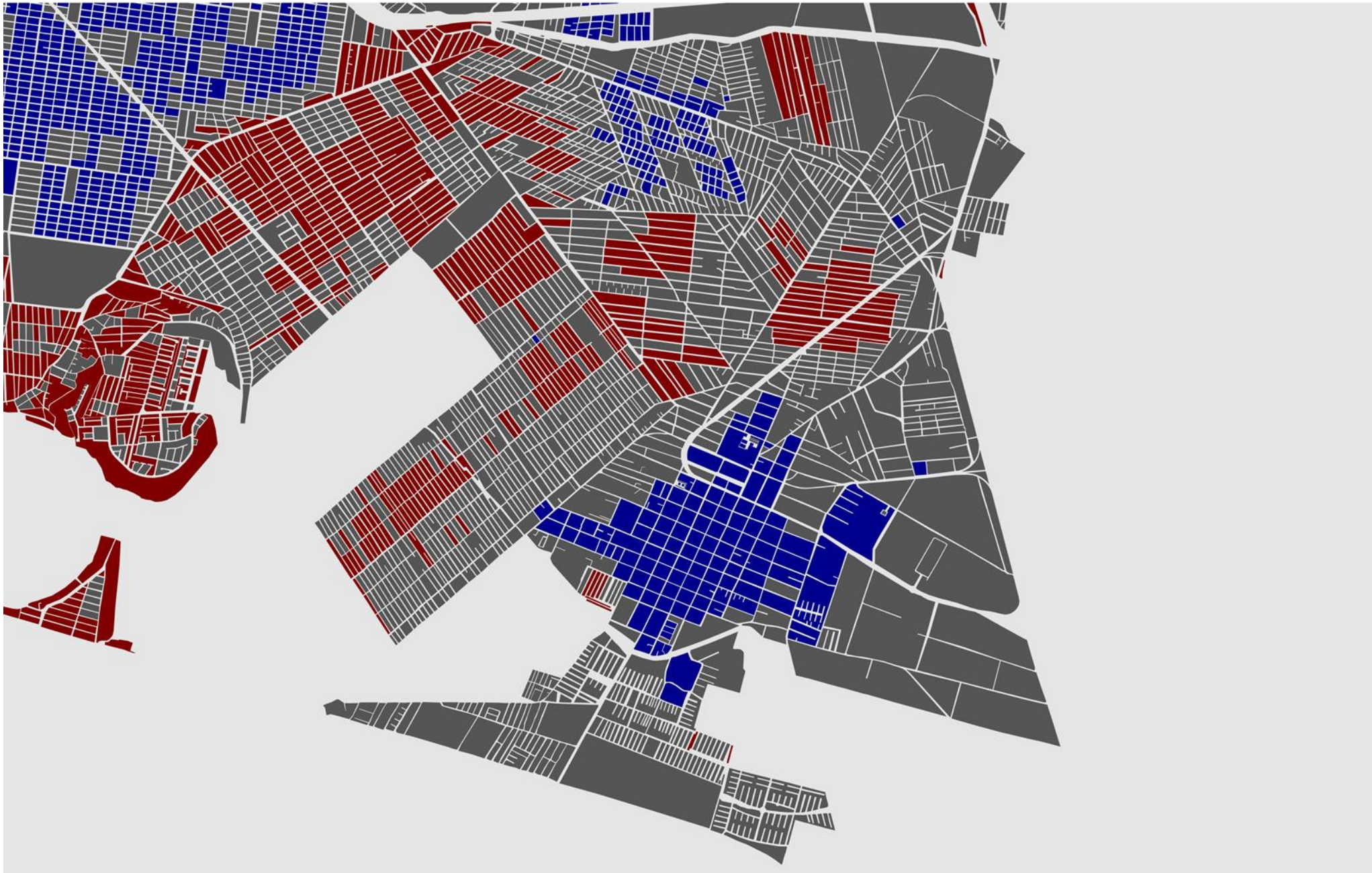

Region: 150250001
Region Level: Localidad
State: México
Mean Area: 9159.018513093435 m2
Mean Φ: 0.3025271767944515
Number of Blocks: 1669
log(Area) Distribution
Φ Distribution
0
2
4
6
8
10
12
0.0
0.2
0.4
0.6
0.8
1.0
0
20
40
60
80
100

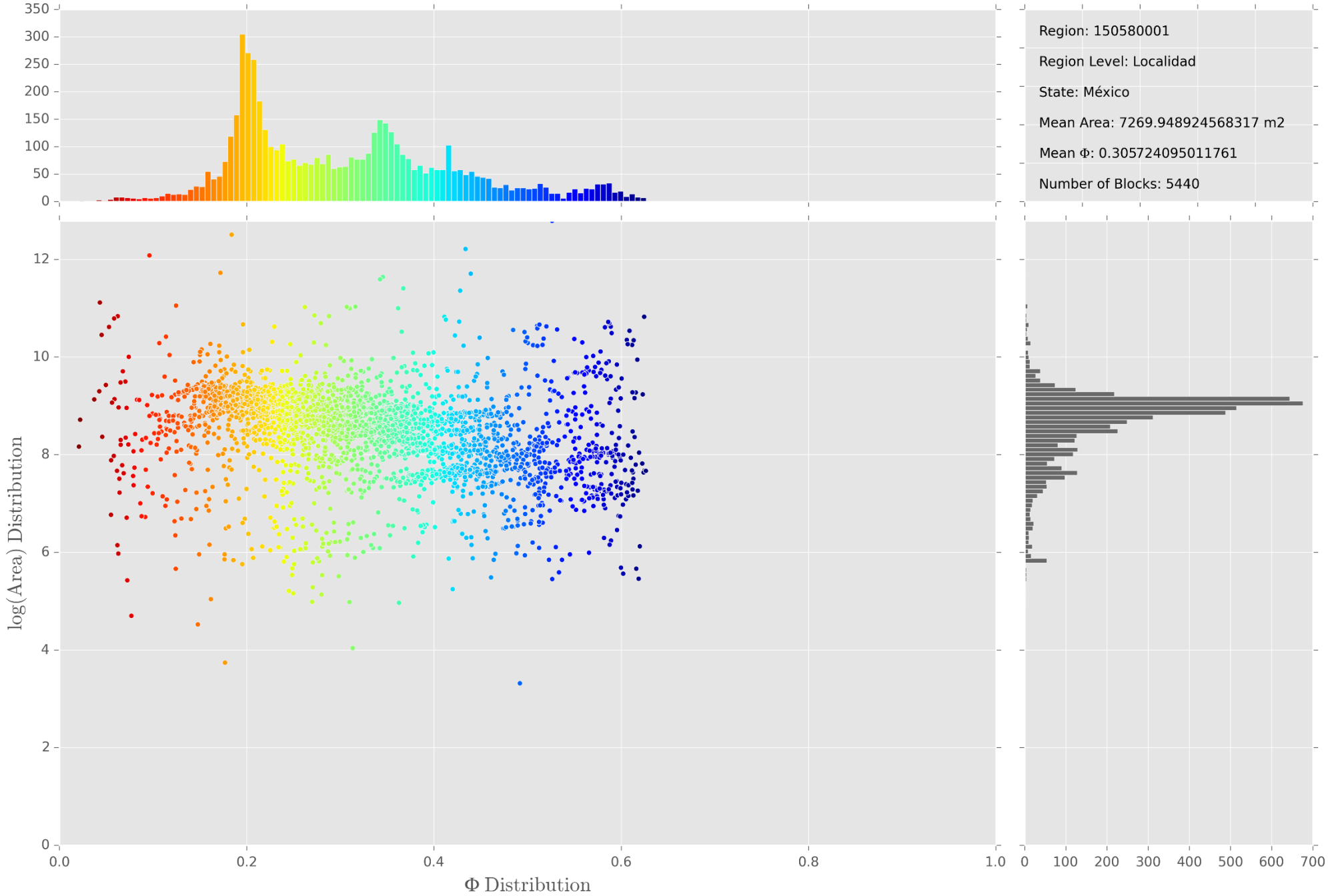
Region: 150250001 Chalco



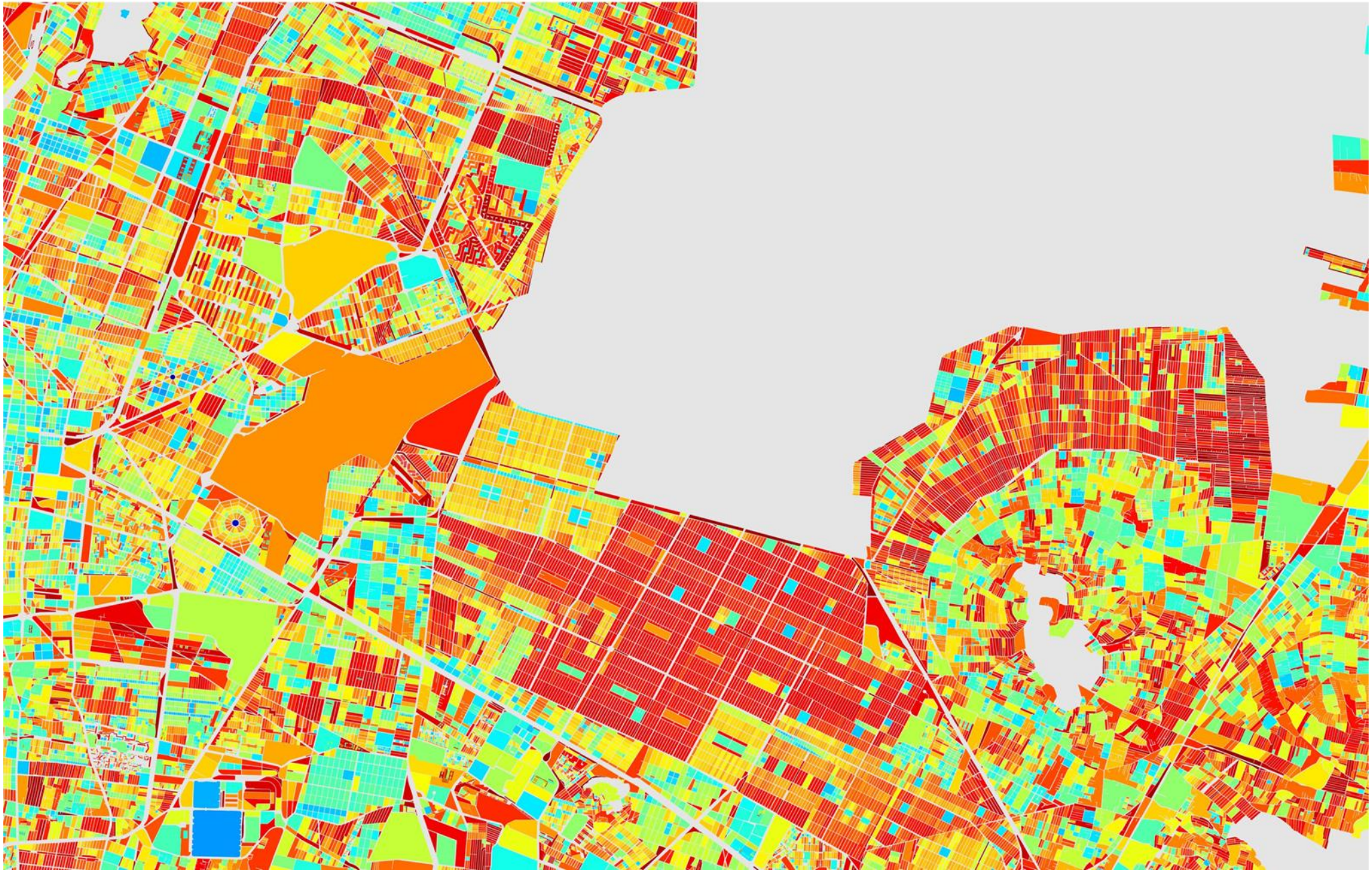
Region: 150250001 Chalco

Spatial Concentration of Φ (Moran's I) HH LL



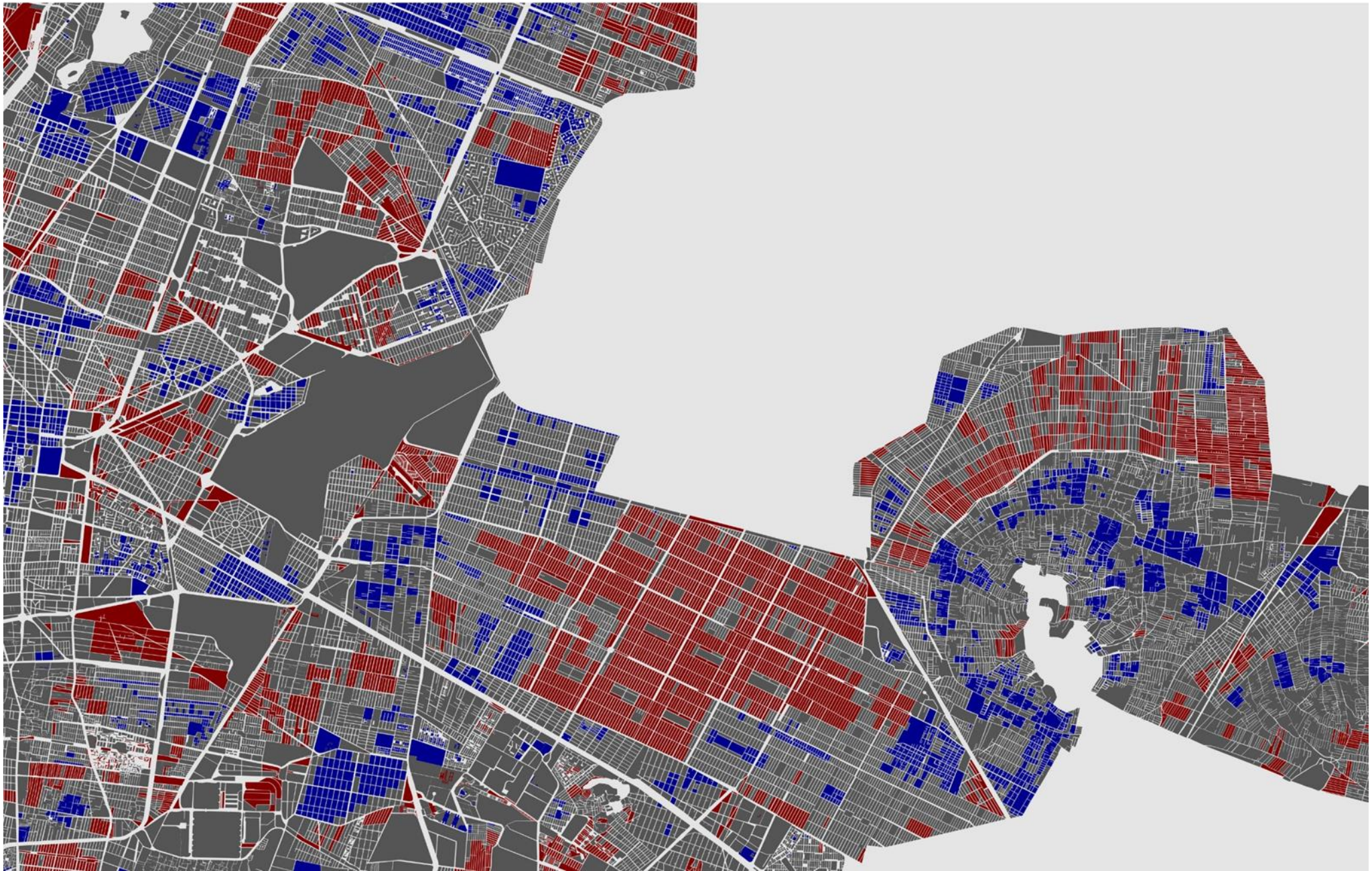

Region: 150580001
Region Level: Localidad
State: México
Mean Area: 7269.948924568317 m2
Mean Φ: 0.305724095011761
Number of Blocks: 5440
log(Area) Distribution
Φ Distribution
0.0
0.2
0.4
0.6
0.8
1.0
0
2
4
6
8
10
12
0
50
100
150
200
250
300
350
0
100
200
300
400
500
600
700

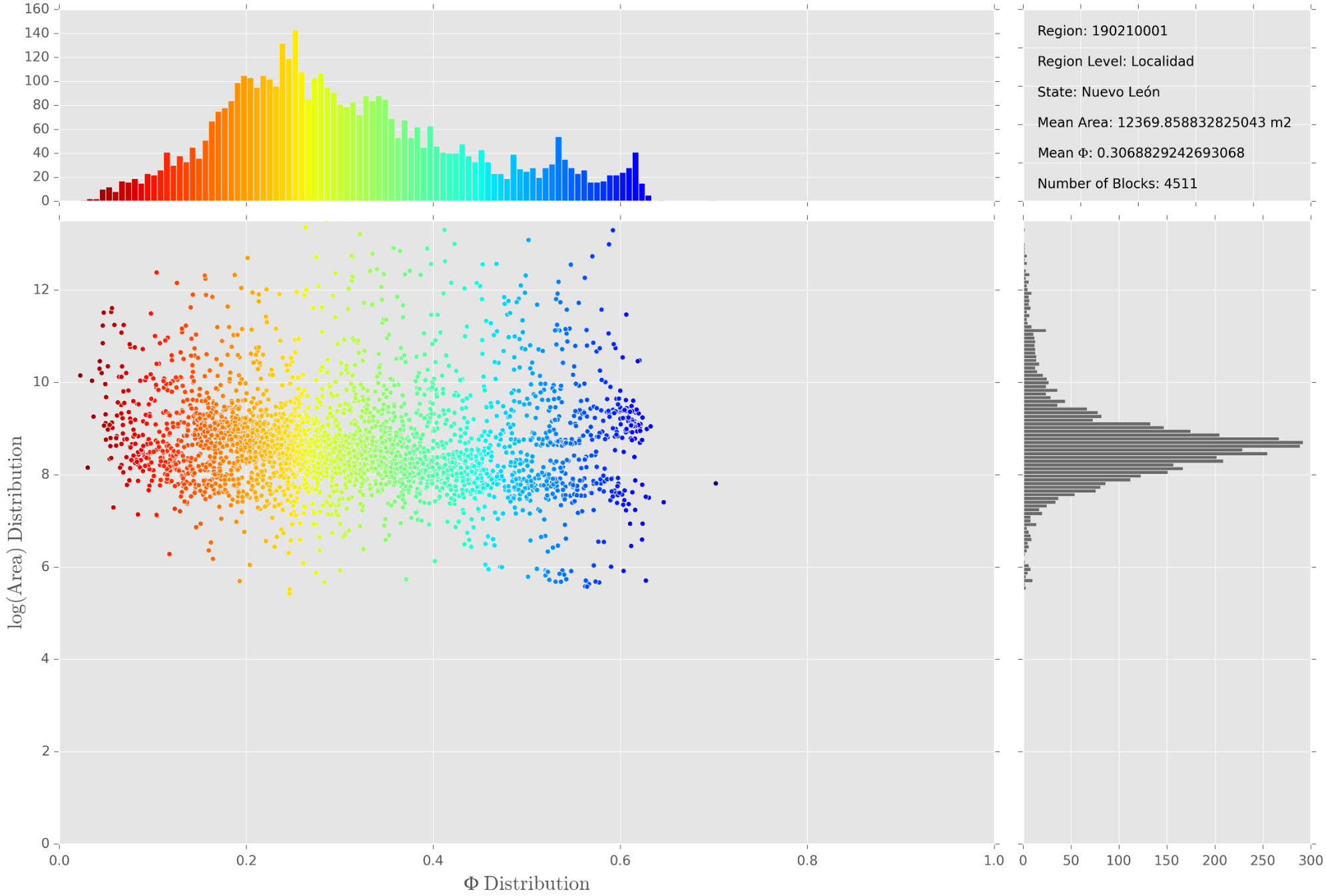
Region: 150580001 Nezahualcóyotl



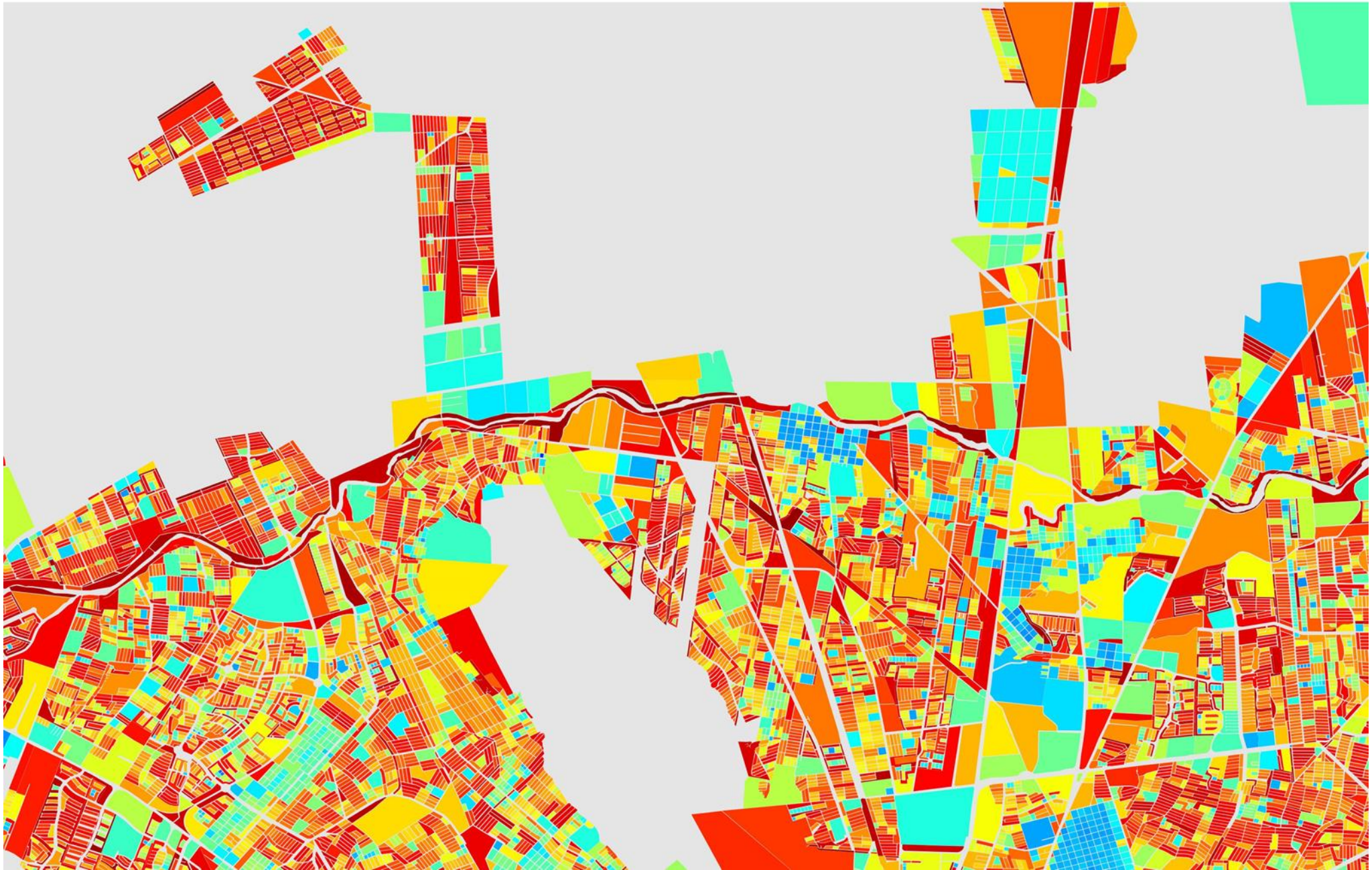
Region: 150580001 Nezahualcóyotl

Spatial Concentration of Φ (Moran's I) HH LL



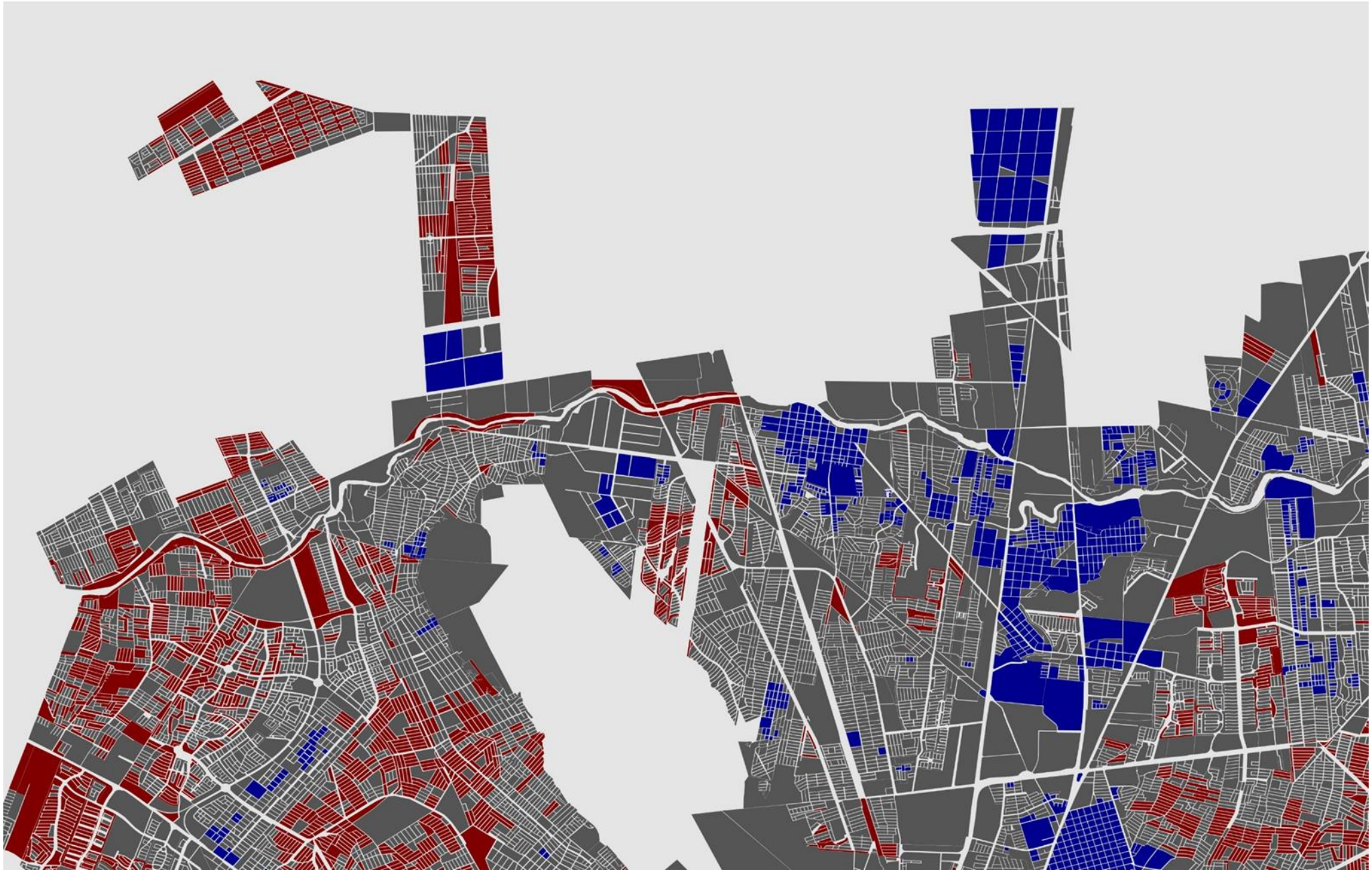

Region: 190210001
Region Level: Localidad
State: Nuevo León
Mean Area: 12369.858832825043 m2
Mean Φ: 0.3068829242693068
Number of Blocks: 4511
log(Area) Distribution
Φ Distribution
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150
200
250
300
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
160

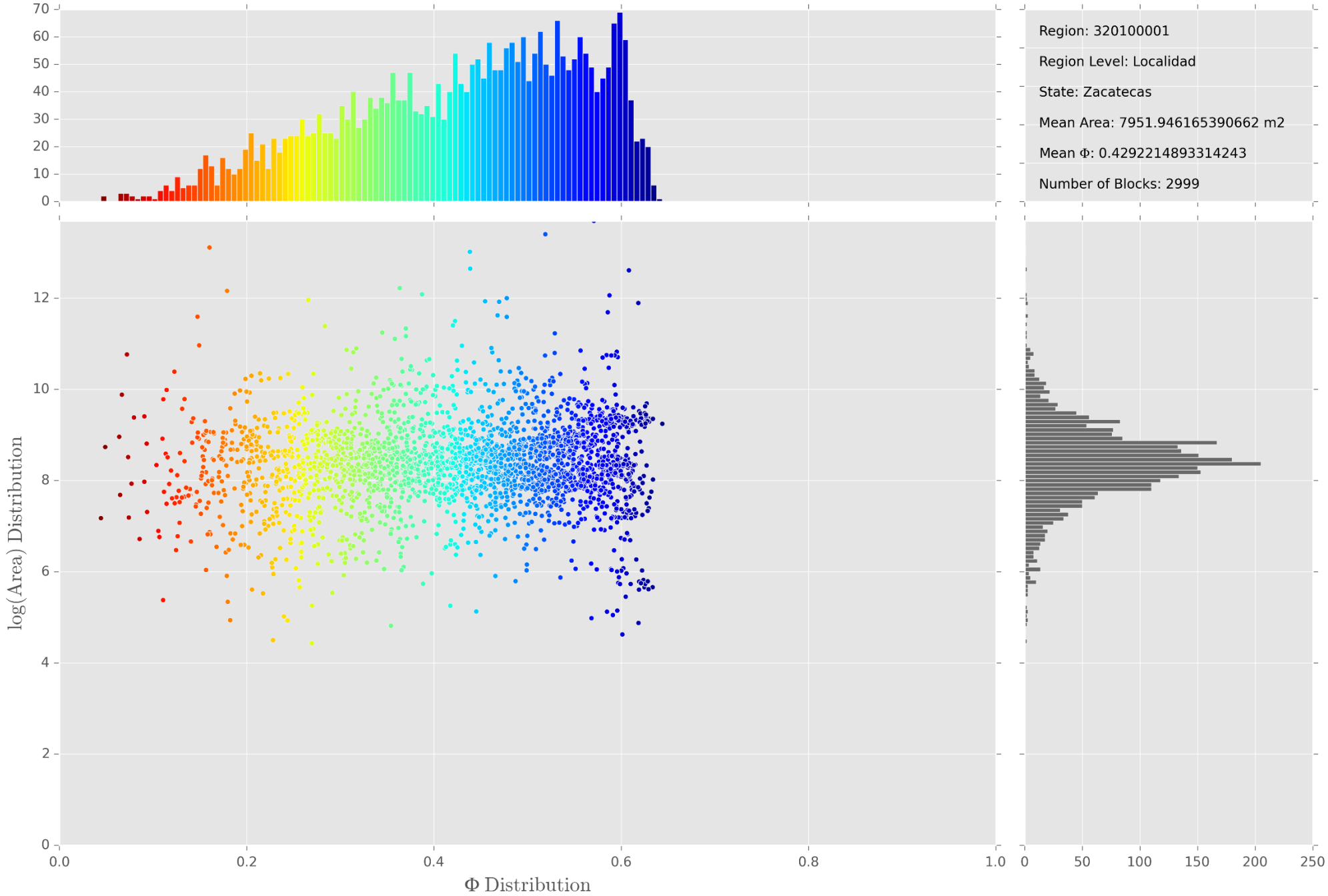
Region: 190210001 Gral. Escobedo



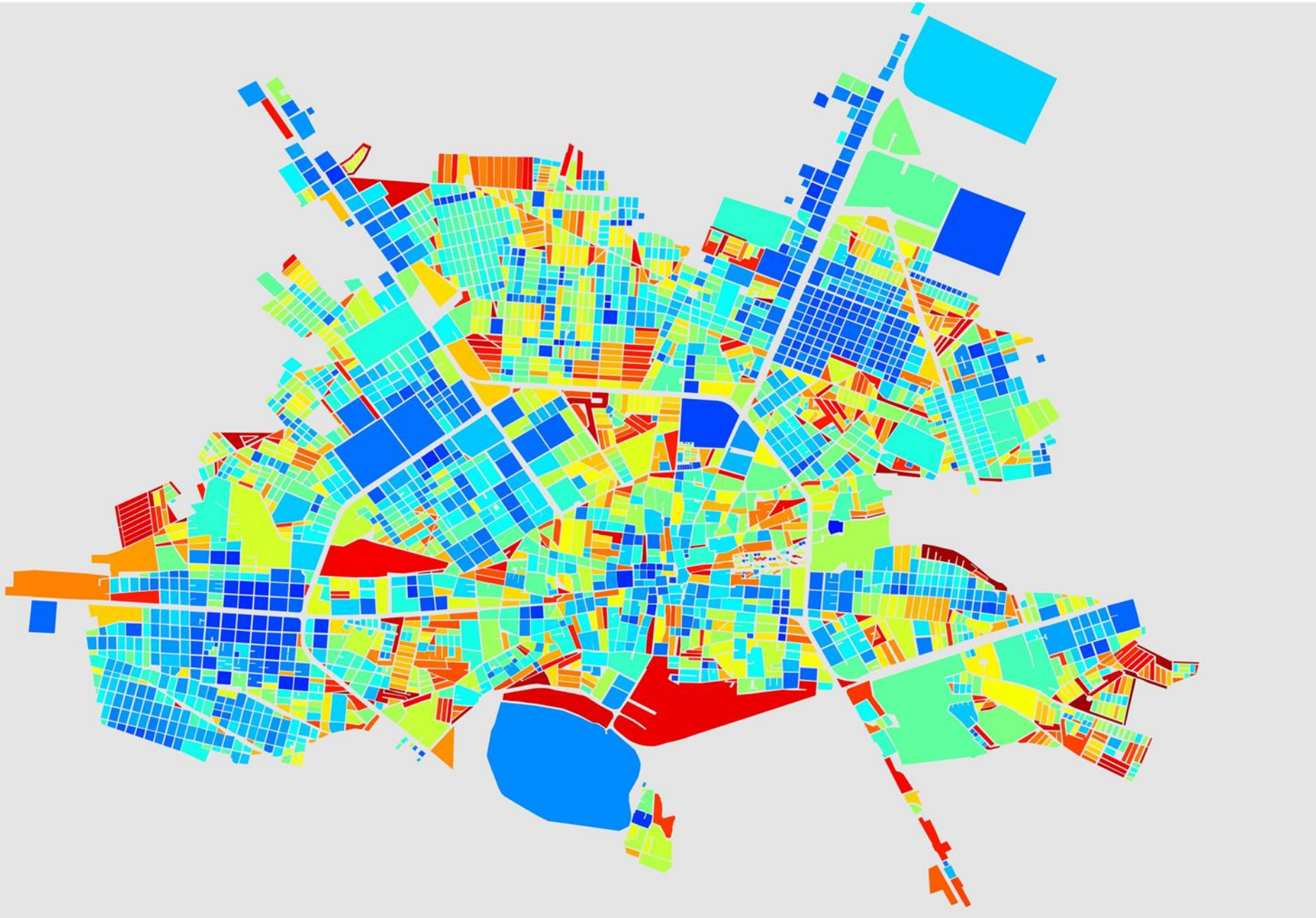
Region: 190210001 Gral. Escobedo

Spatial Concentration of Φ (Moran's I) HH LL



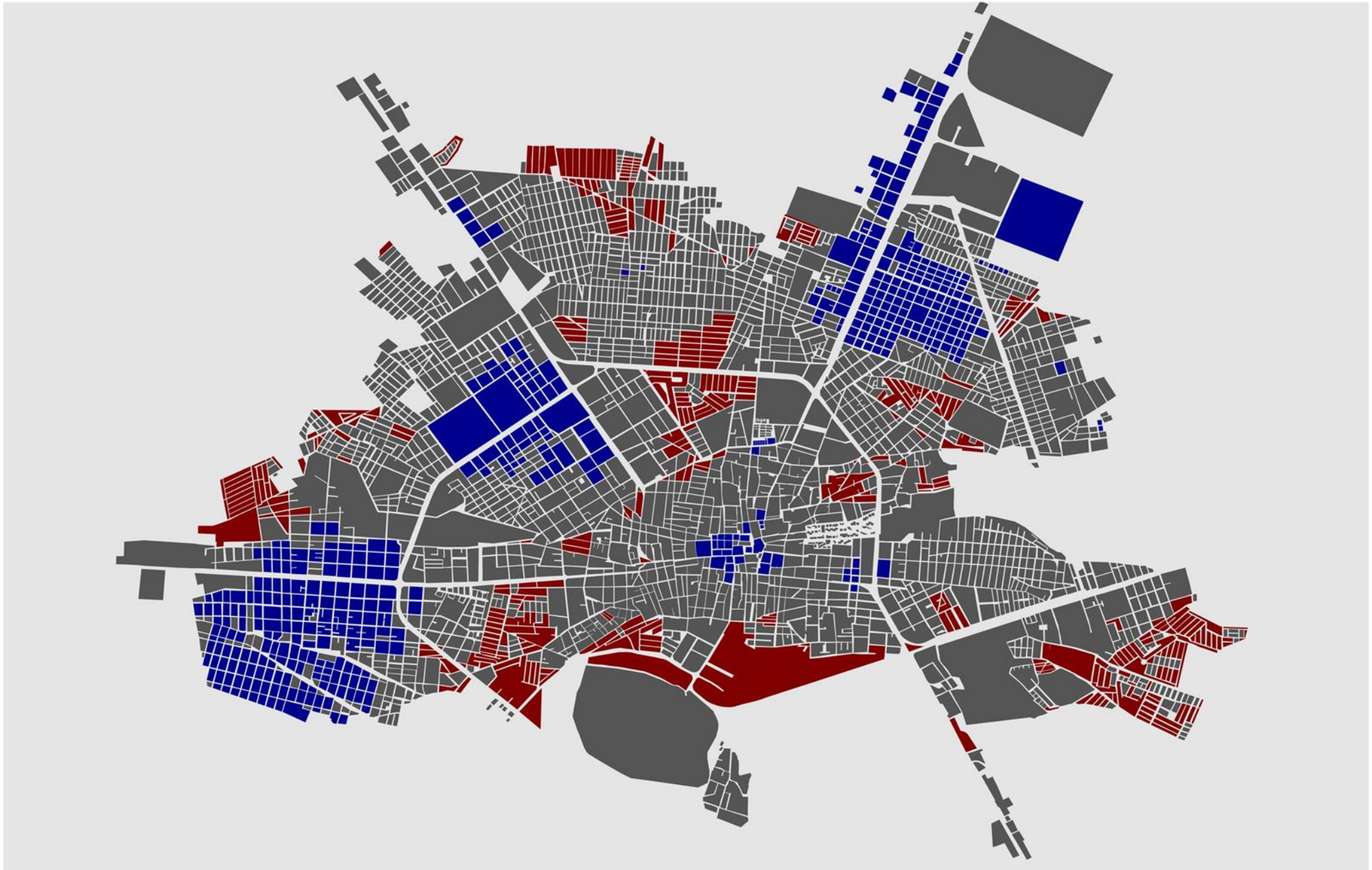

Region: 320100001
Region Level: Localidad
State: Zacatecas
Mean Area: 7951.946165390662 m2
Mean Φ: 0.4292214893314243
Number of Blocks: 2999
log(Area) Distribution
Φ Distribution
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150
200
250
0
2
4
6
8
10
12
0
10
20
30
40
50
60
70

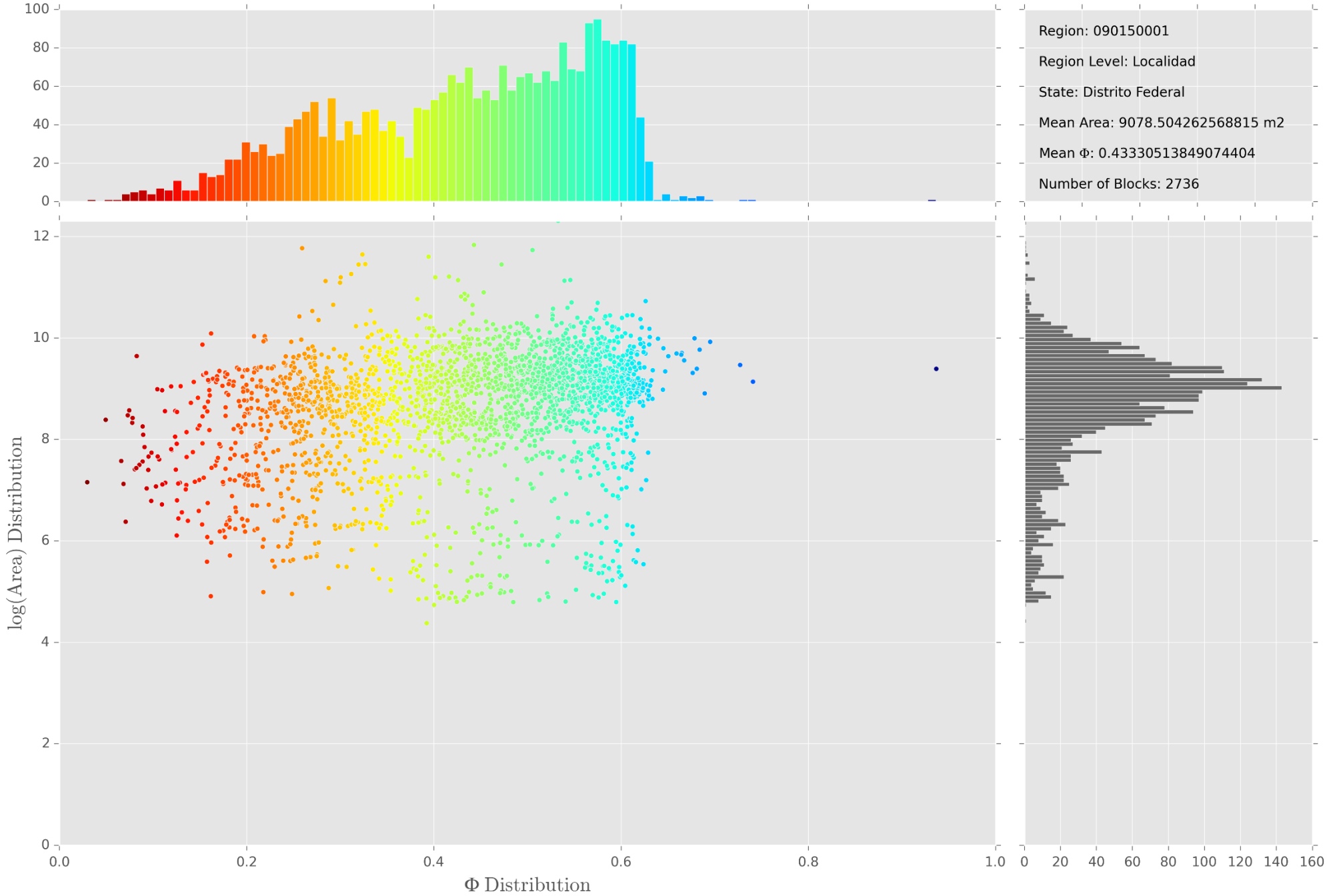
Region: 320100001 Fresnillo



Region: 320100001 Fresnillo

Spatial Concentration of Φ (Moran's I) HH LL

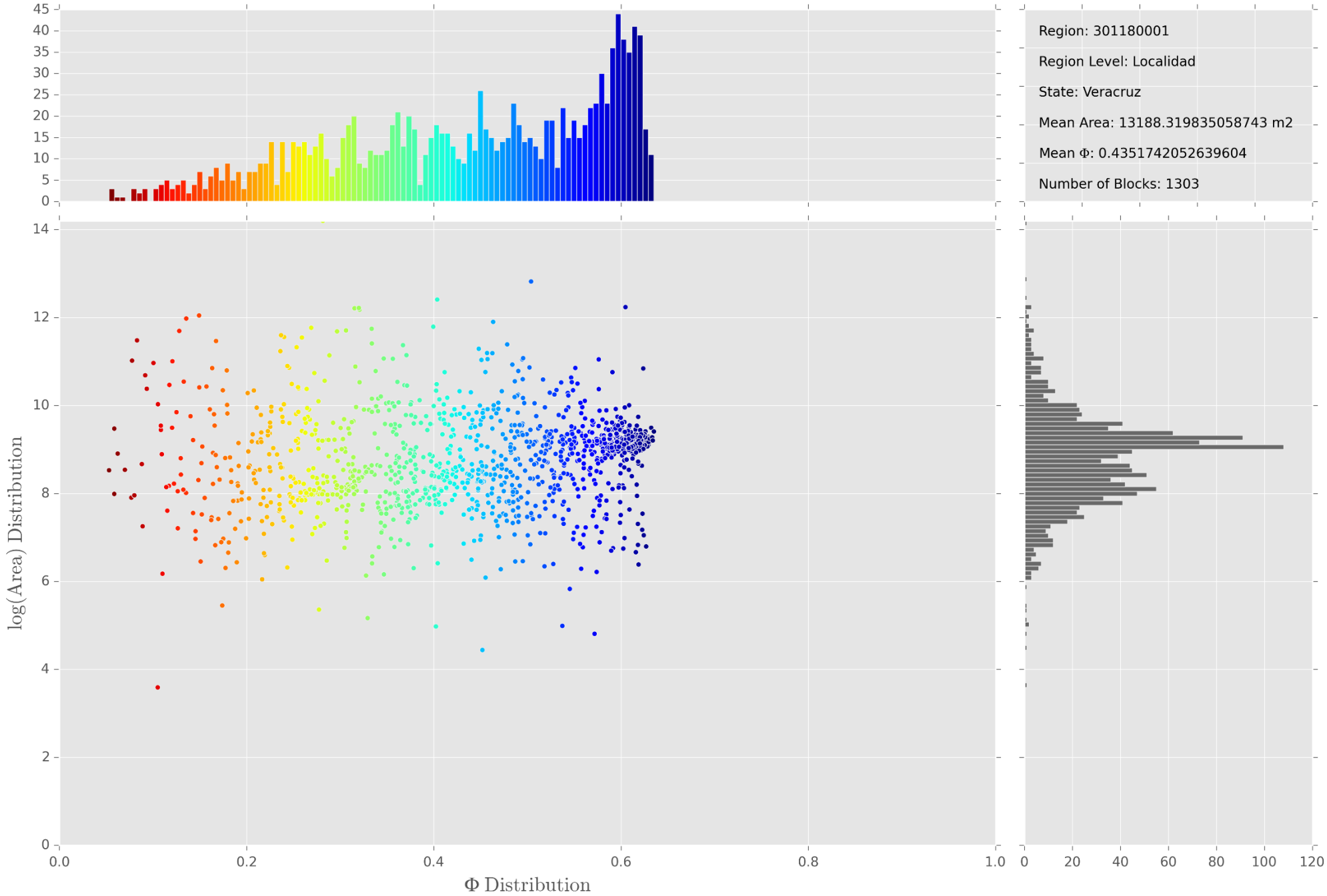



Region: 090150001
Region Level: Localidad
State: Distrito Federal
Mean Area: 9078.504262568815 m2
Mean Φ: 0.43330513849074404
Number of Blocks: 2736
log(Area) Distribution
Φ Distribution
0.0
0.2
0.4
0.6
0.8
1.0
0
20
40
60
80
100
120
140
160
0
2
4
6
8
10
12

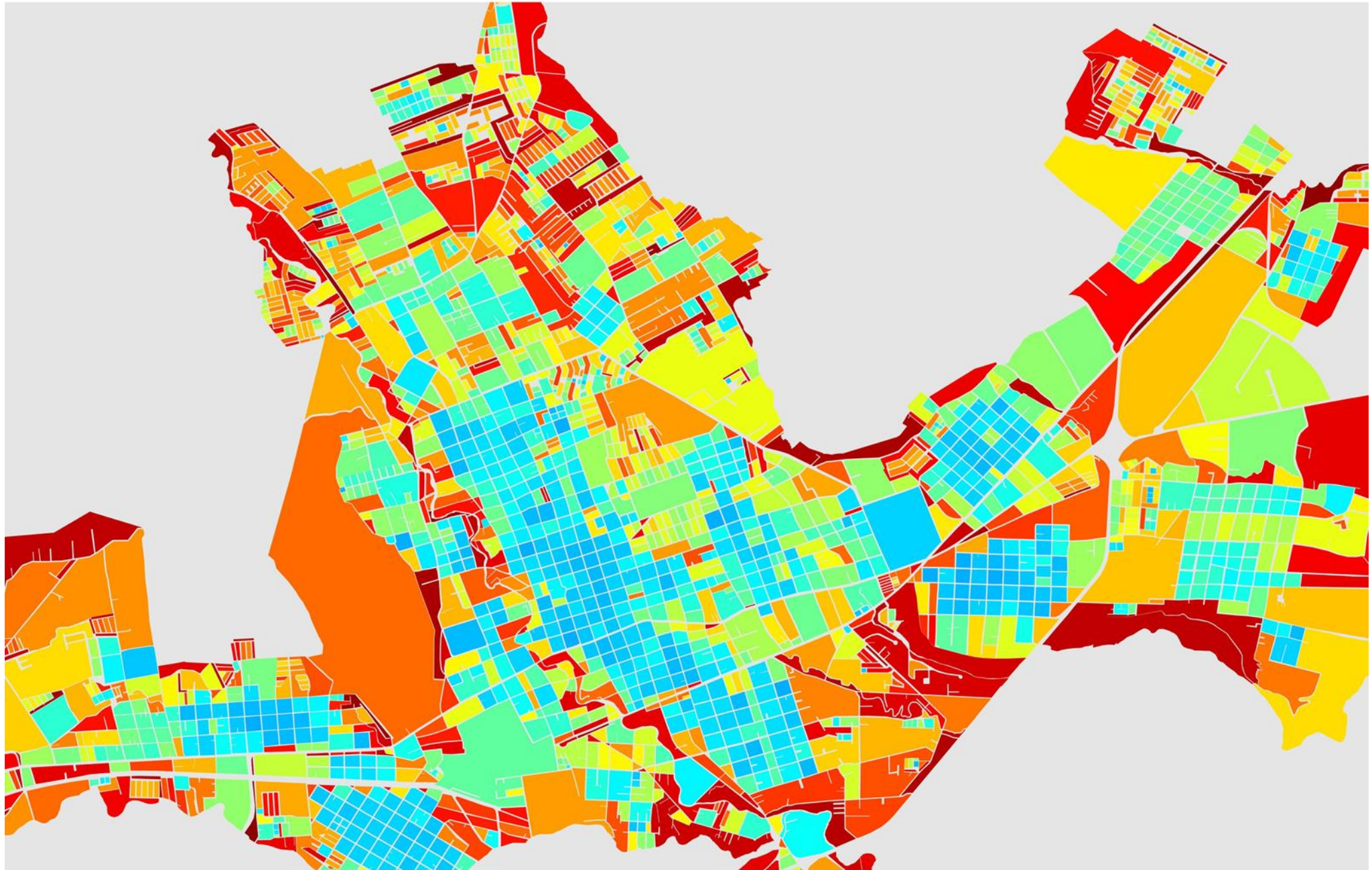
Region: 090150001 Cuauhtémoc

Region: 090150001 Cuauhtémoc

Spatial Concentration of Φ (Moran's I) HH LL

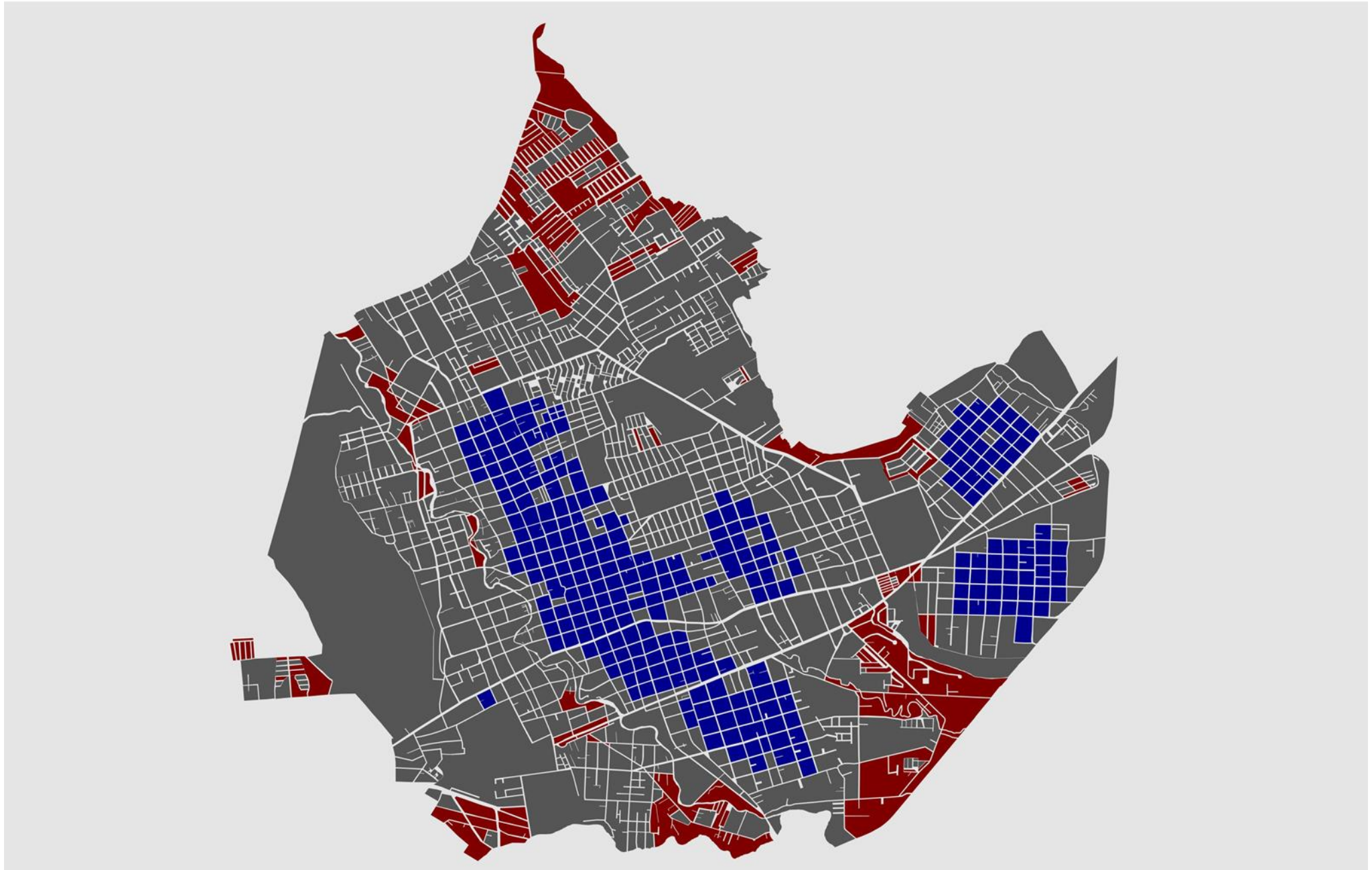

Region: 301180001
Region Level: Localidad
State: Veracruz
Mean Area: 13188.319835058743 m2
Mean Φ: 0.4351742052639604
Number of Blocks: 1303
log(Area) Distribution
Φ Distribution

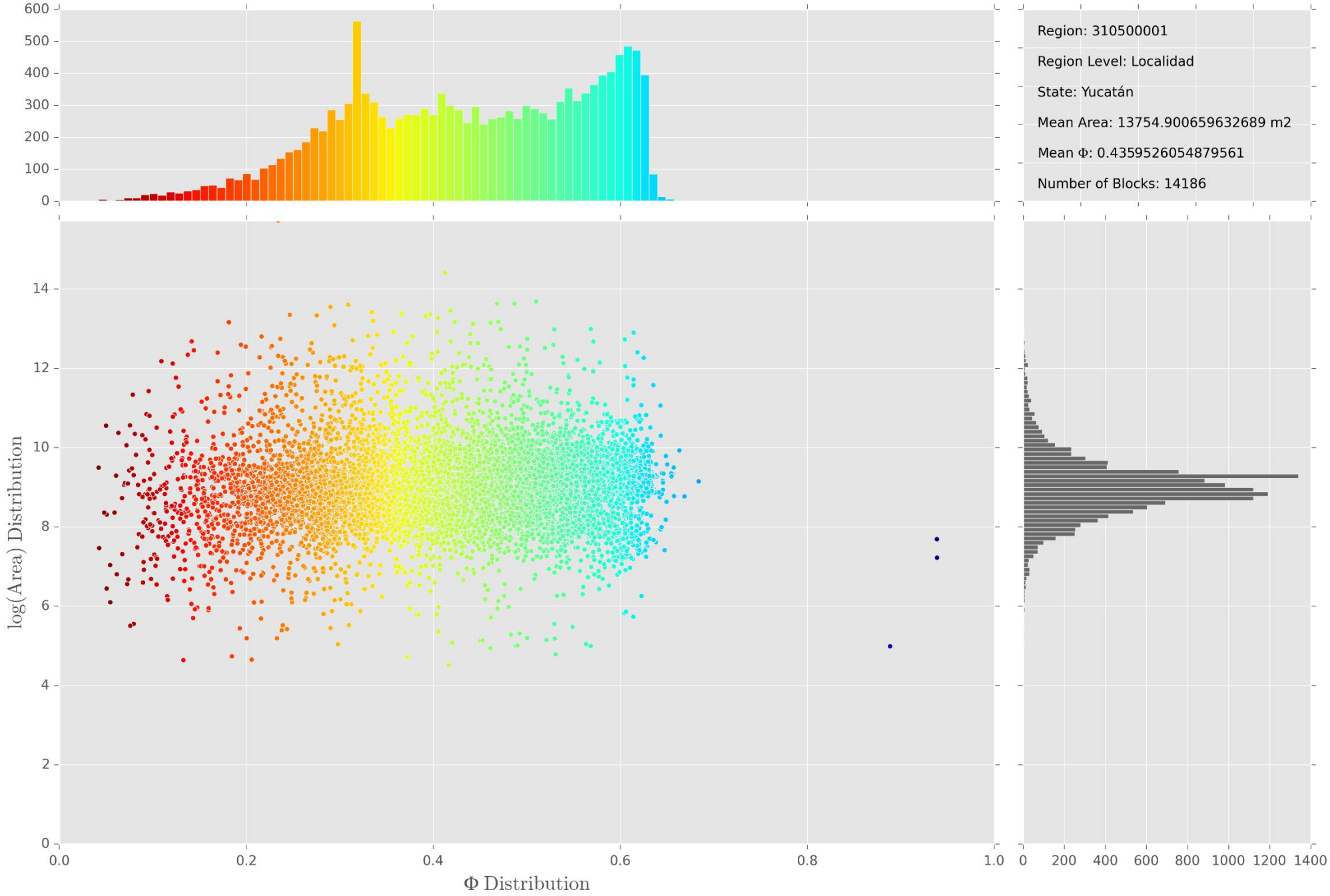
Region: 301180001 Orizaba



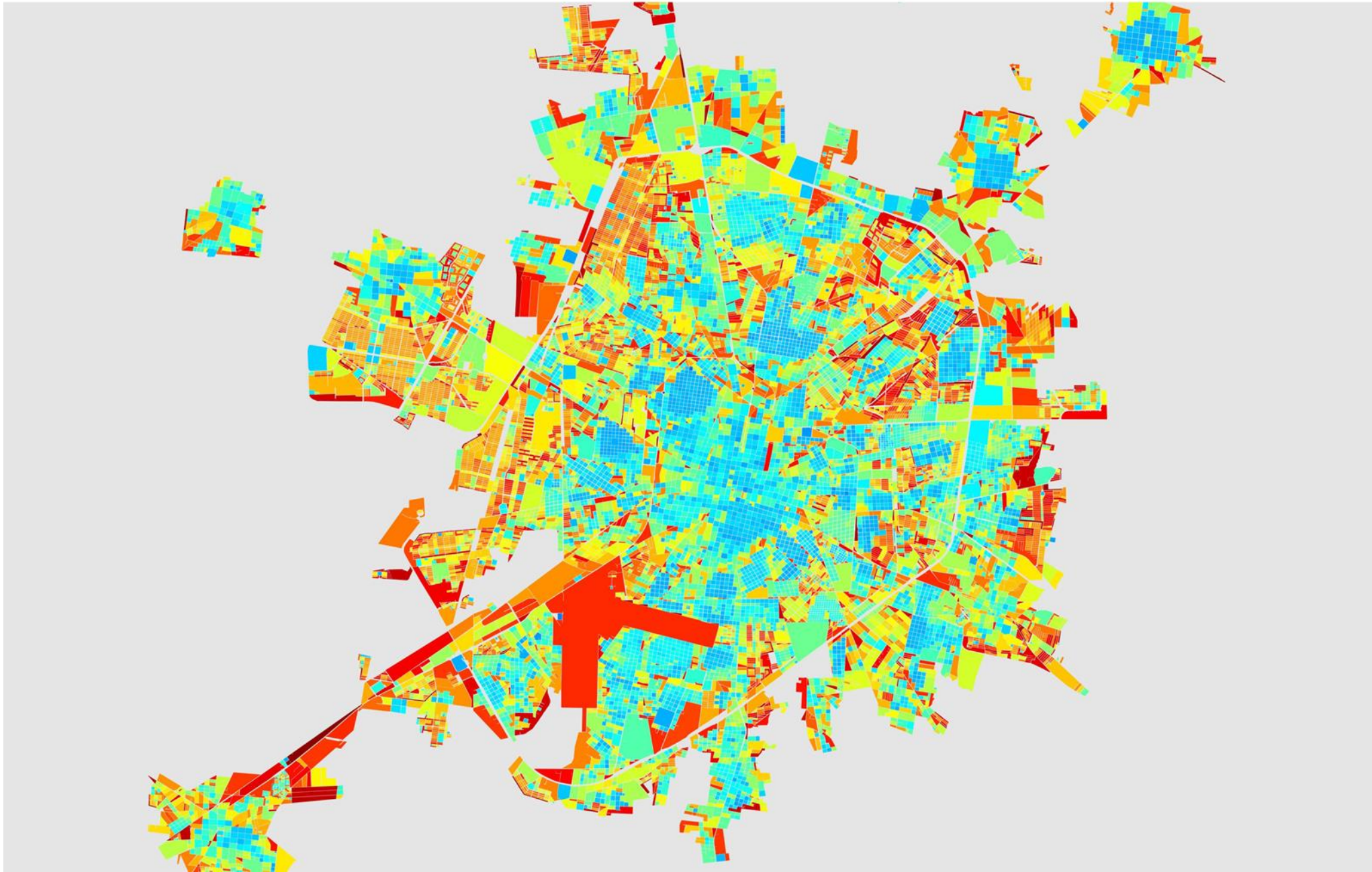
Region: 301180001 Orizaba

Spatial Concentration of Φ (Moran's I) HH LL



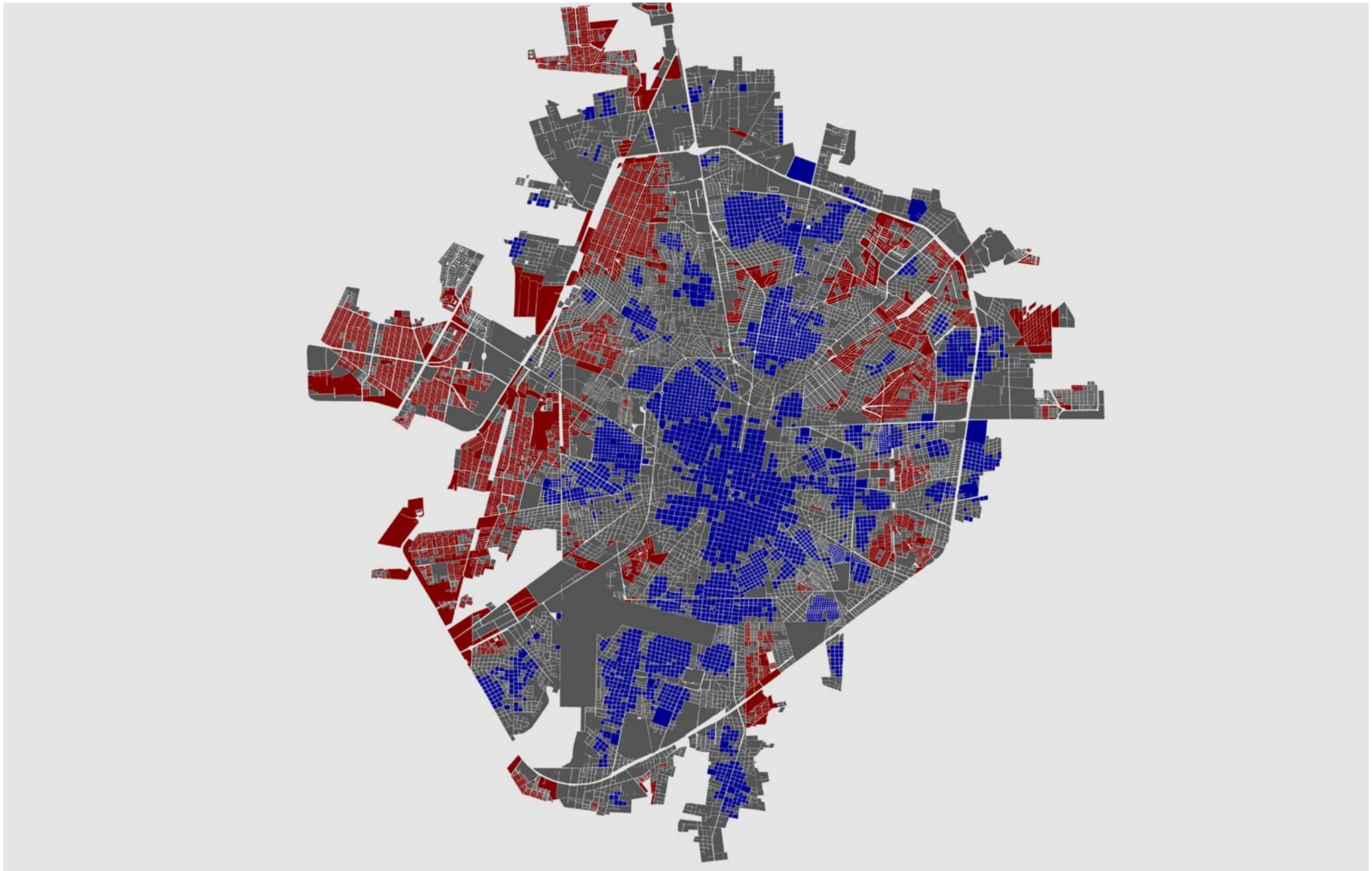

Region: 310500001
Region Level: Localidad
State: Yucatán
Mean Area: 13754.900659632689 m2
Mean Φ: 0.4359526054879561
Number of Blocks: 14186
log(Area) Distribution
Φ Distribution
0
100
200
300
400
500
600
0
2
4
6
8
10
12
14
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
1000
1200
1400

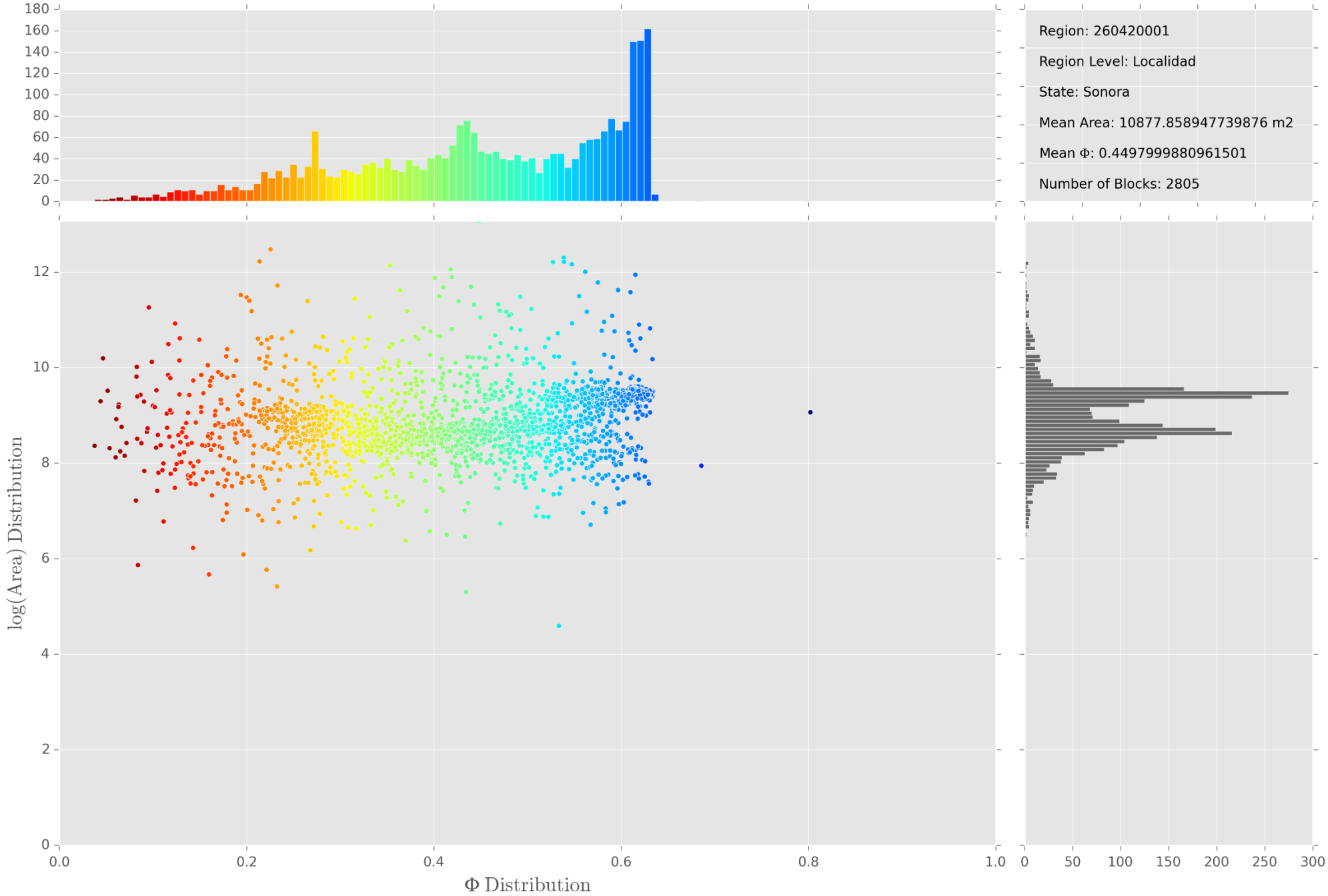
Region: 310500001 Mérida



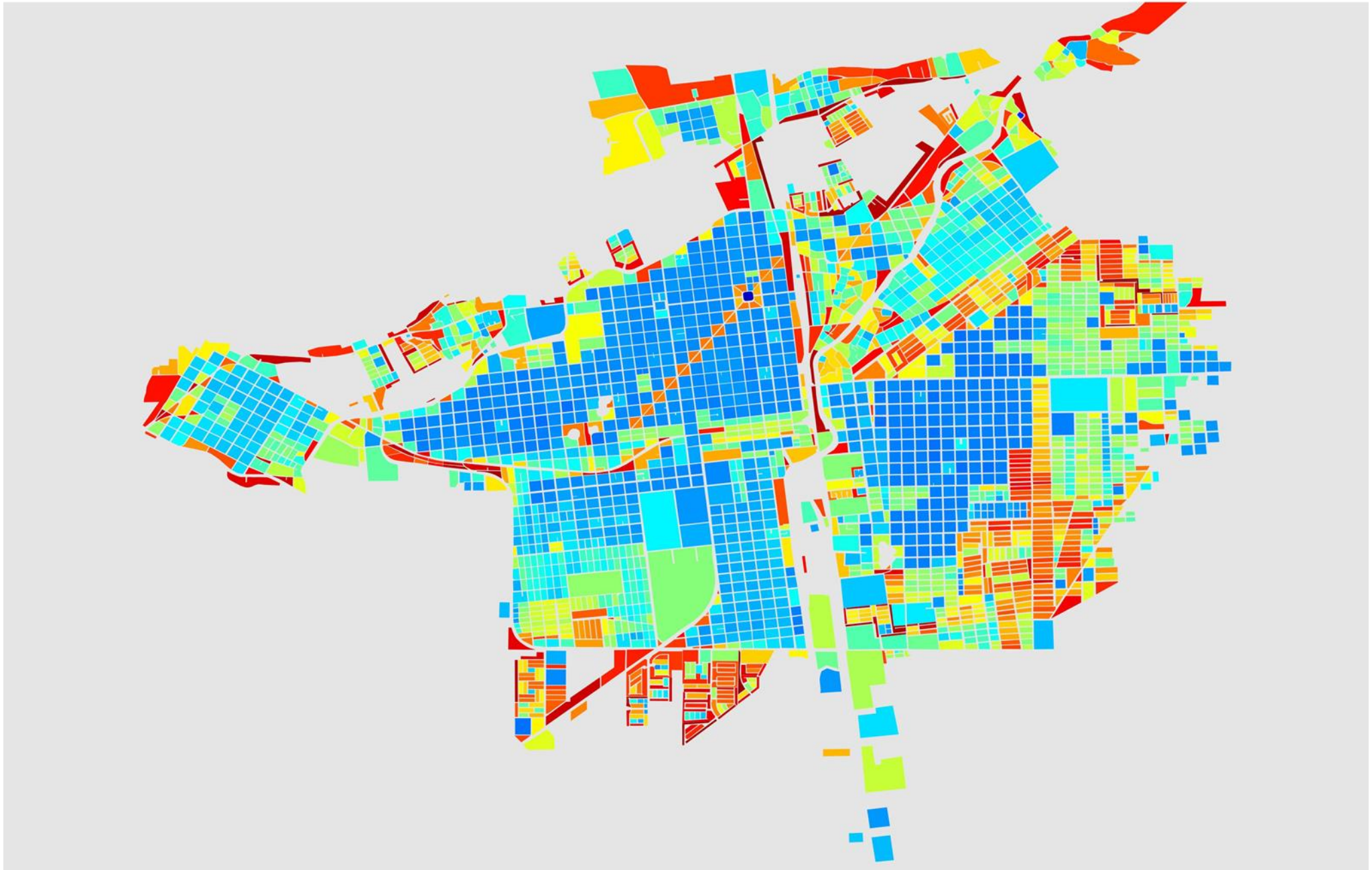
Region: 310500001 Mérida

Spatial Concentration of Φ (Moran's I) HH LL



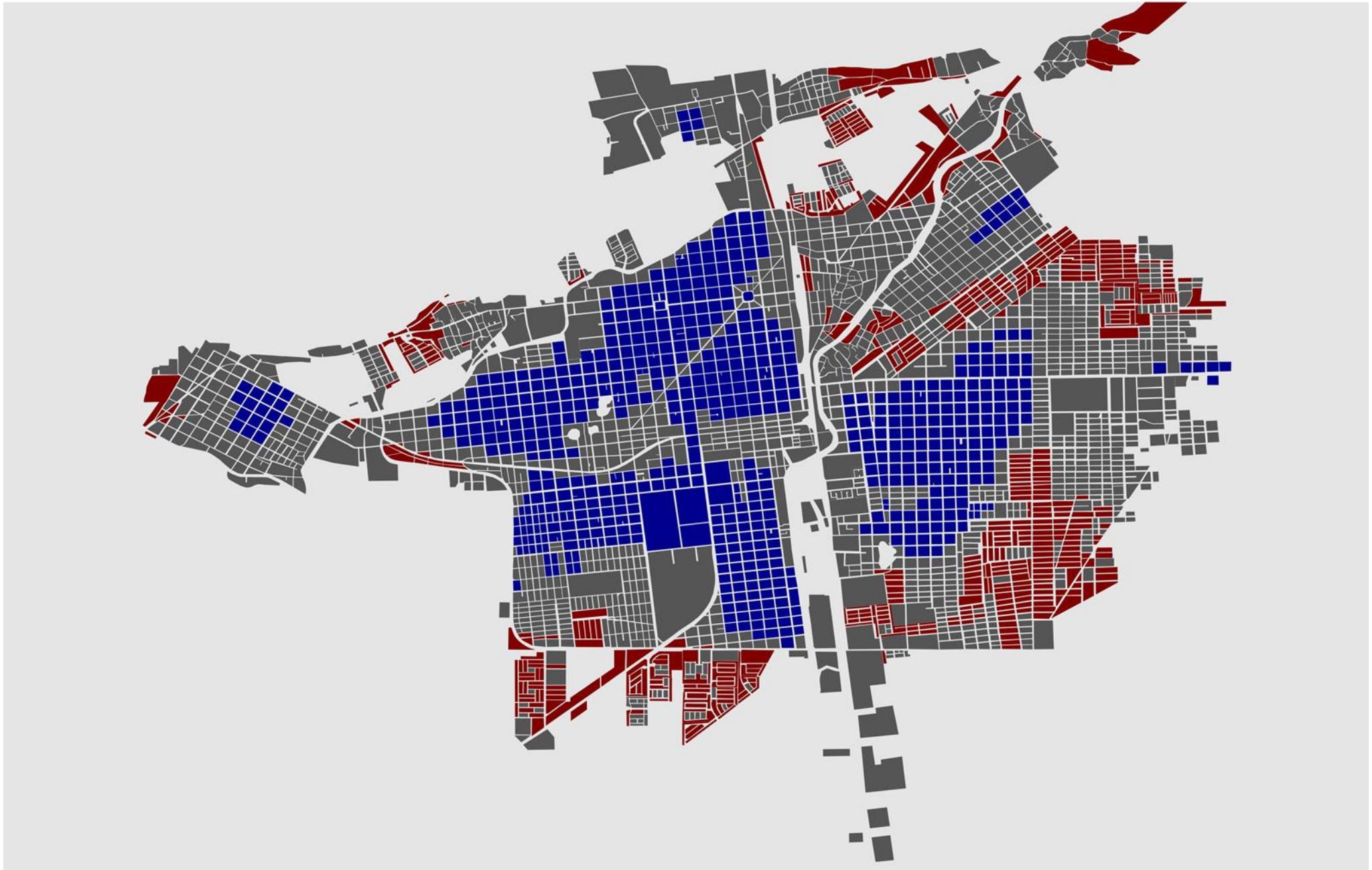

Region: 260420001
Region Level: Localidad
State: Sonora
Mean Area: 10877.858947739876 m2
Mean Φ: 0.4497999880961501
Number of Blocks: 2805
log(Area) Distribution
Φ Distribution

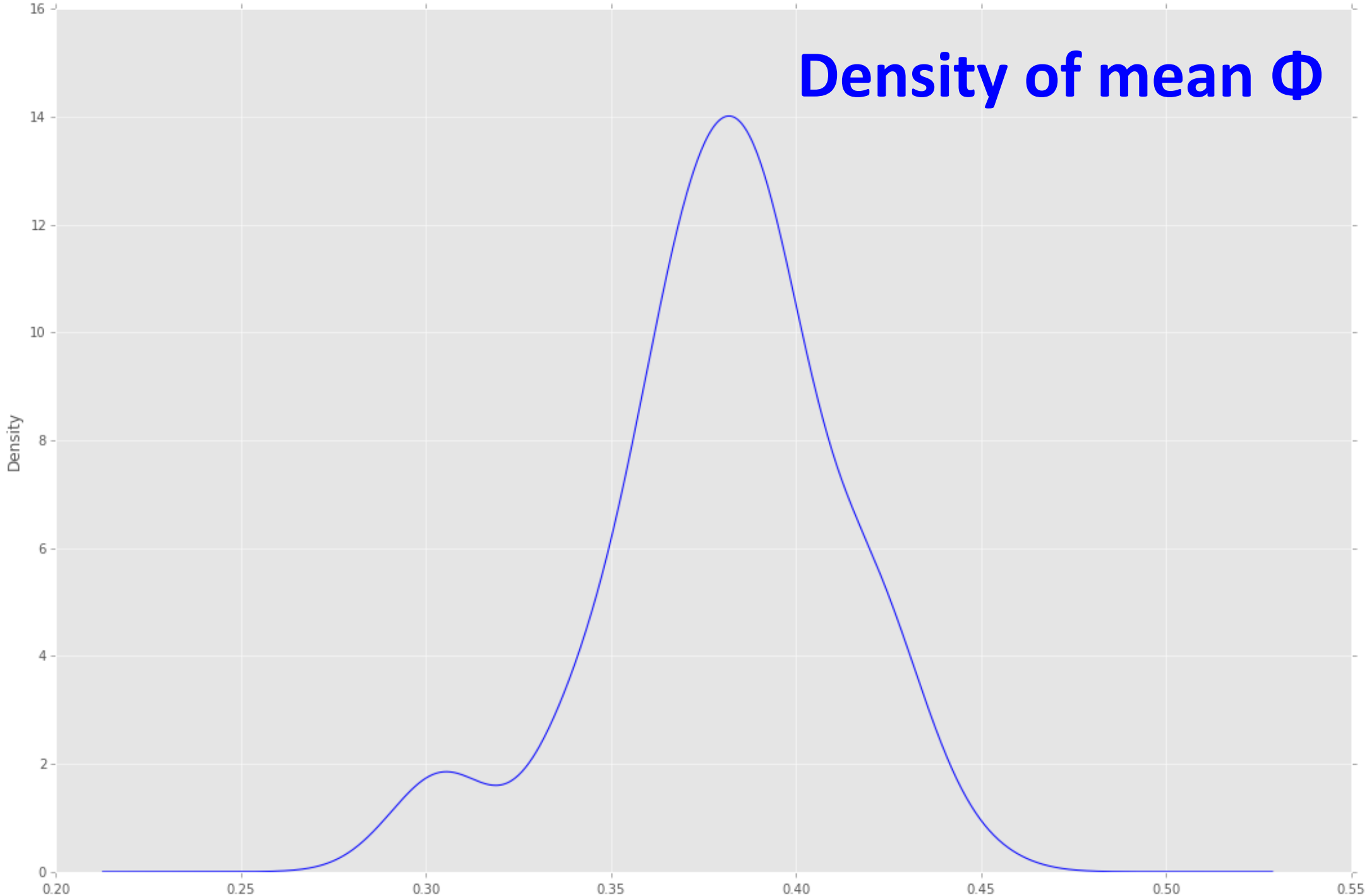
Region: 260420001 Navojoa



Region: 260420001 Navojoa

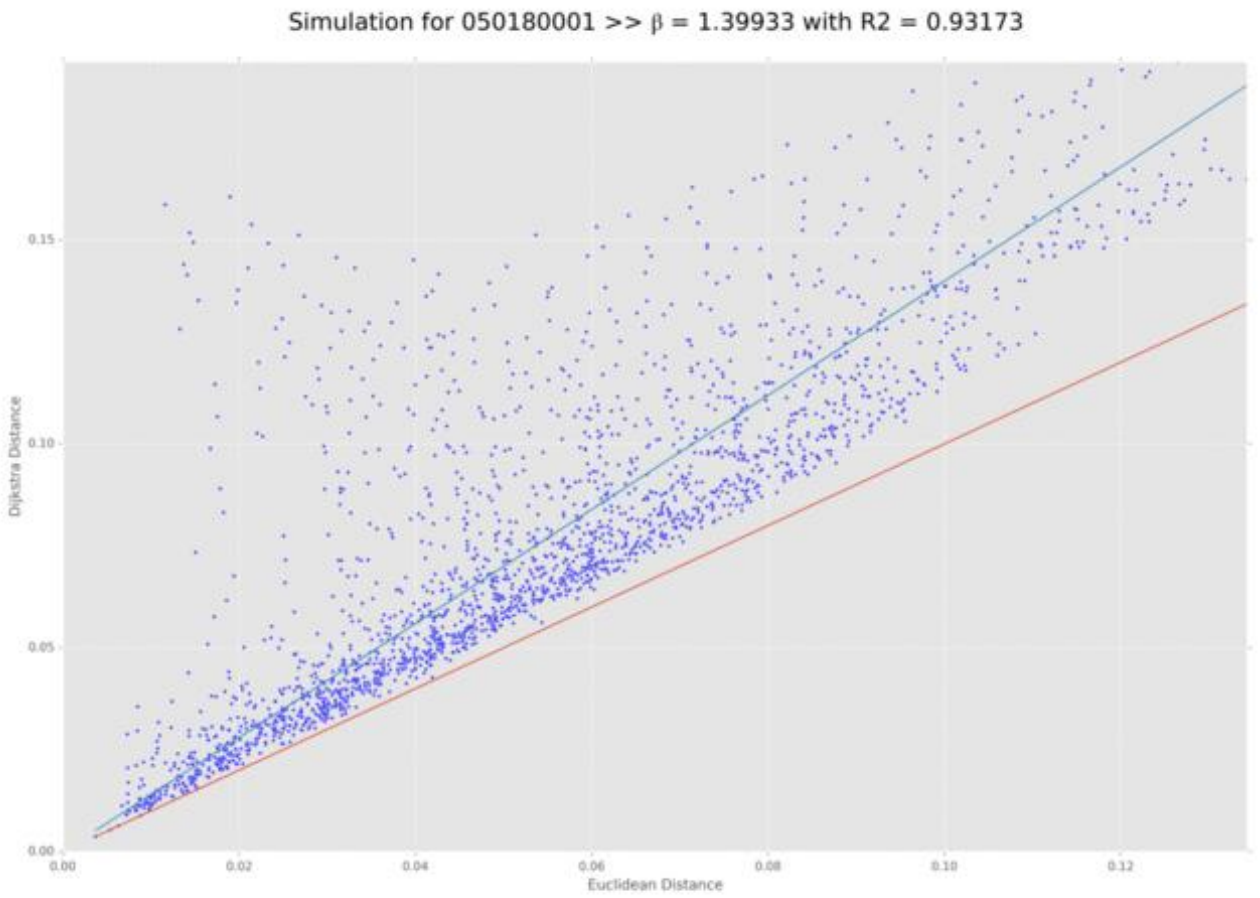
Spatial Concentration of Φ (Moran's I) HH LL



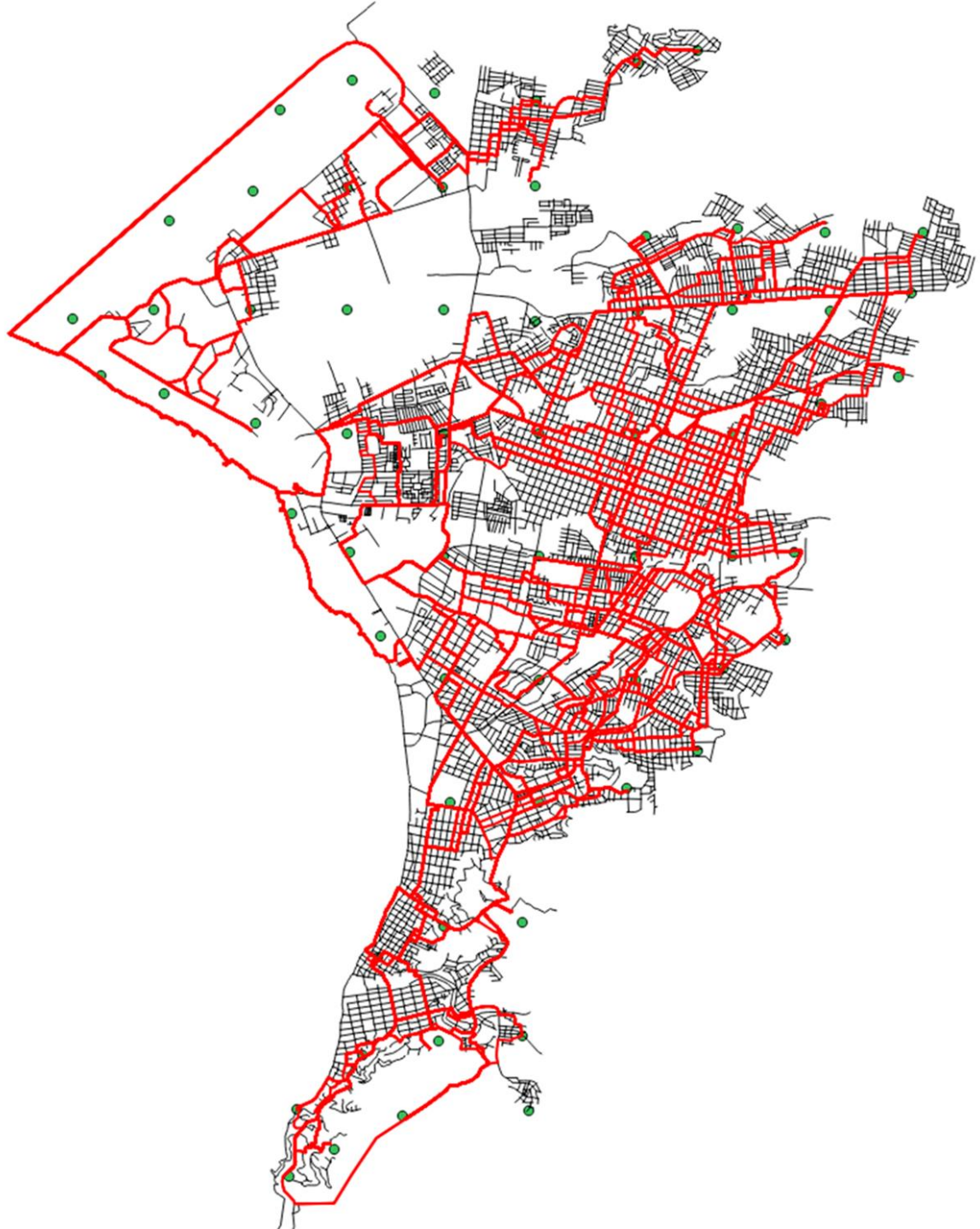

Density of mean Φ
Density
16
14
12
10
8
6
4
2
0
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55

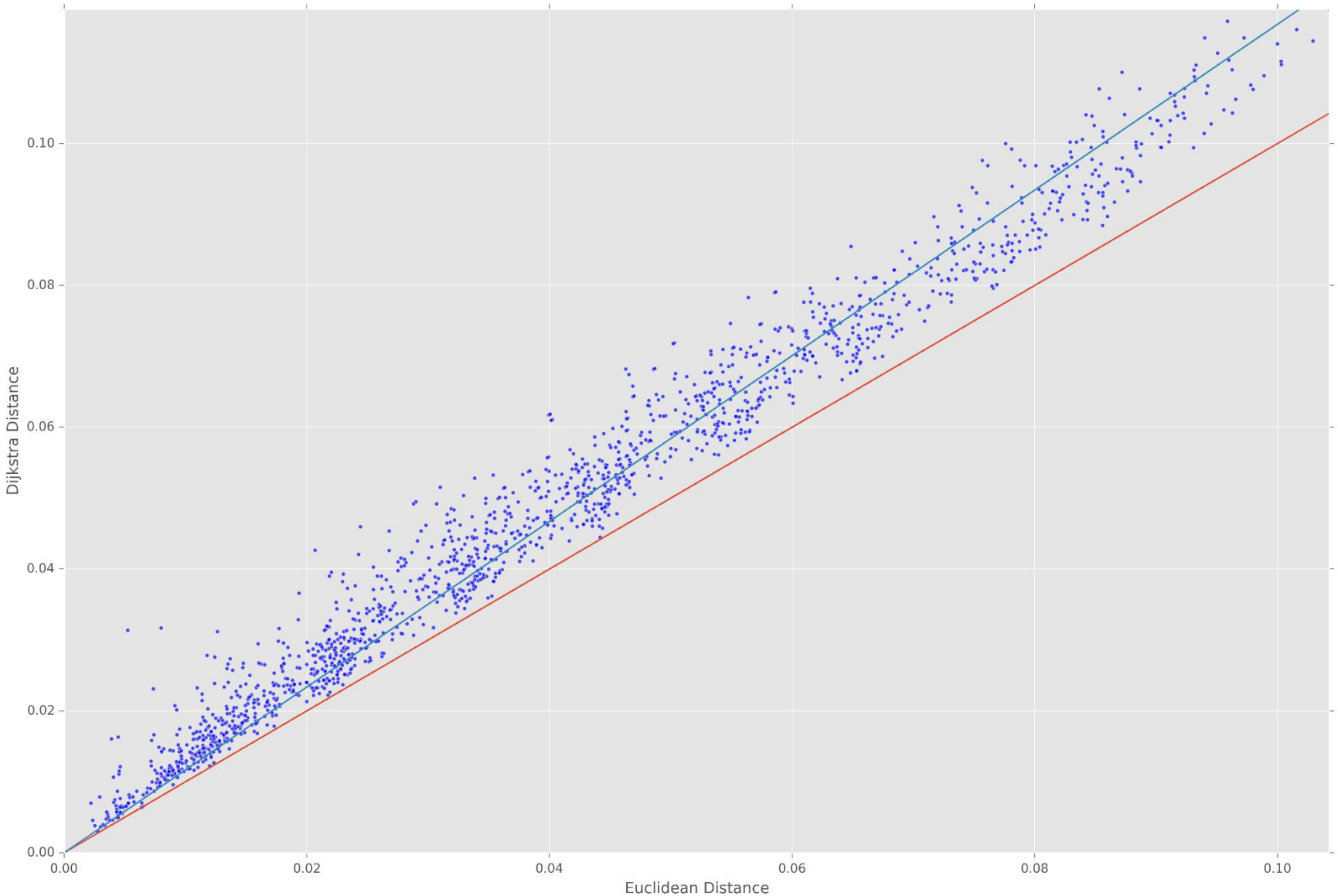
Algorithm II

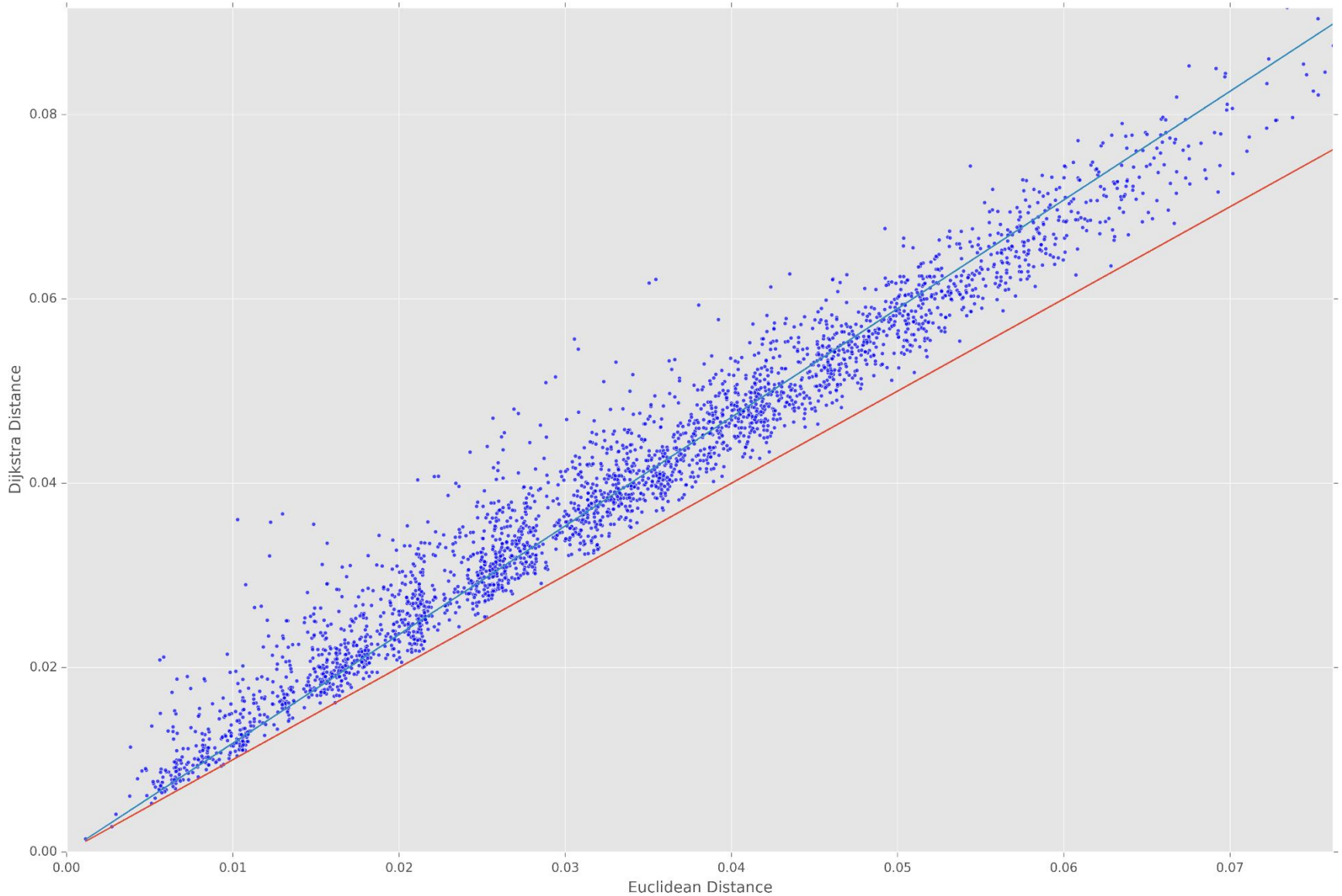

020040001
020020001
020010001
260550001
260430001
080370001
260300001
080190001
080170001
080210001
260290001
260180001
260420001
080320001
050020001
050250001
280270001
050180001
280320001
250010001
100070001
190480001
190060001
280220001
050350001
050300001
250060001
030030001
100050001
280410001
250120001
320100001
320560001
320170001
280030122
280090001
240350001
010010001
240280001
240130001
280380001
180170001
110200001
140670001
141200001
141010001
220140001
301310001
140980001
161080001
130480001
160530001
150690001
150990001
300870001
060100001
090040001
301930001
300280037
060070001
060020001
170070001
300440001
040030001
230040001
300390001
120350001
201840001
301080001
270040001
120290001
200670001
071010001
120010001
070780001
070890001
310500001
040020001
150240001
151090025
150810019
151210001
150200001
150600001
150020015
151090003
150130001
150330001
151040001
090050001
150570001
090020001
090160001
090150001
150370071
150580001
090170001
150310001
090140001
090060001
090040001
090100001
090070001
190210001
190460001
190060001
190480001
190390001
190260001
190310001
190190001

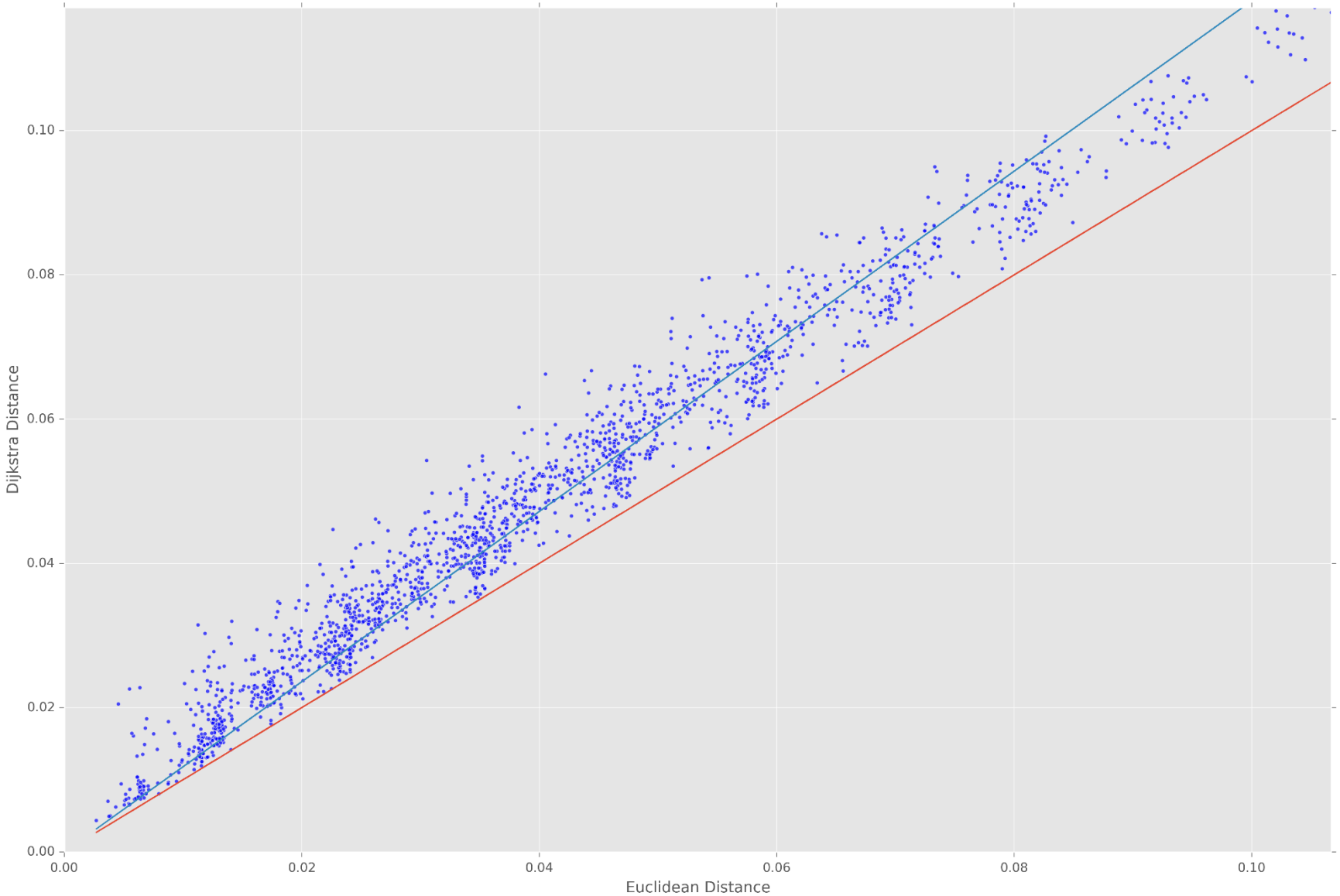


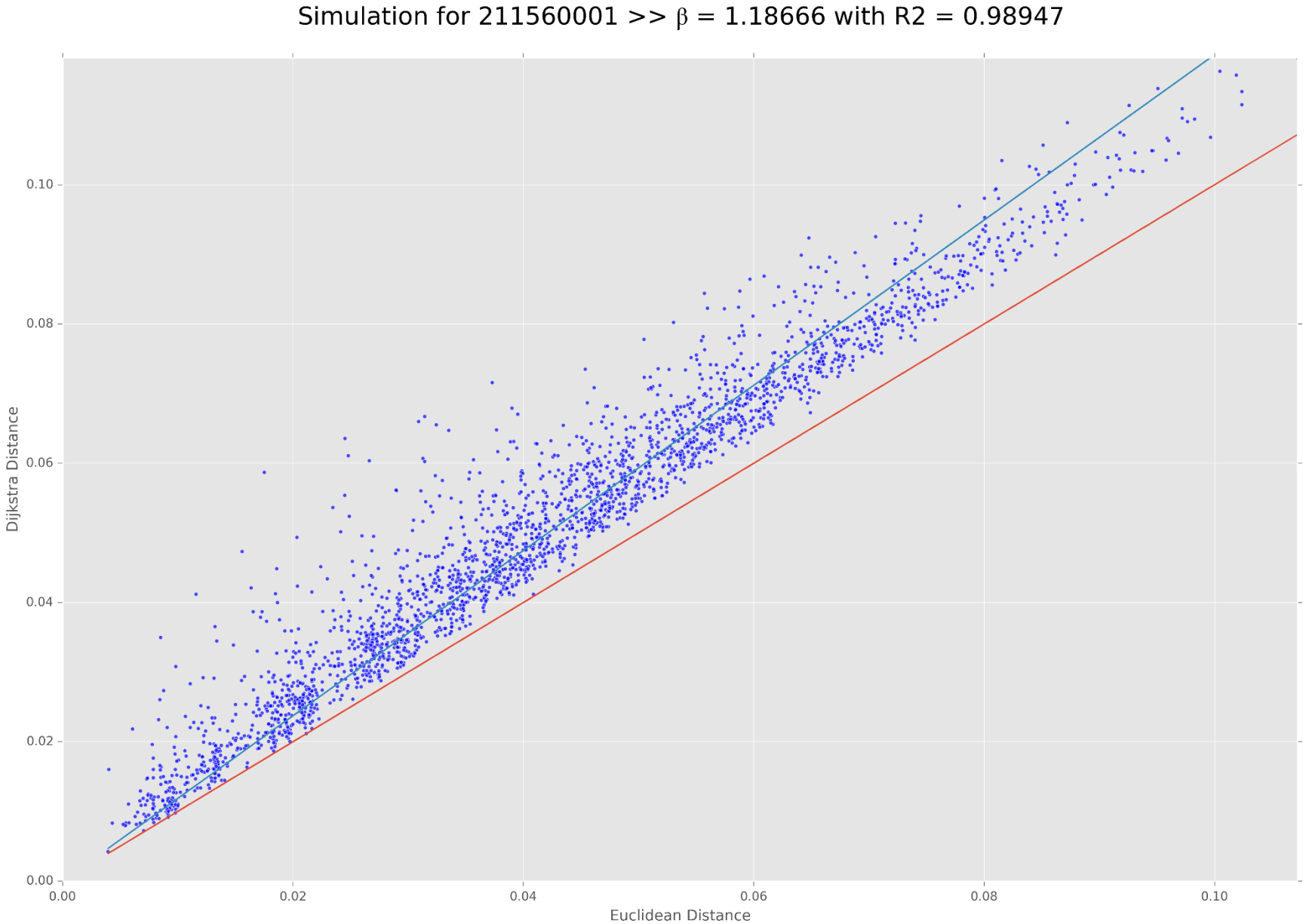
Examples		
	Φ	β
5 Lowest	190310001	150020015
	190060001	080210001
	150250001	300390001
	150580001	201840001
	190210001	211560001
5 Highest	320100001	141010001
	090150001	090150001
	301180001	150130001
	310500001	270040001
	260420001	140670001

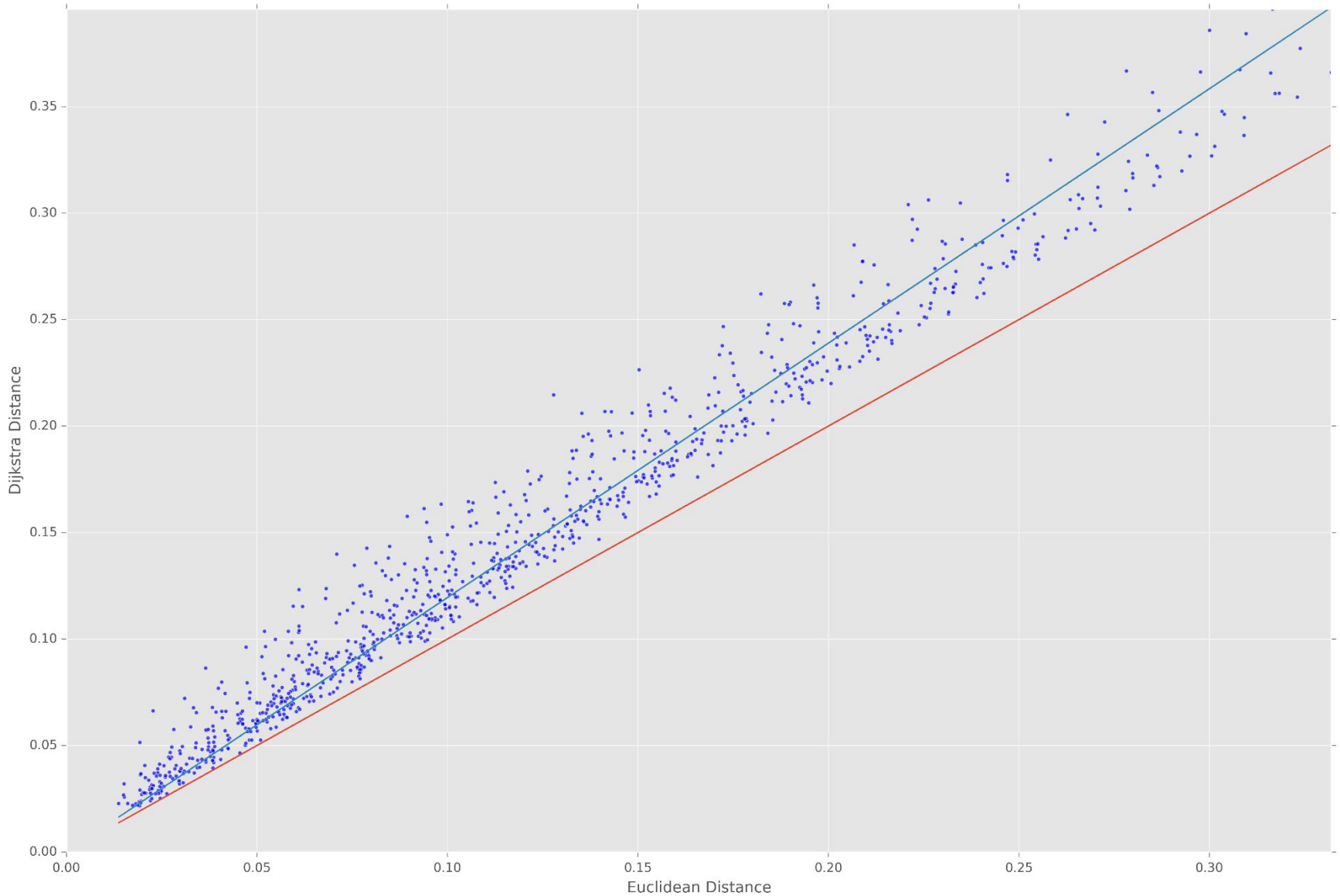



Simulation for 150020015 >> β = 1.16814 with R2 = 0.99296
Dijkstra Distance
Euclidean Distance
0.00
0.02
0.04
0.06
0.08
0.10

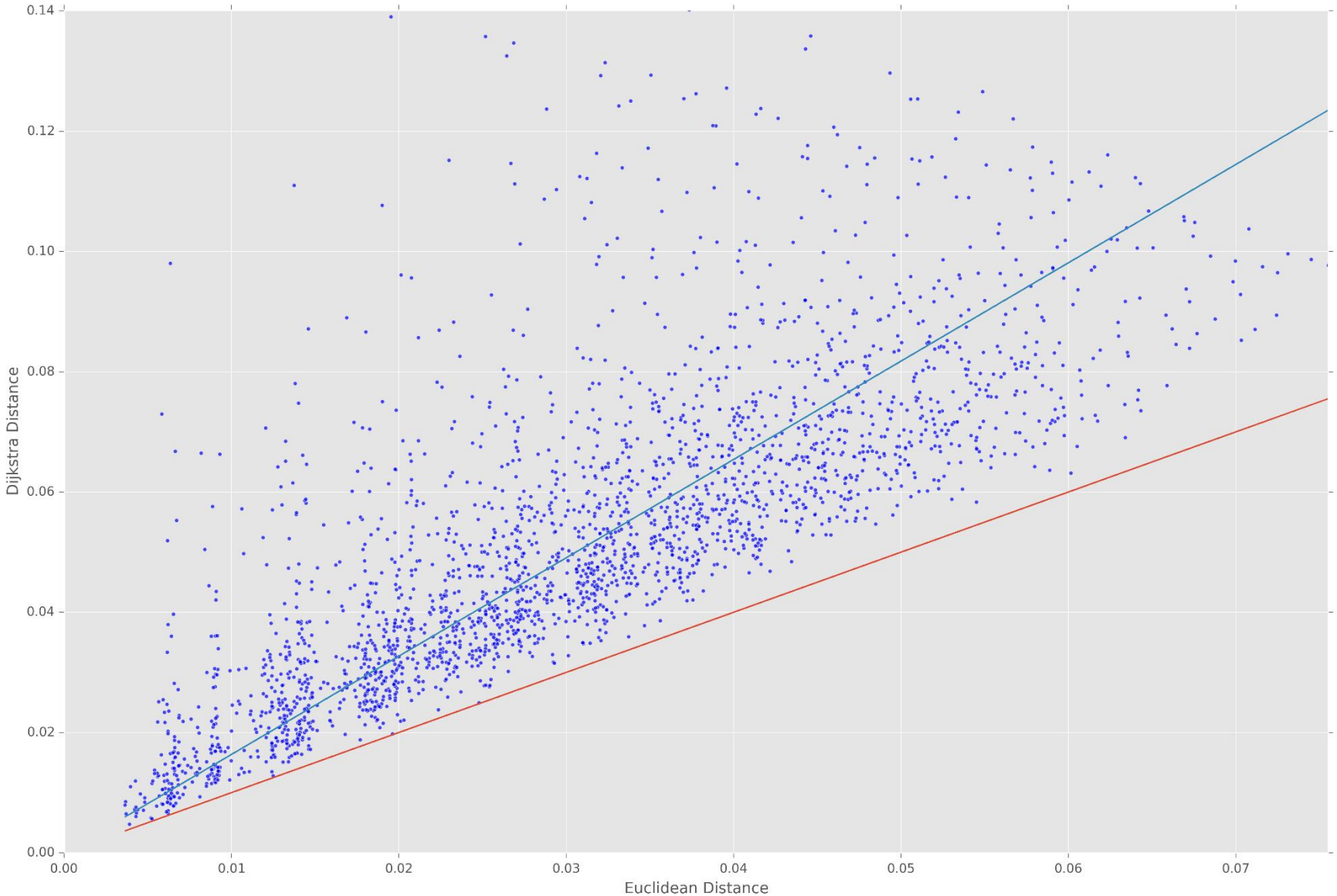

Simulation for 080210001 >> β = 1.17897 with R2 = 0.99254
Dijkstra Distance
Euclidean Distance
0.00
0.02
0.04
0.06
0.08
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07

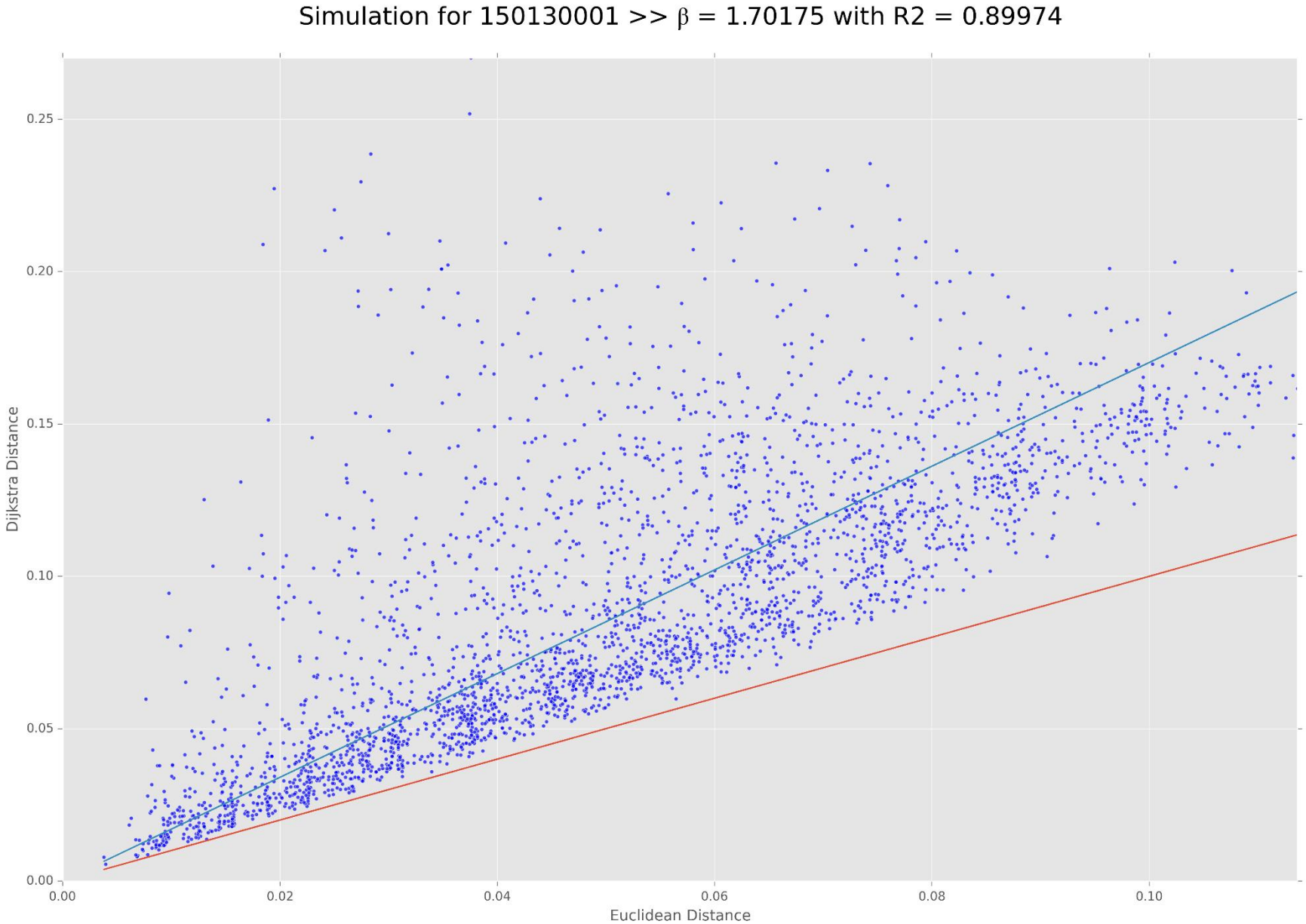

Simulation for 300390001 >> β = 1.17978 with R2 = 0.99181
Dijkstra Distance
Euclidean Distance
0.00
0.02
0.04
0.06
0.08
0.10

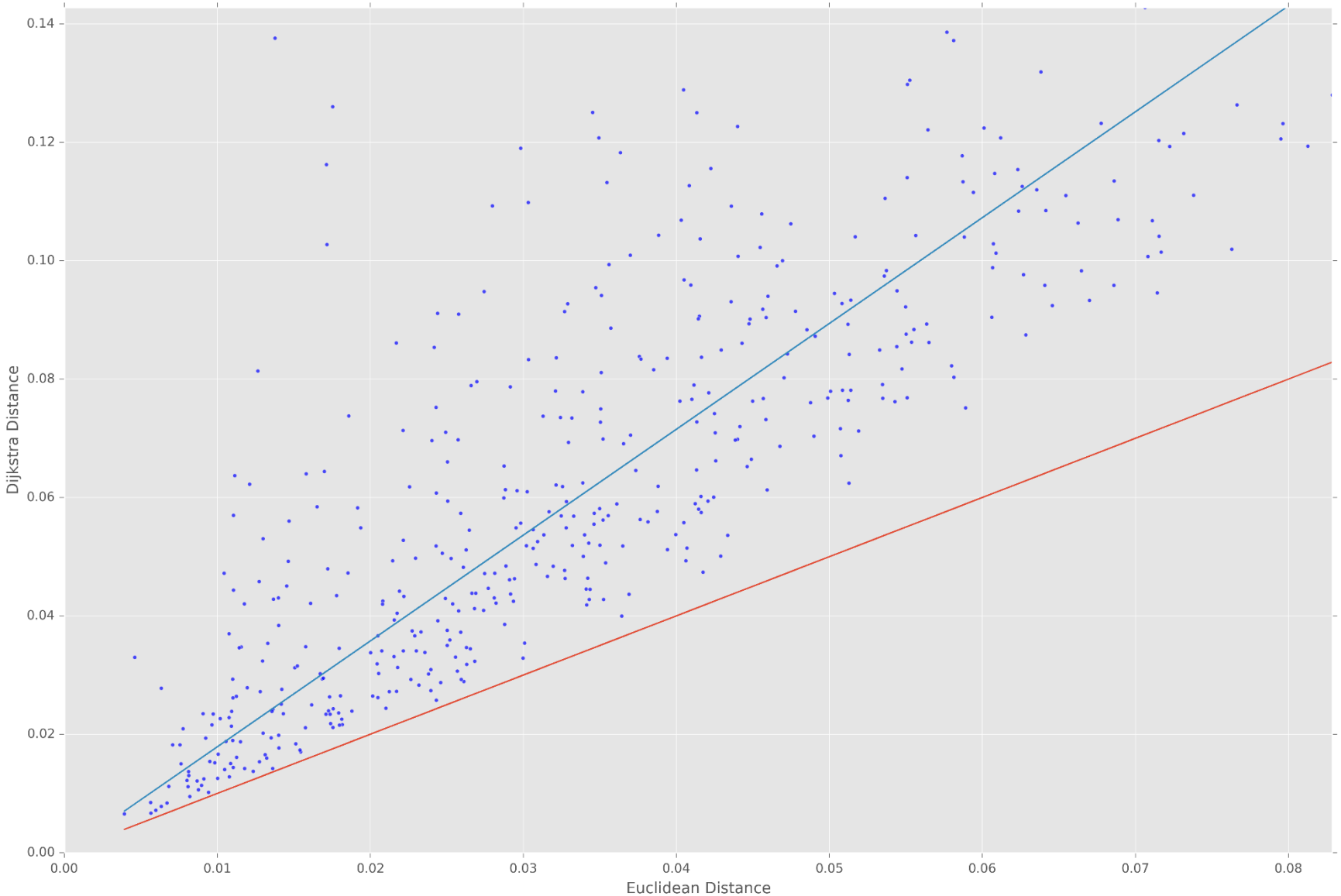

Simulation for 211560001 >> β = 1.18666 with R2 = 0.98947
Dijkstra Distance
Euclidean Distance
0.00
0.02
0.04
0.06
0.08
0.10

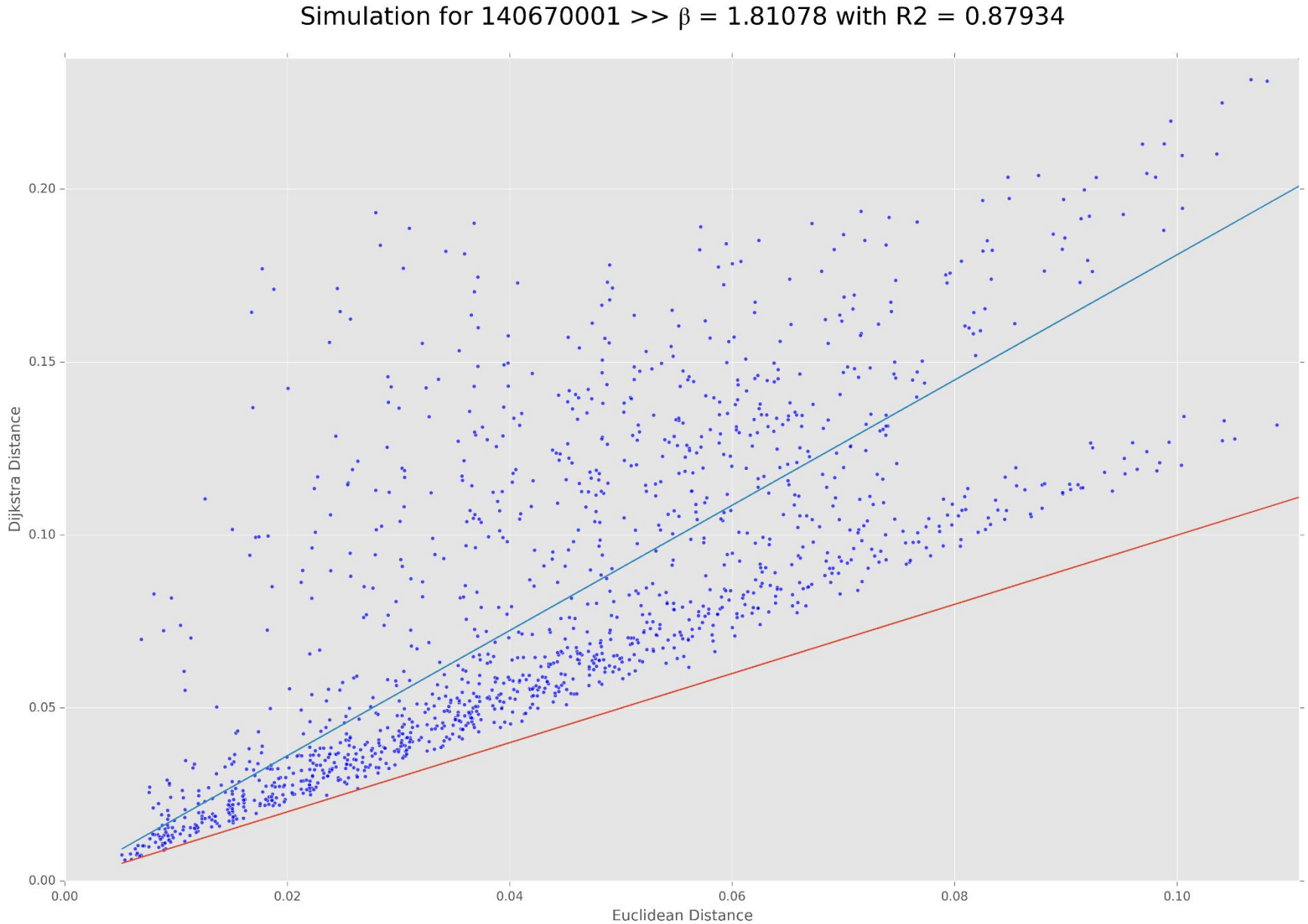

Simulation for 190390001 >> β = 1.19478 with R2 = 0.99153
Dijkstra Distance
Euclidean Distance
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35

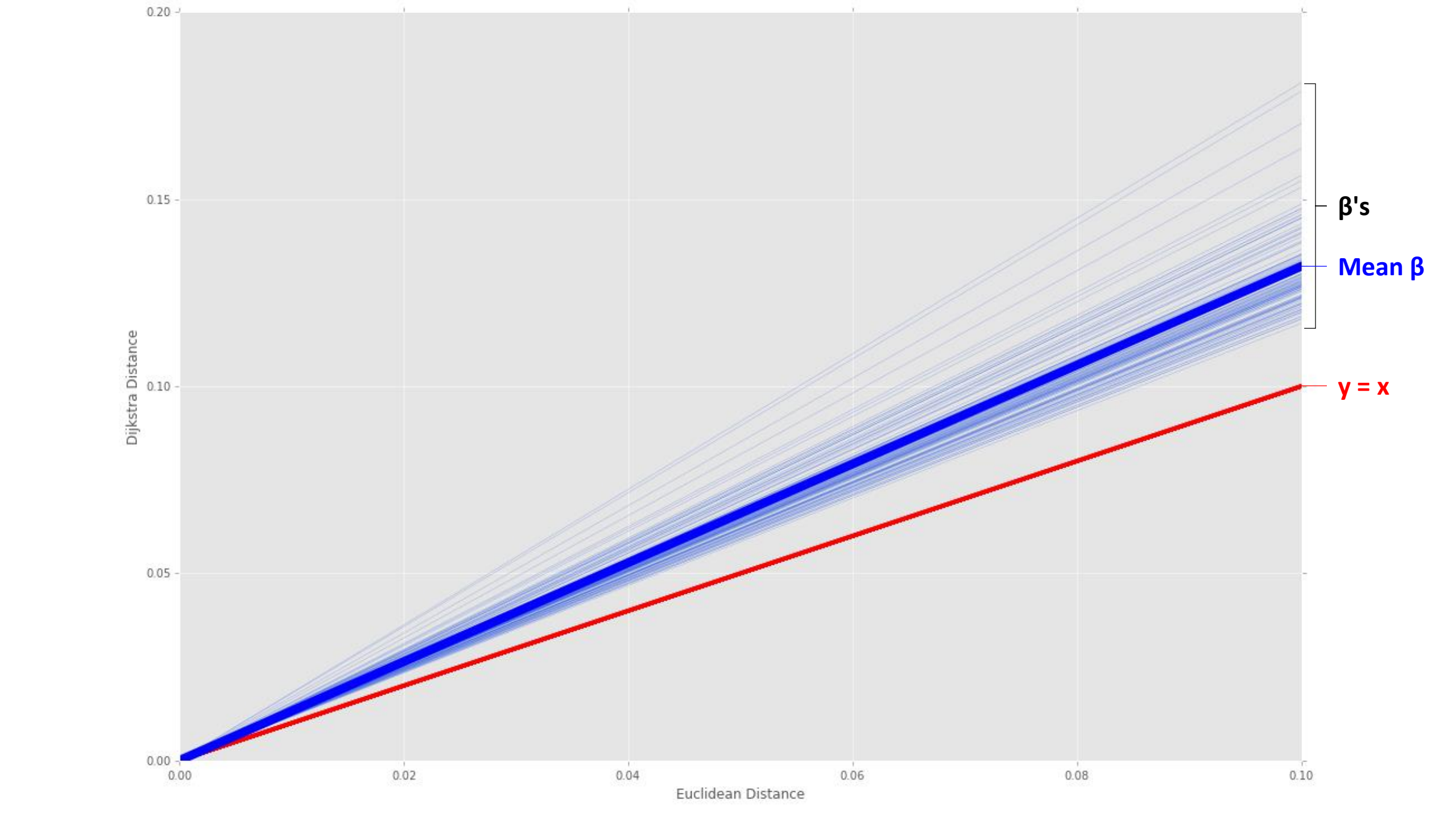

Simulation for 141010001 >> β = 1.56278 with R2 = 0.95991
Dijkstra Distance
Euclidean Distance
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16

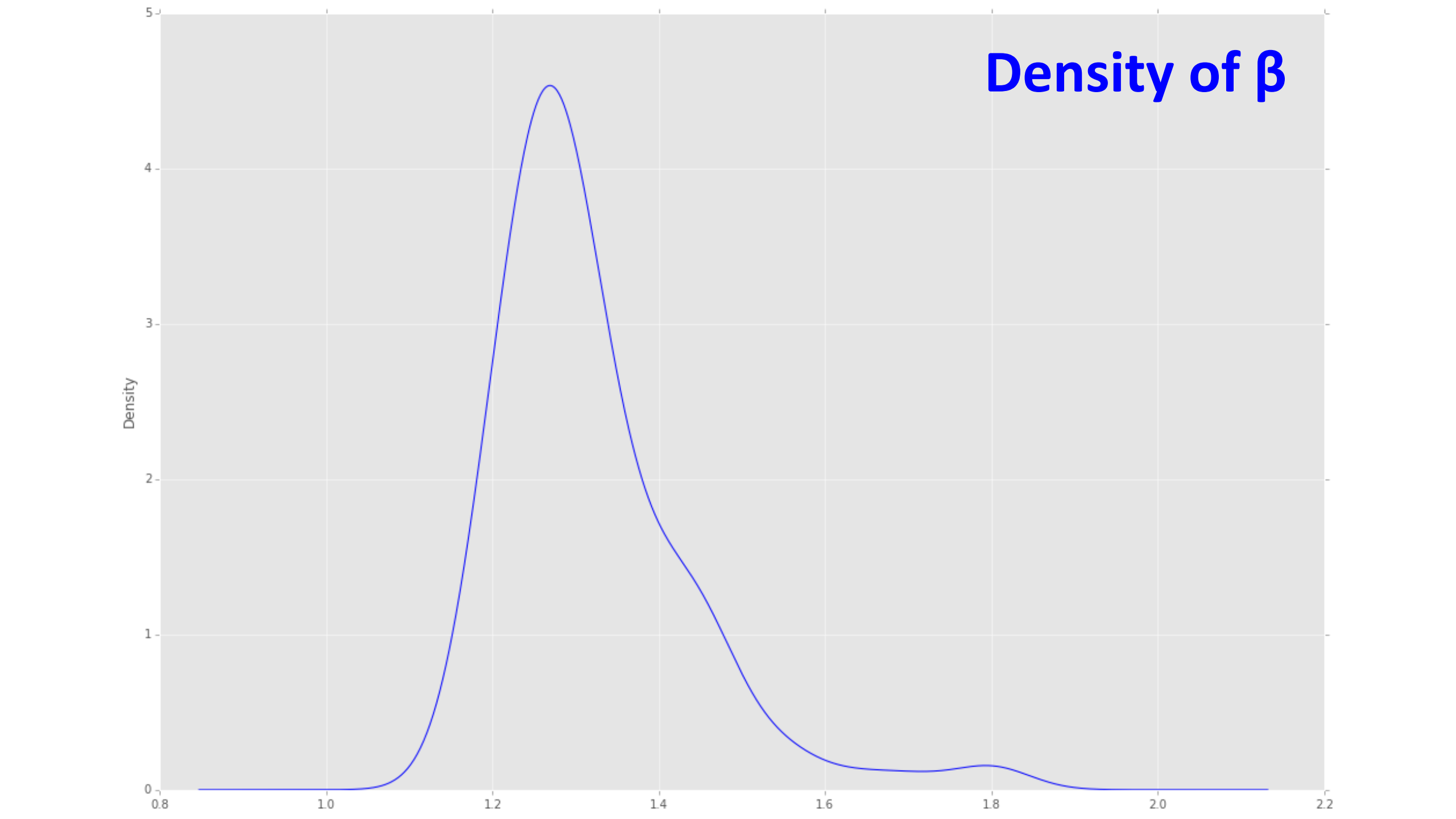

Simulation for 090150001 >> β = 1.63547 with R2 = 0.91985
Dijkstra Distance
Euclidean Distance
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07


Simulation for 150130001 >> β = 1.70175 with R2 = 0.89974
Dijkstra Distance
Euclidean Distance
0.00
0.05
0.10
0.15
0.20
0.25
0.00
0.02
0.04
0.06
0.08
0.10

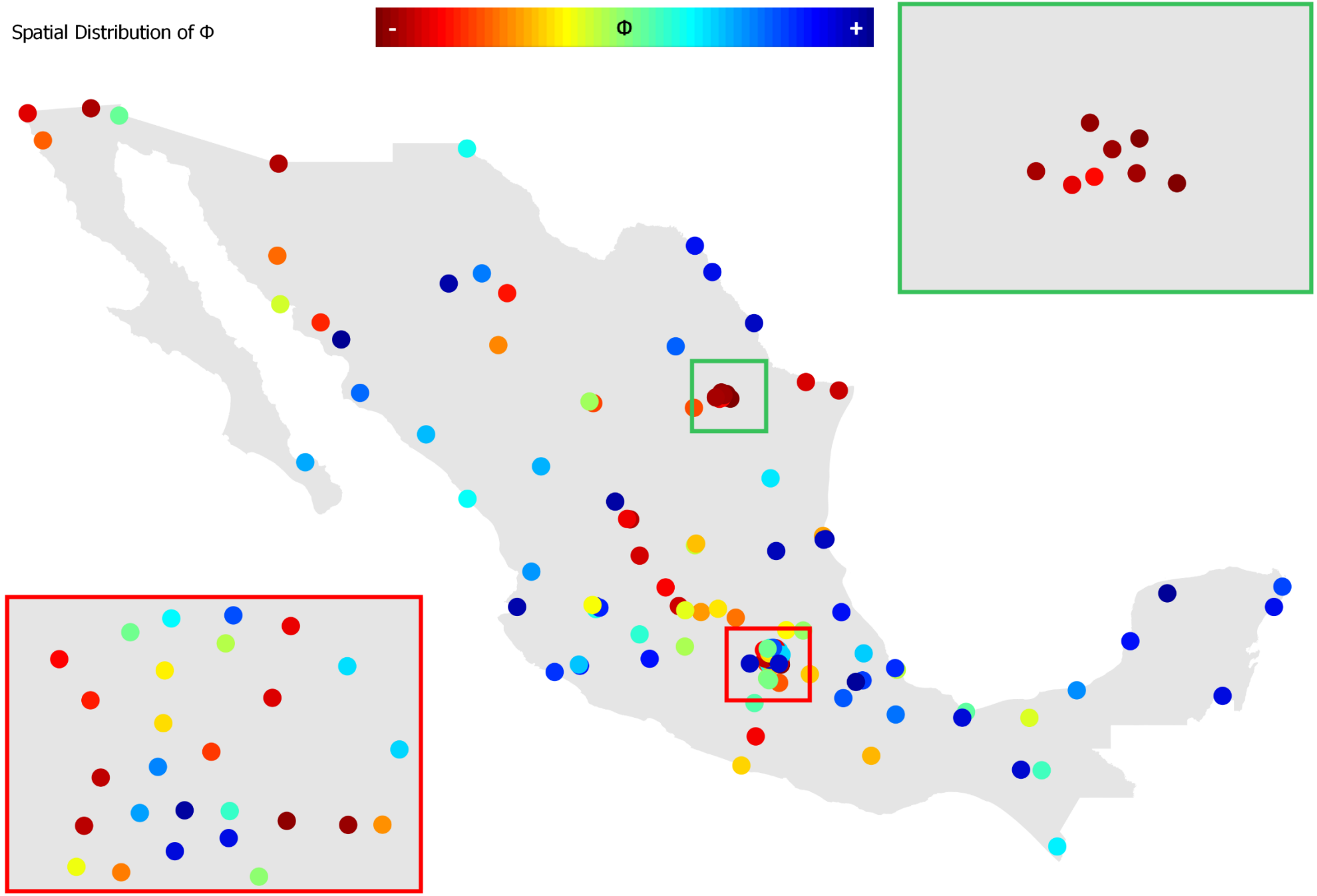

Simulation for 270040001 >> β = 1.78806 with R2 = 0.91747
Dijkstra Distance
Euclidean Distance
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08

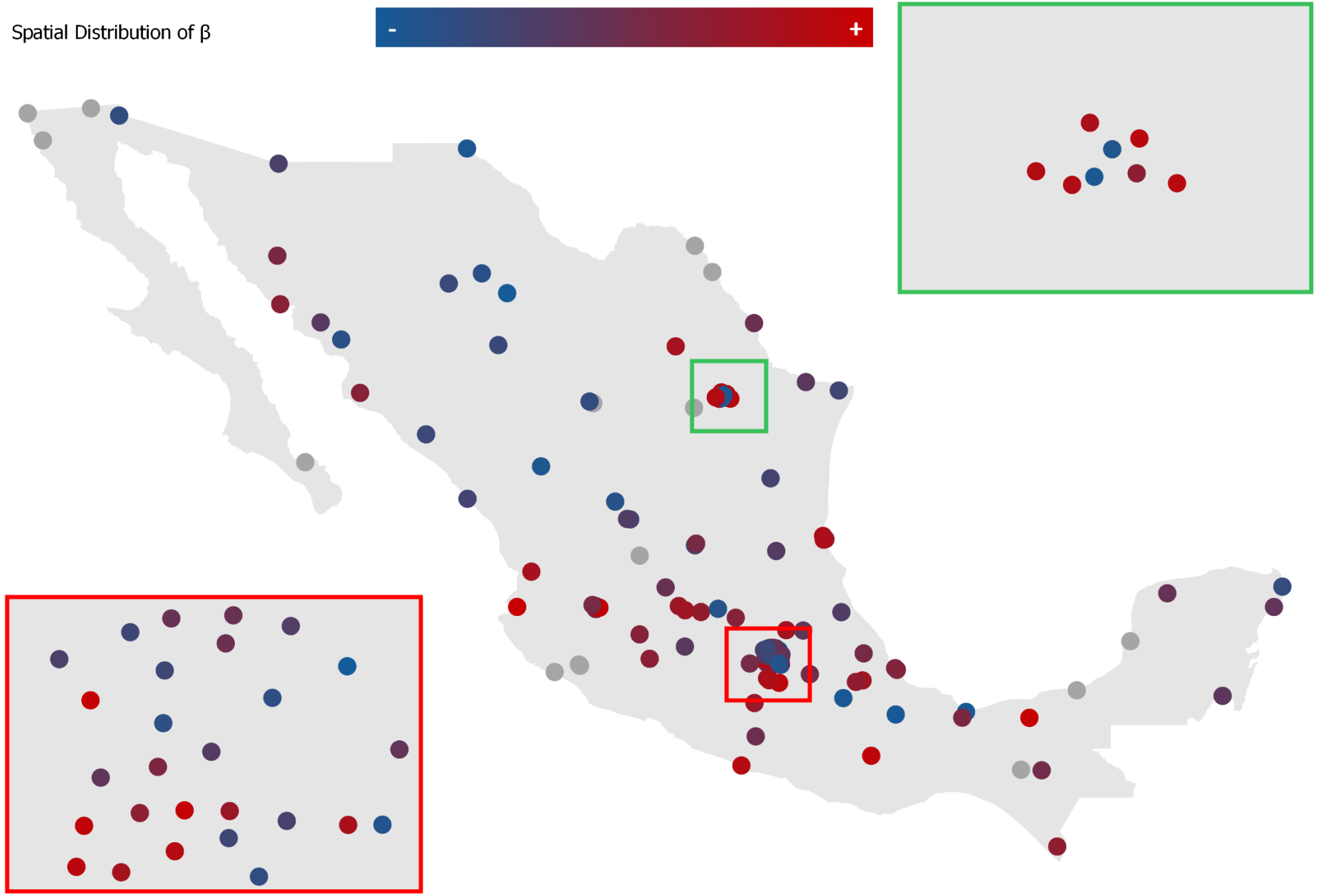

Simulation for 140670001 >> β = 1.81078 with R2 = 0.87934
Dijkstra Distance
Euclidean Distance
0.00
0.05
0.10
0.15
0.20
0.00
0.02
0.04
0.06
0.08
0.10


0.20
0.15
0.10
0.05
0.00
Dijkstra Distance
0.00
0.02
0.04
0.06
0.08
0.10
Euclidean Distance
β's
Mean β
y = x

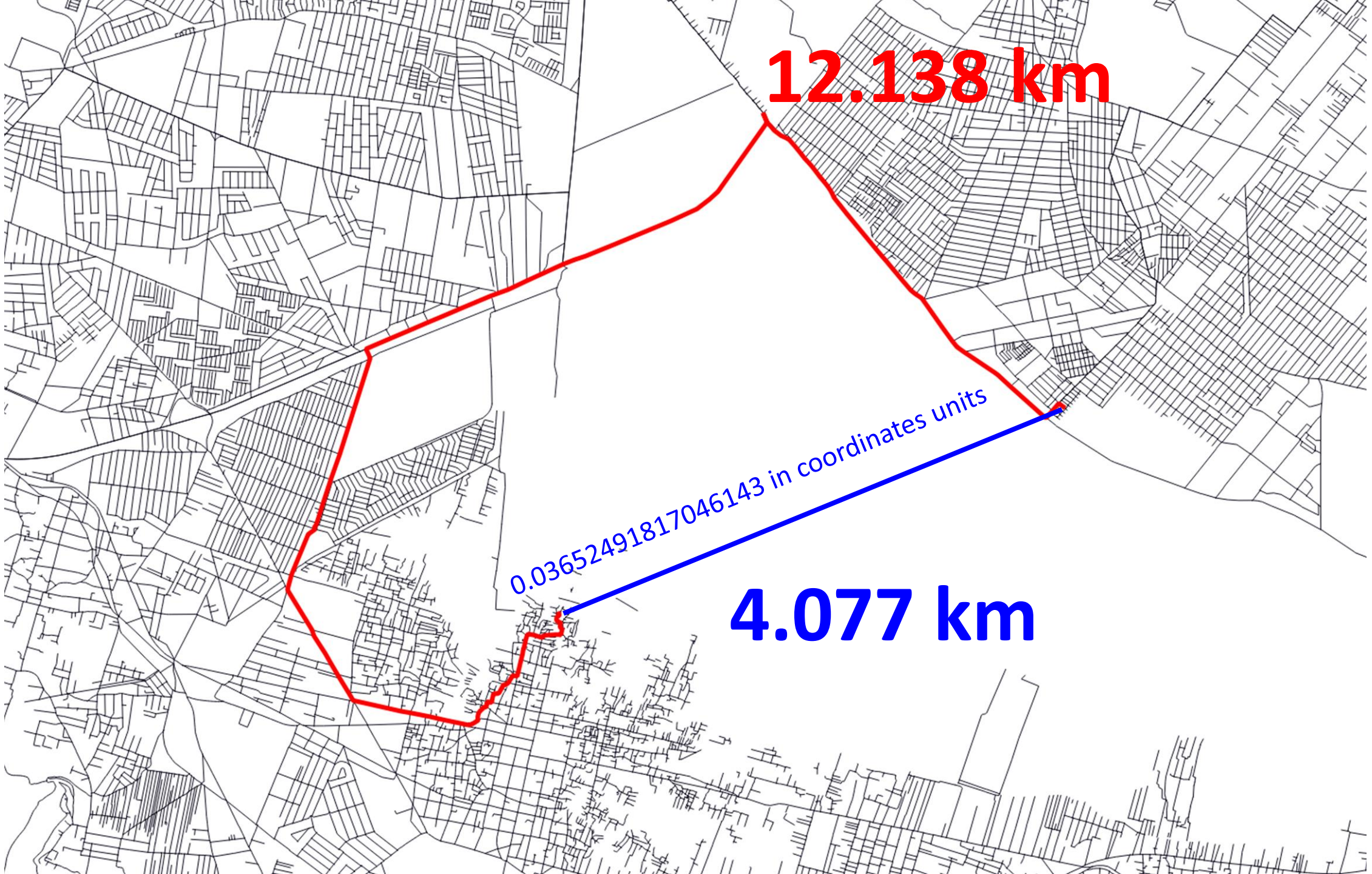

Density of β
Density
0
1
2
3
4
5
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2

City CODE	City Name	City State	Population	Algorithm I		Algorithm II	
				Mean Area	Mean Φ	Beta	Dijsktra Distance SD
090040001	Cuajimalpa de Morelos	Distrito Federal	160,491	27295.93878	0.376659232	1.474568759	0.02345428
090050001	Gustavo A. Madero	Distrito Federal	1,185,772	7099.36916	0.365577541	1.26870061	0.038004088
090060001	Iztacalco	Distrito Federal	384,326	6800.489684	0.412523366	1.241121068	0.021293927
090070001	Iztapalapa	Distrito Federal	1,815,786	6322.997377	0.381481997	1.224558398	0.034798825
090080001	La Magdalena Contreras	Distrito Federal	238,431	11620.30824	0.364117977	1.346301577	0.016890968
090100001	Álvaro Obregón	Distrito Federal	726,664	10990.63236	0.368056536	1.406745271	0.033576391
090110001	Tláhuac	Distrito Federal	305,076	9914.461863	0.421579873	1.486451454	0.030570206
090120001	Tlalpan	Distrito Federal	574,577	15028.53625	0.389124254	1.287113824	0.03098493
090130001	Xochimilco	Distrito Federal	407,885	20853.55692	0.37109726	1.352355407	0.040406396
090140001	Benito Juárez	Distrito Federal	385,439	9092.272765	0.416145379	1.45011575	0.017217731
090150001	Cuauhtémoc	Distrito Federal	531,831	9078.504263	0.433305138	1.635470029	0.025020377
090160001	Miguel Hidalgo	Distrito Federal	372,889	15909.27662	0.394122962	1.335663241	0.026735559
090170001	Venustiano Carranza	Distrito Federal	430,978	8163.707313	0.387355971	1.352689412	0.023601935
100050001	Durango	Durango	518,709	7089.446794	0.39378523	1.198417338	0.033943518
100070001	Gómez Palacio	Durango	257,352	8351.581249	0.381059559	1.233281336	0.025126341
110070001	Celaya	Guanajuato	340,387	10675.4505	0.369775301	1.34282945	0.02661146
110170001	Irapuato	Guanajuato	380,941	12216.61464	0.348786611	1.352709908	0.027292474
110200001	León	Guanajuato	1,238,962	11193.91664	0.359021468	1.280019737	0.050040581
110270001	Salamanca	Guanajuato	160,169	11863.55034	0.376868808	1.383334255	0.020720959
120010001	Acapulco de Juárez	Guerrero	673,479	7607.573957	0.372597968	1.457017929	0.087452824
120290001	Chilpancingo de los Bravo	Guerrero	187,251	7303.751929	0.358625812	1.283854061	0.021400425
120350001	Iguala de la Independencia	Guerrero	118,468	8237.983911	0.385562906	1.352006903	0.022496857
130480001	Pachuca de Soto	Hidalgo	256,584	10123.15388	0.374453578	1.388167972	0.035114158
130770001	Tulancingo de Bravo	Hidalgo	102,406	10579.80754	0.381469314	1.272023154	0.017197205
140390001	Guadalajara	Jalisco	1,495,182	8702.789097	0.417493844	1.263856992	0.03776857


Spatial Distribution of Φ
-
Φ
+

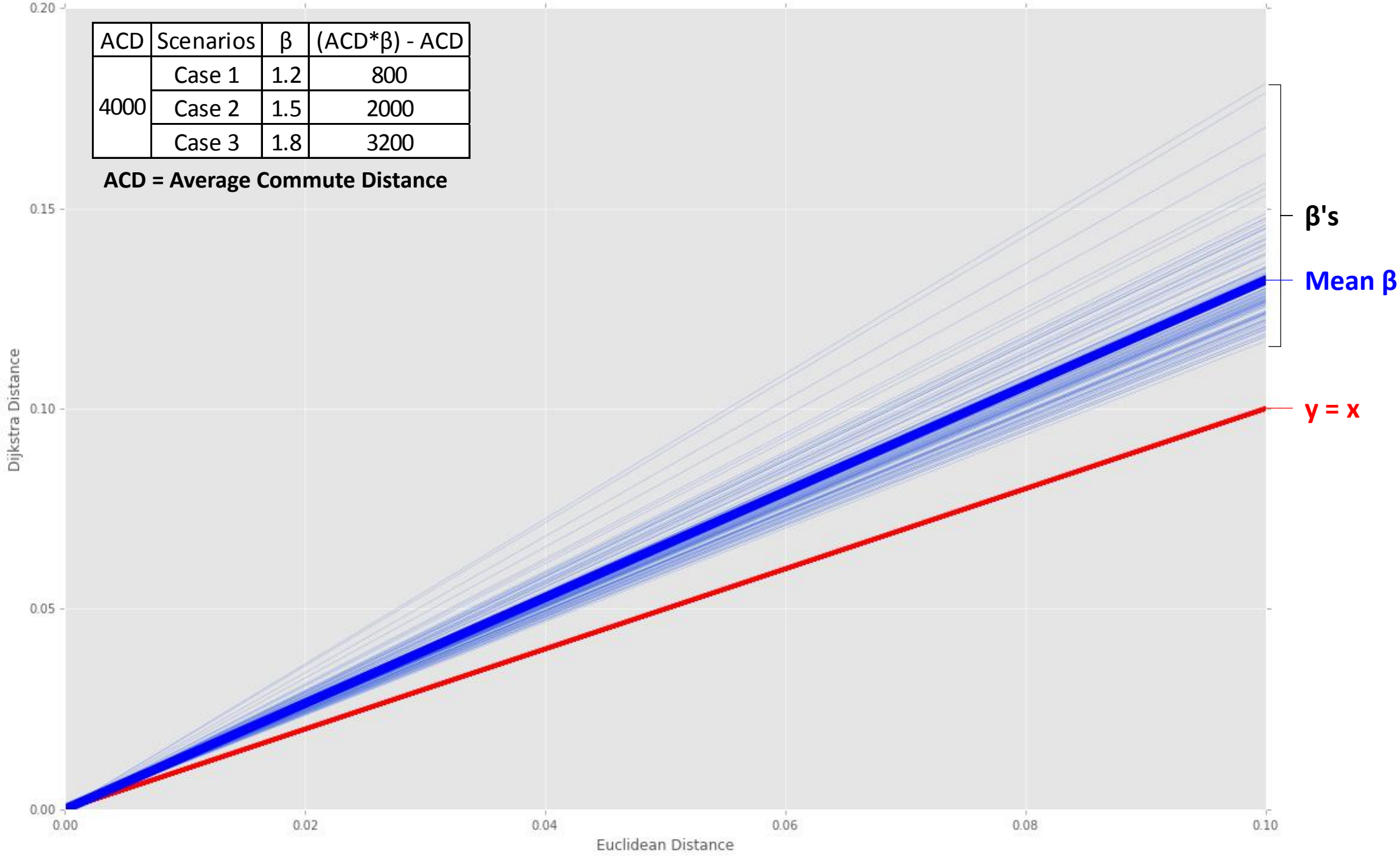

Spatial Distribution of β
-
+

Interpretation of β


12.138 km
0.03652491817046143 in coordinates units
4.077 km

ACD	Scenarios	β	(ACD*β) - ACD
4000	Case 1	1.2	800
	Case 2	1.5	2000
	Case 3	1.8	3200

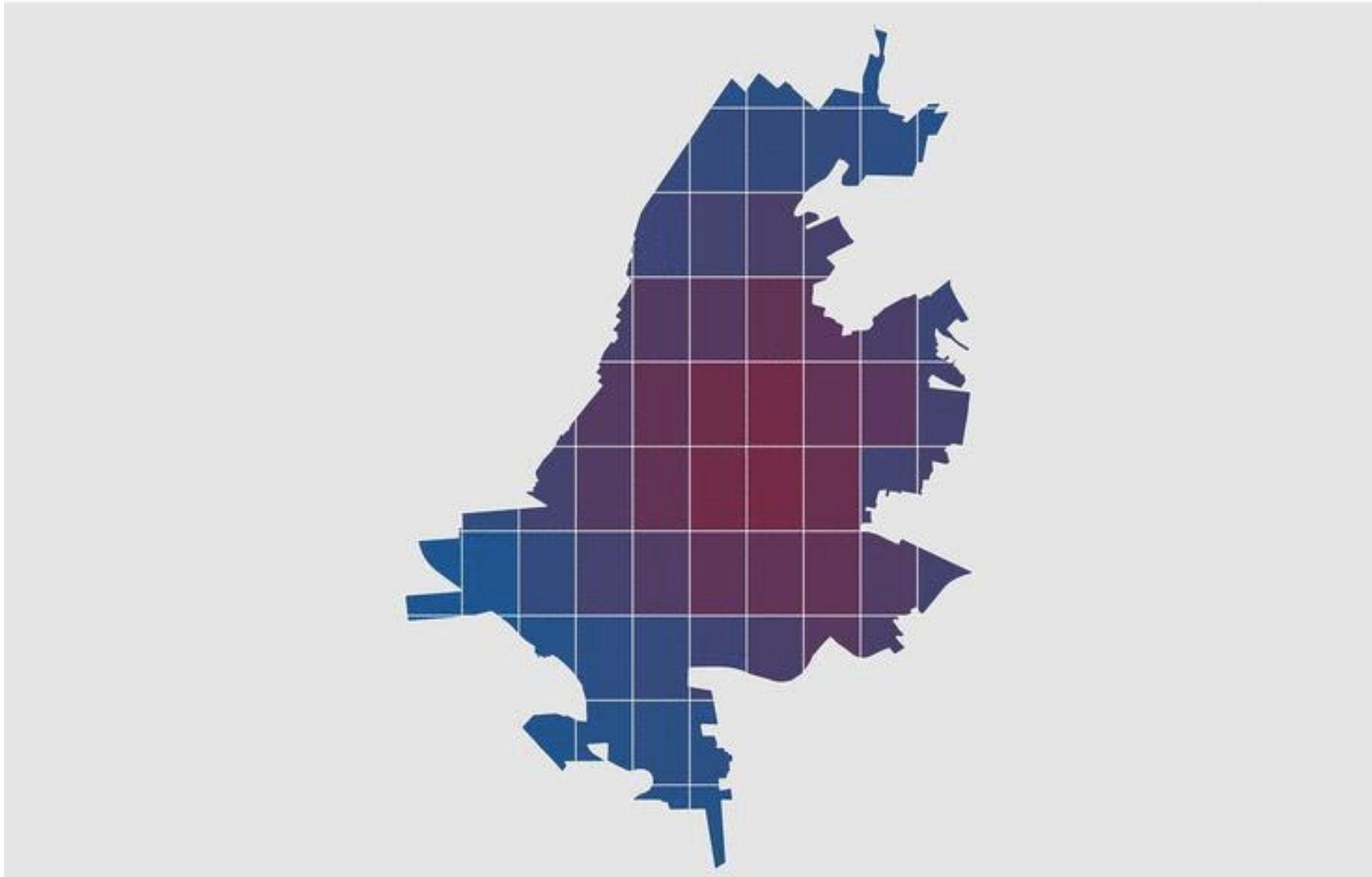
ACD = Average Commute Distance



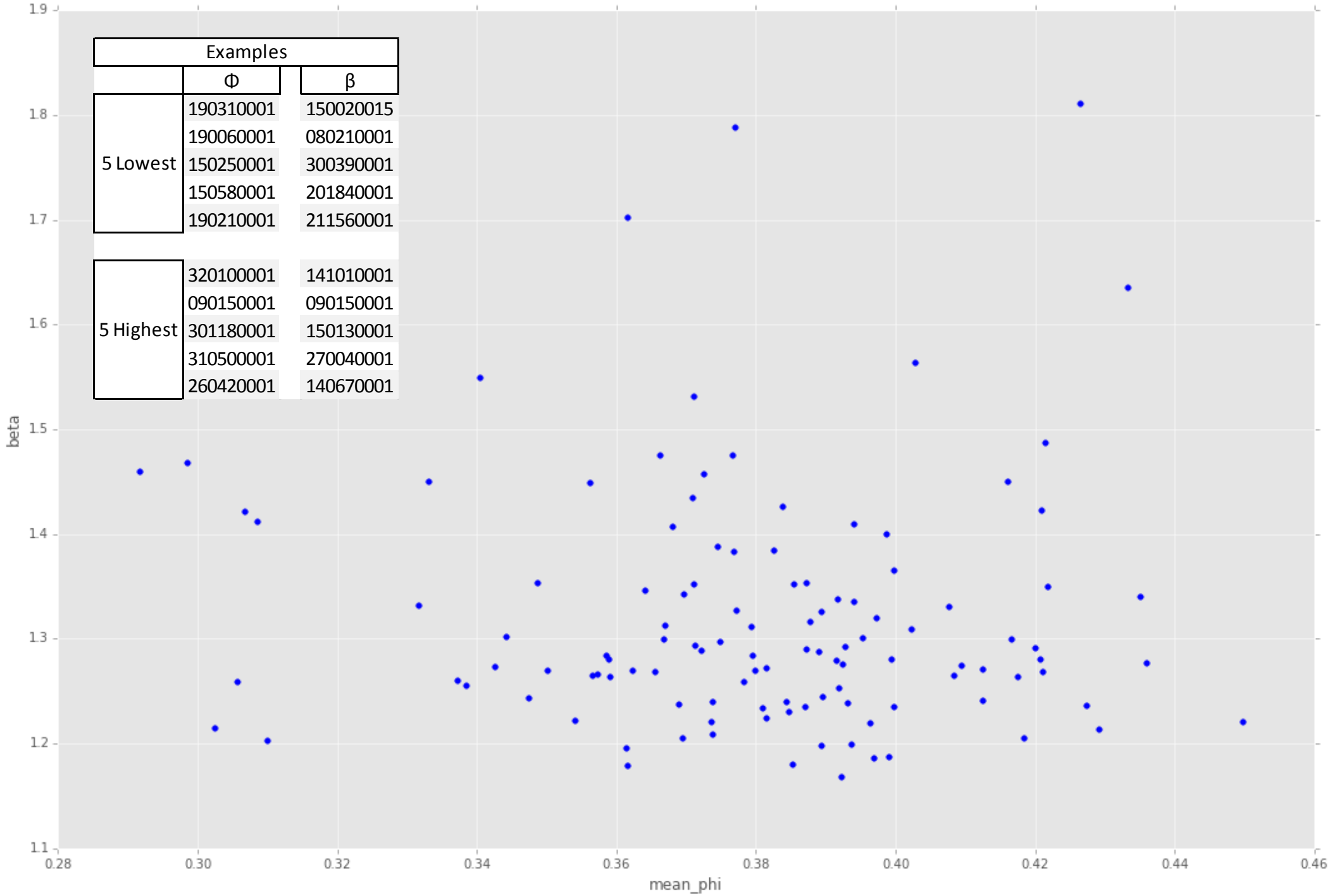
Interpretation of Euclidean / Dijkstra

Region: 050180001 Monclova

- Euclidean Distance / Dijkstra Distance +



Interpretation of Φ vs β


Examples
Φ
β
5 Lowest
190310001
150020015
190060001
080210001
150250001
300390001
150580001
201840001
190210001
211560001
5 Highest
320100001
141010001
090150001
090150001
301180001
150130001
310500001
270040001
260420001
140670001
beta
mean_phi
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
0.28
0.30
0.32
0.34
0.36
0.38
0.40
0.42
0.44
0.46

Conclusions

Conclusions

- According to this simulations, cities fingerprint's (block based) are not necessarily correlated with longer commute patterns.

- Commute patterns are more correlated with properties of the street network rather than to its shape.

- In average, for a universe of 115 cities in Mexico street networks increase 30 percent the distance on each commute as opposed to a theoretical world in where two points are Euclidean distance accessible (a world with no streets).

References

TDMUM_1972 = Sargent 1972. Toward a dynamic model of urban morphology

ACNA_2006 = Andersson 2006. A complex network approach to urban growth

MSRN_2006 = Yin 2006. Measuring the Structure of Road Networks

TSP_2014 = Louf and Barthelemy 2014. A typology of street patterns


''' A city's physical structures, once established, may remain in place for more than 150 years '''