Spatial-Temporal Distributions of Fossil Fuel Resources in West Virginia: 1970 – 2017

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Geography 550: Geographical Information Systems

Abstract:

Spatial proximity to fossil fuel resources has negative health consequences. Fifty-three of West Virginia's fifty-five counties sit upon mineable coal seams, while forty-five have permitted Marcellus Shale well production. The present study examines the spatial and temporal – on a decadal basis – distributions of coal mine and Marcellus shale well locations throughout the state of West Virginia. It was determined that the spatial distribution of fossil fuel production has changed dramatically over time. From 1970 to 2000, the central features of permitted mines in West Virginia were in Raleigh and Kanawha counties. From 2000 to 2017, however, those central features shifted north with the increase of Marcellus Shale production to Roane and Doddridge counties. Further, it was determined that these fossil fuel resources at each decadal interval were clustered according to an average nearest neighbor statistic for both coal and natural gas resources.

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West Virginia has mined bituminous coal since the early 1800s in Wheeling (WV Mine and Safety). More recently, the first Marcellus Shale well site was only permitted in the Kanawha County in 2002 (WV Encyclopedia). The energy sector has been incredibly important to the state: West Virginia is the fourth-largest energy producer in the country with 14% of the national coal production and 6% of natural gas production, respectively (EIA). However, natural gas surpassed coal for the first time in 2019 (EIA).

If the share to the energy sector is changing temporally, what is happening spatially? What is the distribution of fossil fuel production throughout West Virginia, and how has it changed over time? What are the public health outcomes resulting from proximity to fossil fuel production? The present study attempts to answer the first question which could assist in answering the second question in the future.

Materials and Methods:

Coal Mine Data

Underground coal mine shapefiles were obtained from the West Virginia Department of Environmental Protection. Each coal mine shapefile had an associated issue date which was then used to create a new variable – Issue Year – that was used for this analysis. While the coal mine data contained shapefiles for mines throughout the state, the issue date was only reliable starting from 1970 on. Further, to create a 1:1 comparison of central features over time, centroids of the coal mine polygons were calculated using the Feature to Point function in ArcGIS Pro.

In total, the WVDEP issued 3,997 permits to coal mines from 1970 to 2017. 1983 had the highest number of permitted mines issued with 479.

Marcellus Shale Data

Marcellus shale well production and location data were obtained from the West Virginia Geological and Economic Survey. Each Marcellus shale well had an associated issue date which was then used to create a new variable – Issue Year – that was used for this analysis. These data were originally in point form, so no further transformations were necessary. In total, the WVDEP issued 2,881 Marcellus Shale permits from 2000 to 2016. 2007 had the highest number of permitted well sites with 453.

Note on Data:

The WVDEP coal mine data starts prior to 1970 but the issue date isn't reliable. Only locations with reliable issue dates were used in this analysis. Additionally, the WVGES Marcellus Shale well data had permitted well sites up until 2022, while the WVDEP coal mine data only went until 2017.

West Virginia and County Shapefiles:

Shapefiles for the state and each individual county were obtained from the West Virginia Department of Environmental Protection. The datum for this analysis was the NAD 1983 UTM Zone 17N datum.

Spatial Analyses:

All analyses for this study were performed in ESRI ArcGIS Pro 3.1.2 software. Coal mine shapefiles and permitted well sites were imported into ArcGIS Pro. First, the coal mine shapefiles had to be transformed into point data to create a 1:1 comparison of central feature data over time. This transformation was performed using the Feature to Point function which calculated the centroid of each polygon and produced an associated point. The next step was to create a new variable in the coal mine data calculated on issue date. A new field was created called Issue Year which was calculated using python 3's year() function in ArcGIS Pro. This created an associated year value for each coal mine point. Finally, each year was grouped into decades to examine the spatial characteristics of WV DEP permitted mine activity temporally on a decadal scale.

Each decade of permitted mines was then analyzed to create a point density raster grid, a central feature, and a mean center point. These functions identify "the most centrally located feature in a point, line, or polygon feature class" and the "geographic center of a set of features", respectively (Esri). A mask of the WV polygon was employed for each point density raster via the environmental variables. This was to ensure that the point density function didn't "bleed" into adjoining states. Additionally, the spatial autocorrelation distance for each map was specified using the collect events tool to capture multiple sites (both mine and well) that were located at the same location. The distance were spatial autocorrelation was most pronounced was used as the distance threshold in the point density calculation.

A similar process is employed for the Marcellus Shale well data. Unfortunately, the issue date data was not in a standardized format: a transformation of the text string was employed to correct incorrectly specified issue date strings. Python 3's year() function was used to create a new variable called Issue Year. These data, too, were grouped by decade according to issue date to analyze natural gas production on a decadal scale. Central Feature and Mean Center function were calculated to find where, spatially, natural gas production was located throughout the state foe each decade.

A spatial join was employed to join WVDEP coal mine data to each respective county. The county shapefile was used as the clip feature to join coal mine location data by county. This data was then exported to excel, grouped by decade and pivoted to create number of coal mines by decade by county (Table 1).

Results:

The first decade of coal mine data had 289 permitted coal mines throughout the state. Most of these coal mines were in a six-county cluster of Kanawha, Boone, Logan, Wyoming, Raleigh, and Fayette (Figure 1; Table 1). A point density estimation was calculated on the locations of 1970s coal mines as well as a feature point for the Central Feature and Mean Center of these coal mines. The Central Feature for the 1970's bin was the NuEast Mining Corp site which was issued a permit on December 4th, 1979. The Mean Center calculation was located northeast of the Central Feature in Nicholas County.

The 1980s had the most mine activity of any of the analyzed decades (Table 1). In total, there were 1,854 coal mines permitted in the 1980s. The spatial distribution of the coal mines has started to shift south: a point density estimation was calculated which shows that Logan County has the most activity. (Figure 3) The Central Feature and Mean Center functions show that the No. 77 Surface Mine in Kanawha County is the most central coal mine while the mean center mine is, again, located in Nicholas County.

There was a roughly 48% decline in the number of permitted coal mines from the 1980s to the 1990s: 1,854 to 961. According to the point density estimation, Boone County has the highest magnitude of coal miles, while the Central Feature is also located in Boone. The Twilight

Upper Cedar Grove coal mine operated by Independence Coal Company is the central most feature, while the Mean Center is in Fayette County (Figure 5).

The turn of the millennium saw, once again, a decline in coal mine permits. The 2000s had 571 permitted mines (Table 1). This was a 40.5% decline from the 1990s and a 69.2% decrease from the high point of the 1980s. A point density estimate was calculated which showed that the magnitude of permitted mine sites has decreased and shifted spatially. Boone County and Fayette Counties had the Central-most Feature and Mean Center Feature, respectively (Figure 7).

The final decade, 2010s, of the coal mine data had the fewest permitted mines since the 1970s with 320 (Table 1). This is a 44% decrease since the 2000s and an 83% decrease since the 1980s. Raleigh County had the central most feature while Fayette Count have the mean center feature. A point density estimation was calculated which found that the southernmost county in West Virginia, McDowell County, had the highest magnitude of permitted wells (Figure 9).

The next section of this analysis is an examination of permitted Marcellus Shale wells from the WV Department of Environmental Protection. In the 2000s, the WV DEP permitted 1,628 well sites in West Virginia (Table 2). The Central-most Feature was Triad Resources' site in Roane County which was also the where the Mean Center Feature was located. In one decade, the spatial distribution of fossil fuel resources shifted from the southern part of the state to the center (Figure 11).

The 2010's is the last decade in the analysis of Marcellus Shale well location data. In this decade, the WV DEP issued 2,950 permits (Table 2). A point density estimate was calculated which showed that Doddridge County had the highest magnitude of permitted well sites in the state. Additionally, the Central Feature and Mean Center features have shifted north. Jay-Bee Oil

& Gas was the central feature in Tyler County while the Mean Center feature was located in Wetzel County (Figure 13). There were zero permitted well sites south of Kanawha County.

It was determined using the Average Nearest Neighbor statistic that coal mines and natural gas wells were clustered at every decadal interval (Figure 2; Figure 4: Figure 6: Figure 8; Figure 10; Figure 12: Figure 14).

Tables 1 and 2 were illustrative in finding the difference between permitted coal mine activity and Marcellus shale well activity by county. For example, Doddridge had no newly permitted coal mines in the study period but was the county with the highest number of permitted wells in the natural gas data.

Logan County, on the other hand, had the highest number of permitted mine activity between 1970-2017, a very high number (202) of permitted well activity between 2000-2009 and then zero permitted well activity from 2010-2019. Did Logan County miss out on the Marcellus Shale boom? The same pattern holds for Mingo, Boone, and McDowell Counties. The area once dominated by coal now left behind by natural gas.

Discussion:

The spatial characteristics of fossil fuel production has shifted over time. Coal, which was once the largest producer in the energy sector in the state, is now second to natural gas. The mean location of fossil fuel production used to be at the nexus of Logan, Boone, Raleigh, and Fayette Counties; now, Doddridge and Wetzel Counties are where most of the fossil fuel production is located.

What effect does this have on a population? From an economic standpoint, local economies depended on the jobs and tax base that no longer exists; from a public health standpoint, the concomitant health effects associated with fossil fuel production are real and need to be addressed. As for areas with current fossil fuel production, populations need to know if the air they breathe and water they drink are contaminated.

Rabinowitz, et al, found that living within 1km of a natural gas well was associated with upper respiratory conditions (Rabinowitz, et al, 2015). Hendryx and Ahern surveyed 16,493 West Virginians and found that higher levels of coal production were associated with “worse adjusted health status” (Hendryx & Ahern, 2008). Hendryx, et al, find that chemical discharge quantities were associated with higher “non-cancer mortality rates” (Hendryx, 2012). Ahern (2011) finds that birth defects were significantly higher in mountain-top mining areas than non-mining areas. Hendryx (2015), in a review of the literature, finds that a link in “epidemiological disease patterns for populations located in proximity to surface mining”.

This analysis set out to examine where fossil fuel production occurred throughout the state and how those spatial characteristics changed over time. From a managerial perspective, it would be beneficial to know where mines and well sites are located spatially to monitor methane emissions or coal mine refuse; from a public health perspective, looking to the past would be beneficial to link fossil fuel production to deleterious health outcomes in the present and future.

Coal mines and natural gas wells are clustered spatially throughout the state. Temporally, when they were permitted has a direct association with fossil fuel emissions and pollution. Knowing both characteristics is key in identifying epidemiological connections between human health and fossil fuel production.

References:

Ahern, M. M., Hendryx, M., Conley, J., Fedorko, E., Ducatman, A., & Zullig, K. J. (2011). The association between mountaintop mining and birth defects among live births in central Appalachia, 1996-2003. *Environmental research*, 111(6), 838–846. https://doi.org/10.1016/j.envres.2011.05.019

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Mining in West Virginia: A capsule history. WV Office of Miners' Health Safety and Training. (2022, February 7). https://minesafety.wv.gov/historical-statistical-data/mining-in-west-virginia-a-capsule-history/#:~:text=1810%20First%20commercial%20coal%20mine,coal%20to%20the%20salt%20industry.

Rabinowitz, P., Slizovskiy, I., Lamers, V., Trufan, S., Holford, T., Dziura, J., Peduzzi, P., Kane, M., Reif, J., Weiss, T., Stowe, M. (2015). Proximity to Natural Gas Wells and Reported Health Status: Results of a Household Survey in Washington County, Pennsylvania. *Environmental Health Perspectives*. 123 (1). 21-26

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Table 1:

Coal Mines						
County	1970-1979	1980-1989	1990-1991	2000-2009	2010-2020	County Total
Logan	19	260	97	56	29	461
Boone	37	194	108	87	24	450
Mingo	20	170	120	66	24	400
McDowell	20	128	111	51	55	365
Nicholas	20	136	50	30	17	253
Kanawha	34	121	33	37	18	243
Raleigh	13	75	49	41	27	205
Wyoming	12	77	51	29	29	198
Fayette	11	88	24	33	14	170
Monongalia	9	82	29	16	11	147
Preston	16	96	19	3	1	135
Greenbrier	20	50	31	12	10	123
Webster	5	37	26	16	6	90
Harrison	1	26	23	9	10	69
Upshur	3	28	28	5	3	67
Randolph	4	32	17	6	5	64
Barbour	2	35	13	7	7	64
Grant	6	28	16	10	2	62
Wayne	0	23	28	6	3	60
Clay	6	30	15	4	3	58
Marion	1	28	10	6	3	48
Mineral	7	14	7	6	0	34
Lincoln	0	6	12	11	4	33
Braxton	1	20	4	4	3	32
Tucker	6	10	6	2	1	25
Mercer	0	8	6	1	4	19
Lewis	4	11	3	0	0	18
Mason	1	7	5	3	0	16
Taylor	0	6	3	2	3	14
Marshall	0	2	4	7	1	14
Brooke	1	7	1	1	0	10
Ohio	0	5	0	1	2	8
Berkeley	3	3	0	1	1	8
Jefferson	1	4	1	0	0	6
Pocahontas	0	4	2	0	0	6
Pendleton	2	1	0	1	0	4

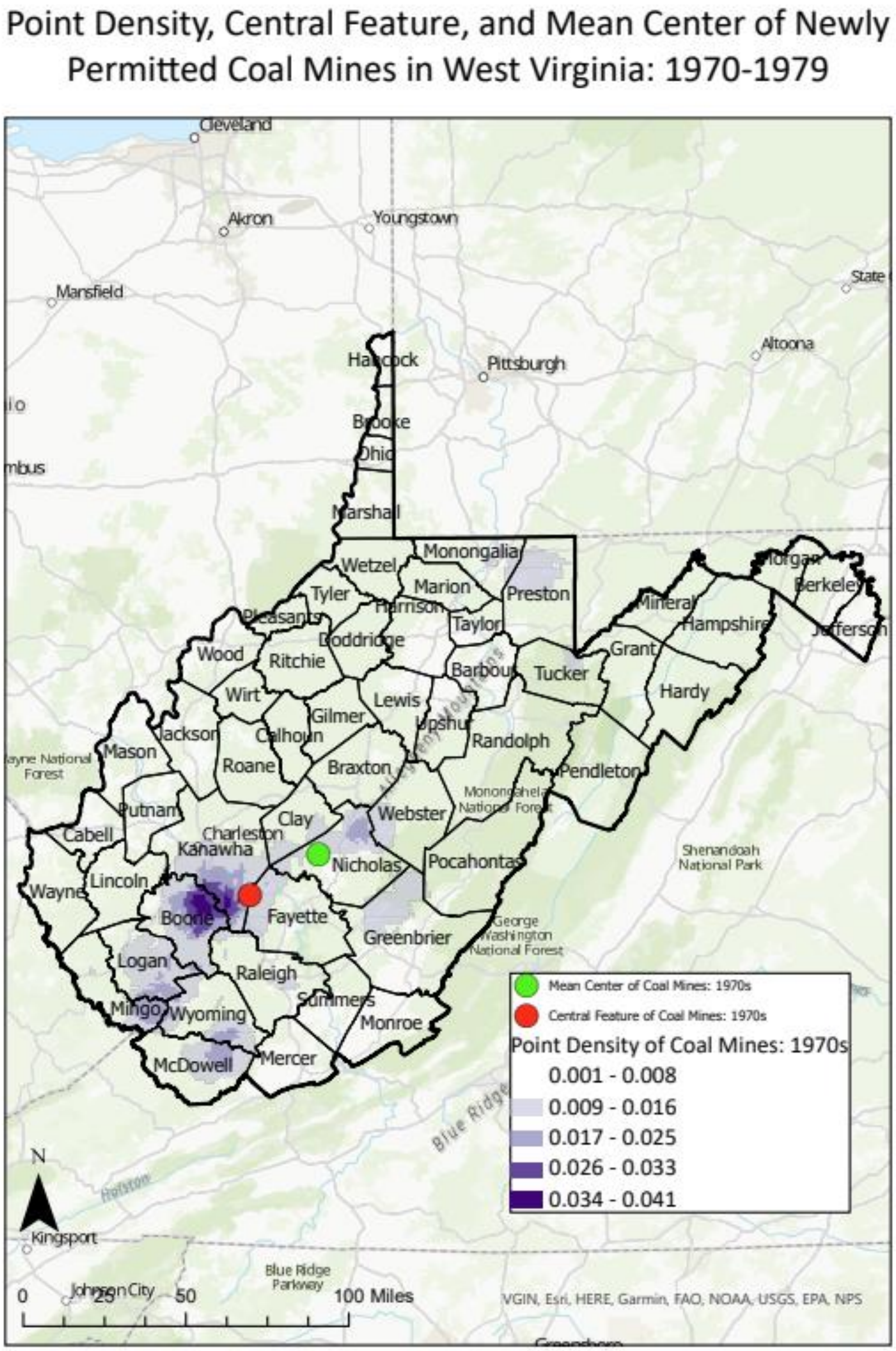
Hancock	1	1	1	0	0	3
Wood	0	0	2	1	0	3
Morgan	2	0	1	0	0	3
Gilmer	0	0	2	0	0	2
Hampshire	1	0	1	0	0	2
Ritchie	0	0	1	0	0	1
Roane	0	0	1	0	0	1
Putnam	0	1	0	0	0	1
Decade Total	289	1,854	961	571	320	3,995

Table 2:

Natural Gas Wells			
County	2000-2009	2010-2019	Grand Total
Doddridge	111	521	632
Marshall	52	444	496
Tyler	46	385	431
Wetzel	67	356	423
Ritchie	148	257	405
Harrison	48	260	308
Logan	202	0	202
Kanawha	189	2	191
Ohio	0	170	170
Brooke	0	131	131
Upshur	56	72	128
Boone	124	2	126
Jackson	122	3	125
Monongalia	1	104	105
Lincoln	112	0	112
Marion	9	78	87
Putnam	75	12	87
Taylor	8	67	75
Roane	62	0	62
Barbour	7	35	42
Mingo	29	1	30
McDowell	27	2	29

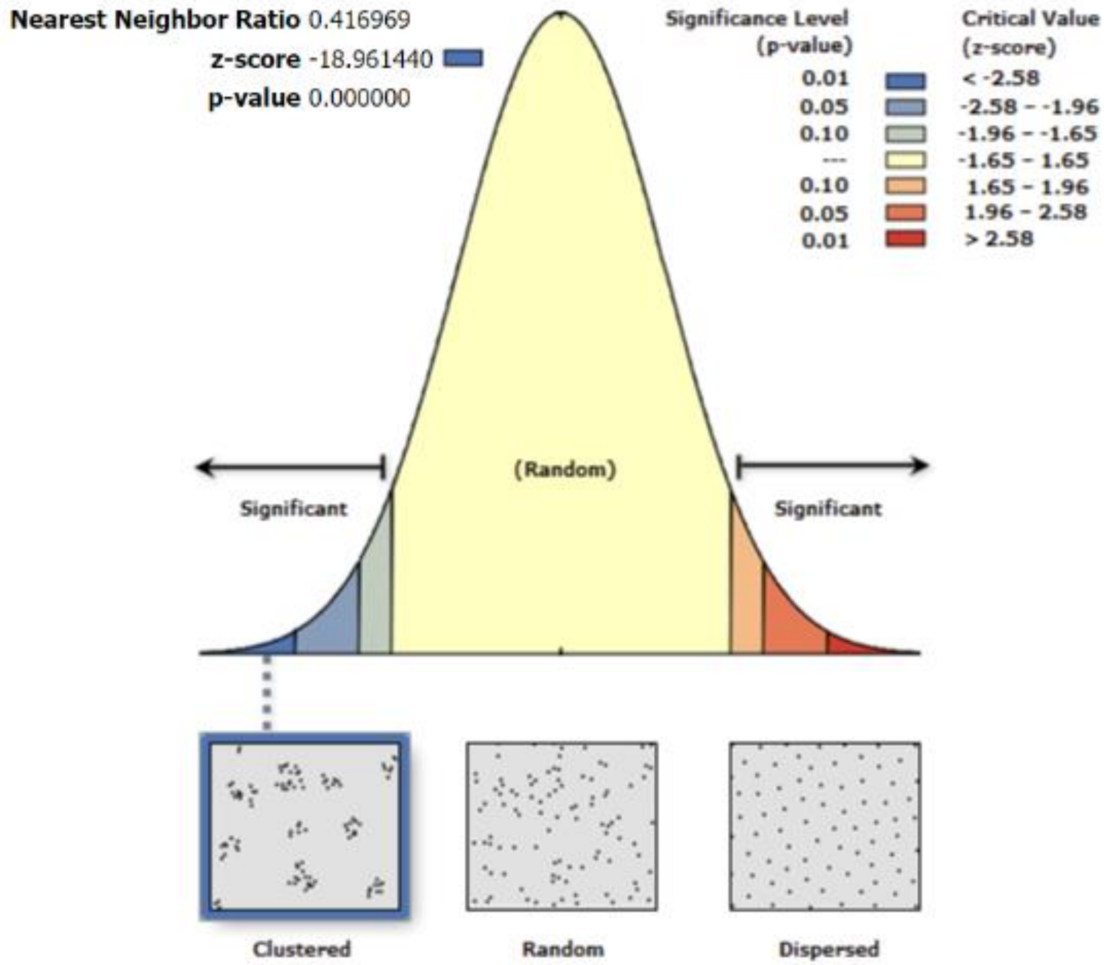
Wyoming	27	0	27
Preston	17	9	26
Pleasants	12	8	20
Gilmer	9	7	16
Lewis	10	5	15
Calhoun	14	0	14
Wayne	13	0	13
Nicholas	7	5	12
Webster	4	3	7
Randolph	5	2	7
Braxton	3	0	3
Greenbrier	0	3	3
Raleigh	3	0	3
Grant	1	2	3
Wirt	1	1	2
Hancock	2	0	2
Hardy	1	0	1
Fayette	1	0	1
Mason	1	0	1
Tucker	0	1	1
Wood	0	1	1
Clay	1	0	1
Pendleton	0	1	1
Mineral	1	0	1
Grand Total	1628	2950	4578

Figure 1:



Chad Efaw
Projected Coordinate System: NAD 1983 UTM 17N
Source: West Virginia Department of Environmental Protection

Figure 2: The ANN statistic suggesting the spatial clustering of coal mines (1970-1979)

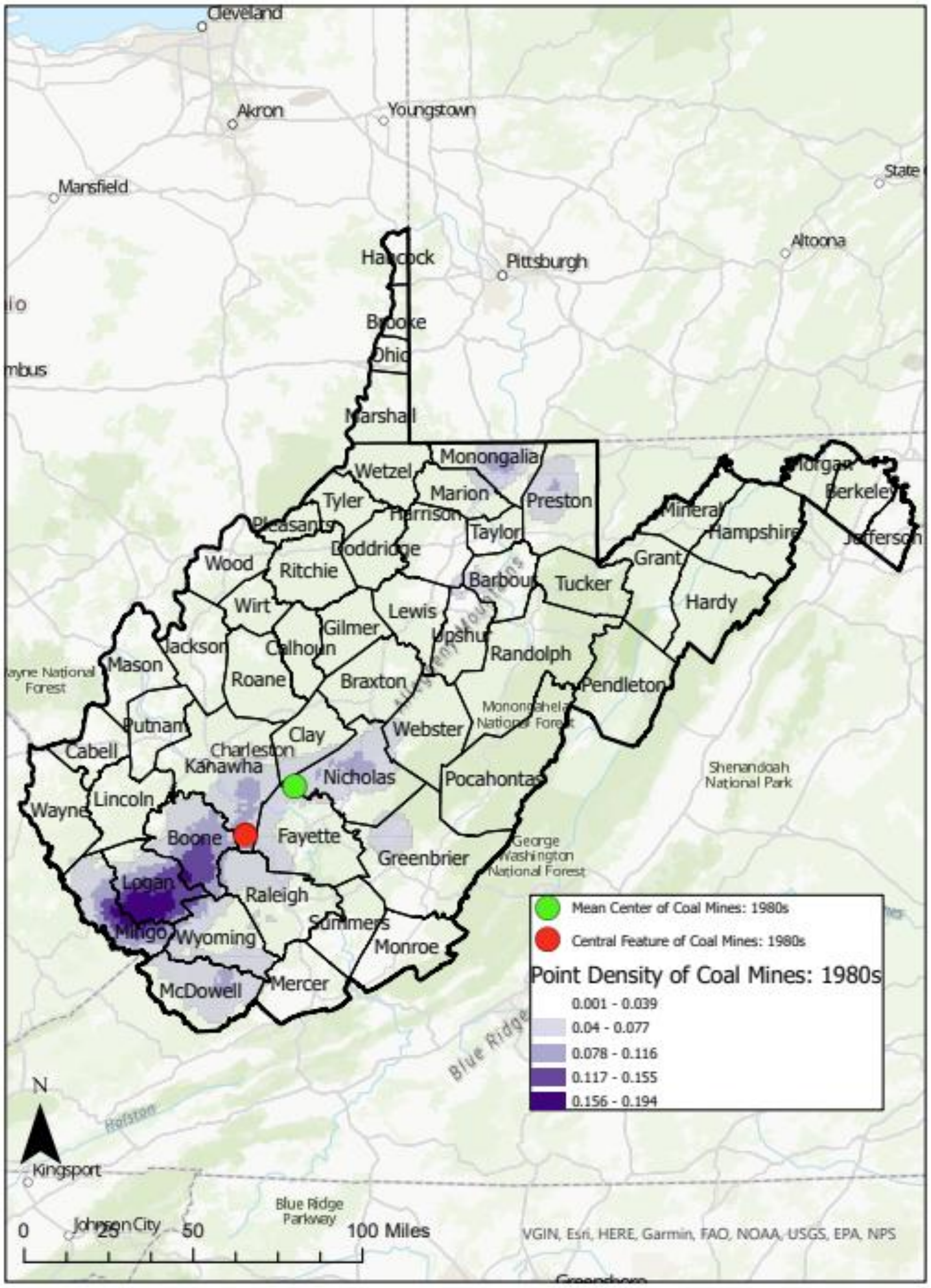


Given the z-score of -18.96144, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Average Nearest Neighbor Summary	
Observed Mean Distance	5226.5178 Meters
Expected Mean Distance	12534.5418 Meters
Nearest Neighbor Ratio	0.416969
z-score	-18.961440
p-value	0.000000

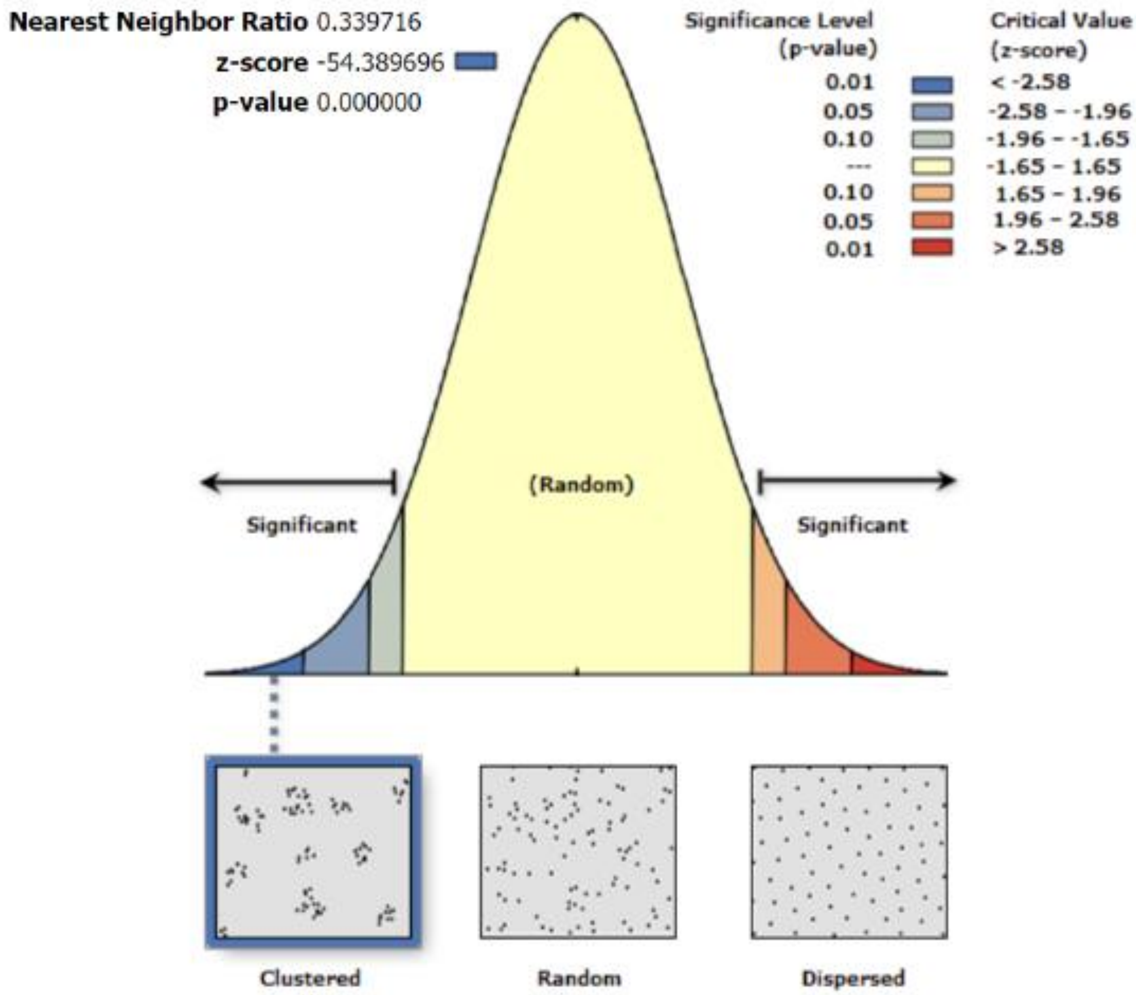
Figure 3:

Point Density, Central Feature, and Mean Center of Newly Permitted Coal Mines in West Virginia: 1980-1989



Chad Efaw
Projected Coordinate System: NAD 1983 UTM 17N
Source: West Virginia Department of Environmental Protection

Figure 4: The ANN statistic suggesting the spatial clustering of coal mines (1980-1989)

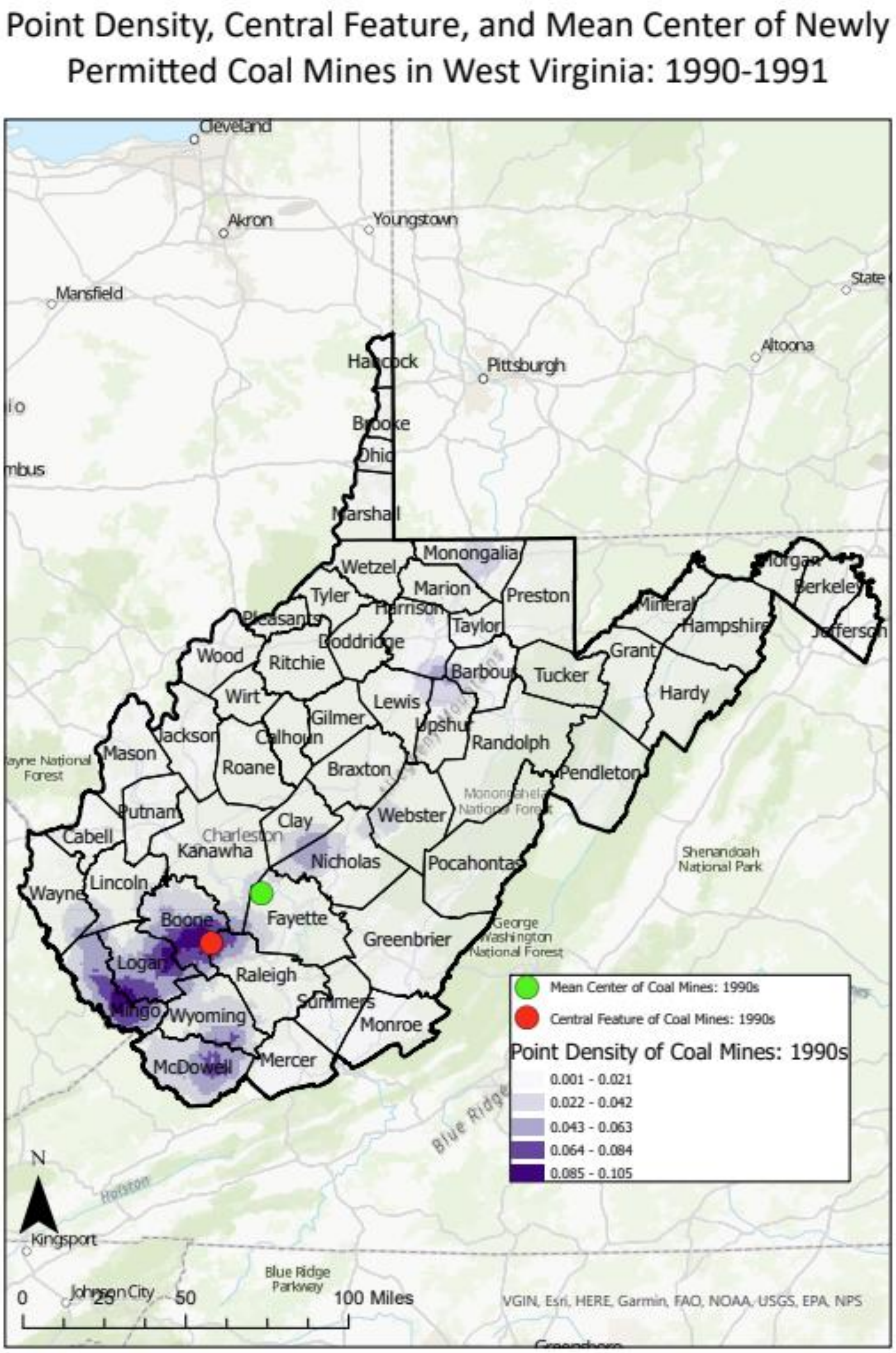


Given the z-score of -54.389696, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Average Nearest Neighbor Summary

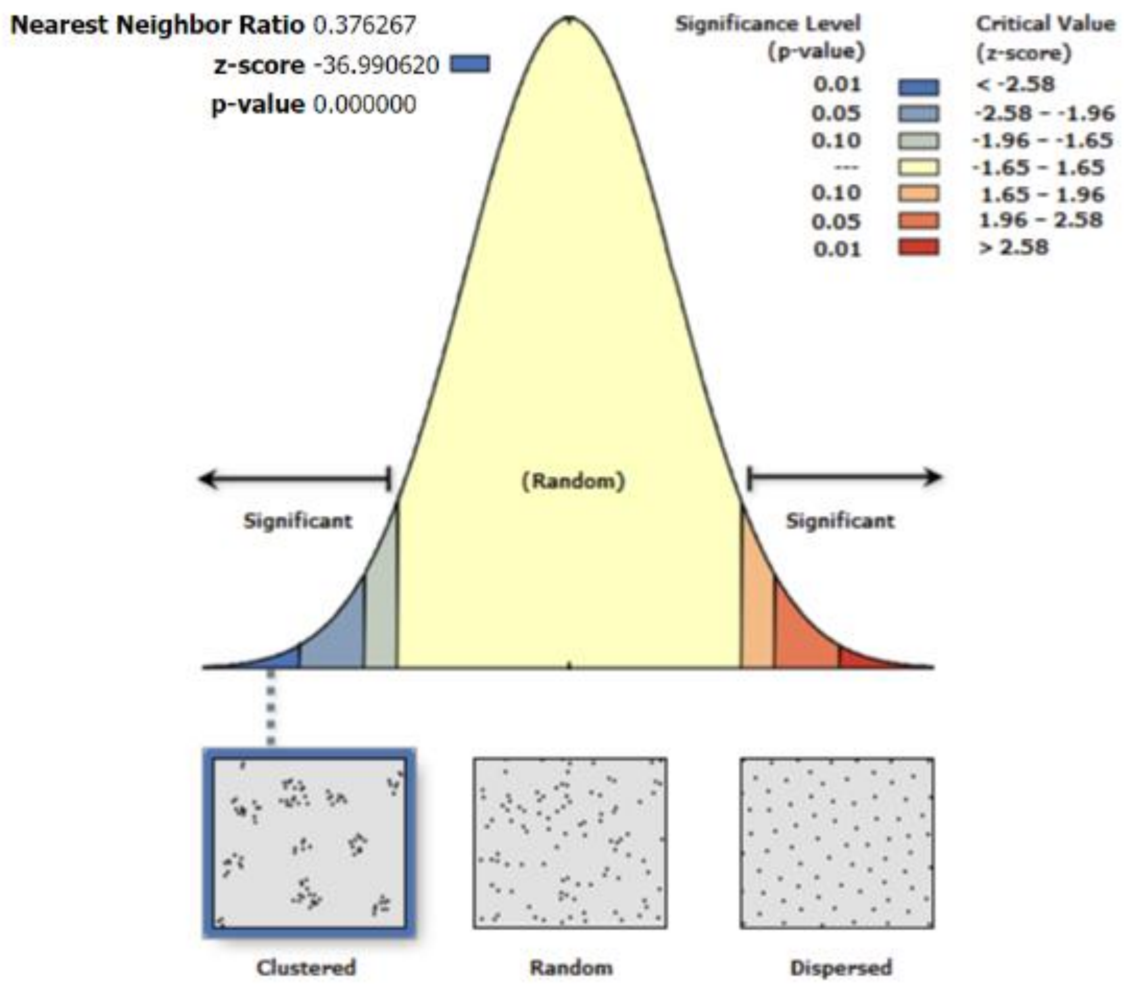
Observed Mean Distance	1675.3687 Meters
Expected Mean Distance	4931.6768 Meters
Nearest Neighbor Ratio	0.339716
z-score	-54.389696
p-value	0.000000

Figure 5:



Chad Efaw
Projected Coordinate System: NAD 1983 UTM 17N
Source: West Virginia Department of Environmental Protection

Figure 6: The ANN statistic suggesting the spatial clustering of coal mines (1990-1999)



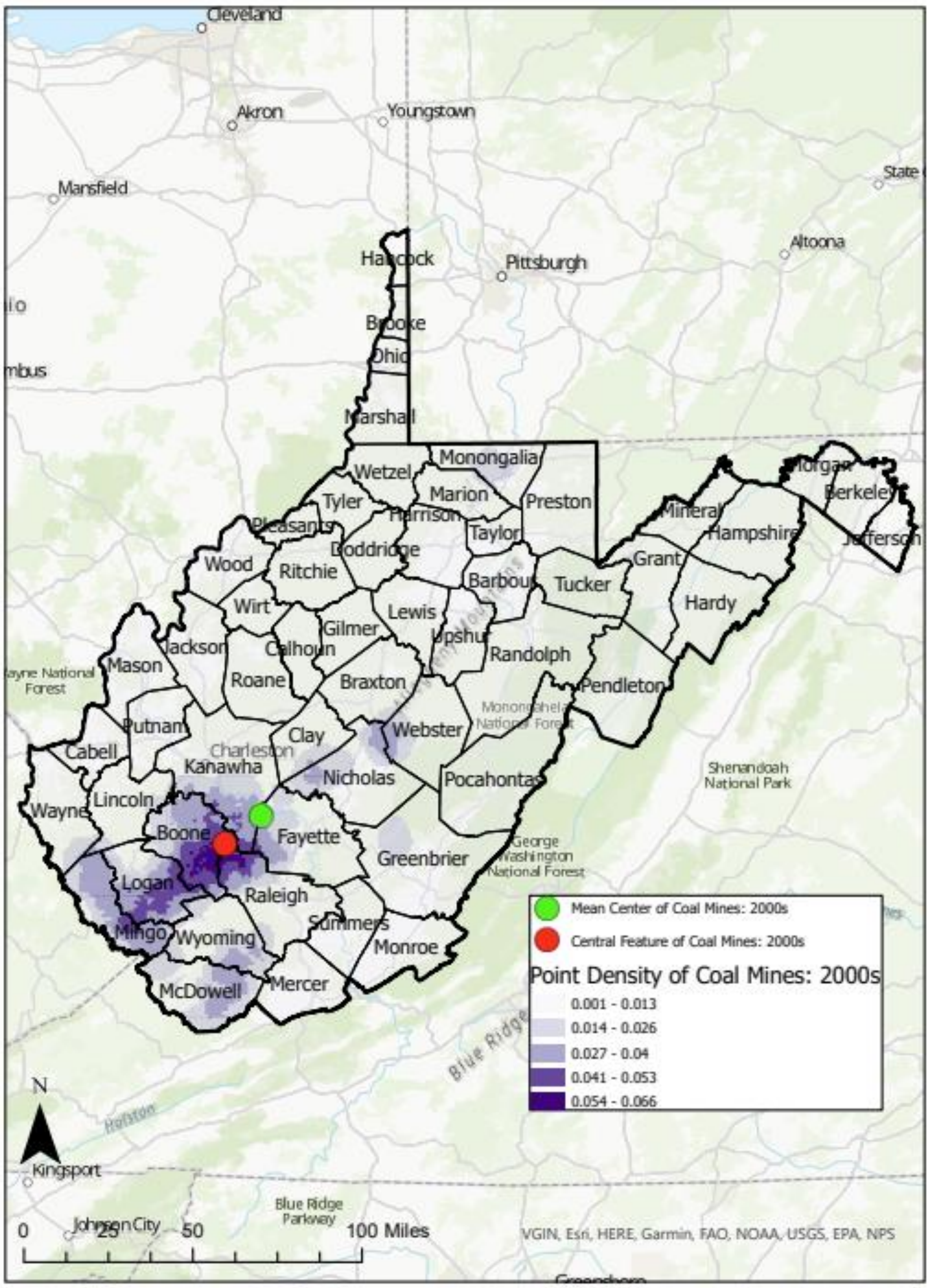
Given the z-score of -36.99062, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Average Nearest Neighbor Summary

Observed Mean Distance	2535.1177 Meters
Expected Mean Distance	6737.5579 Meters
Nearest Neighbor Ratio	0.376267
z-score	-36.990620
p-value	0.000000

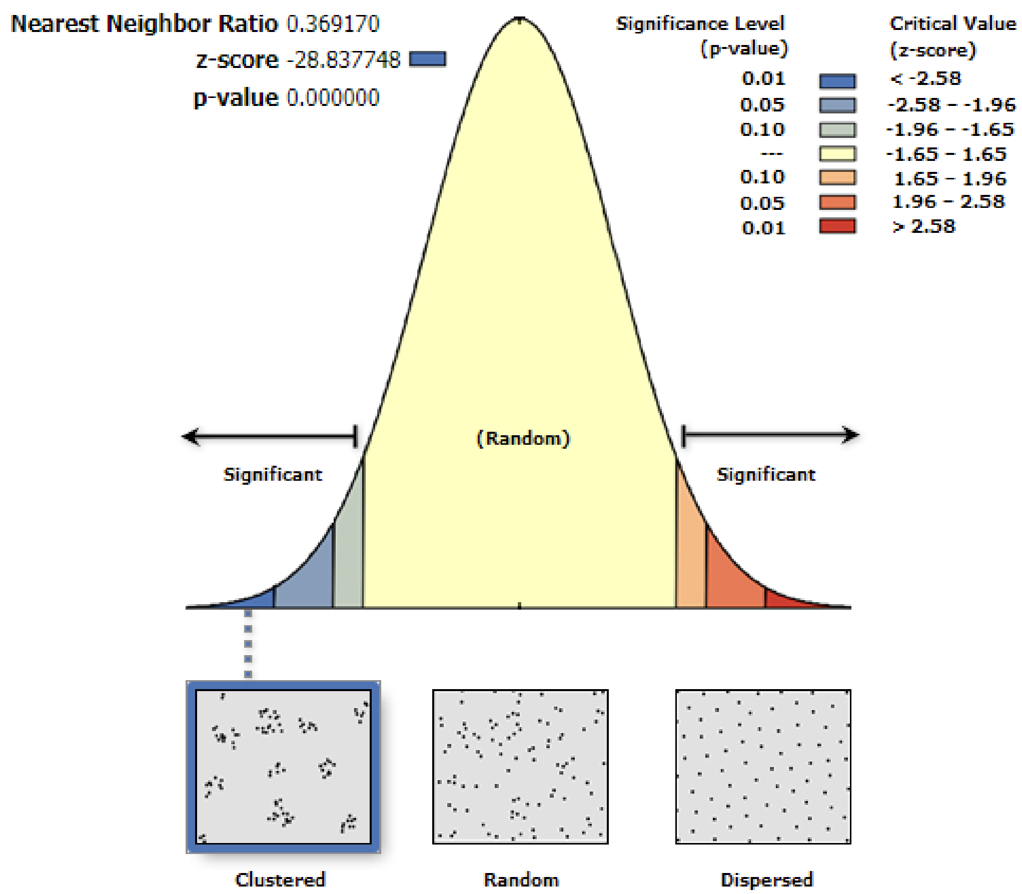
Figure 7:

Point Density, Central Feature, and Mean Center of Newly Permitted Coal Mines in West Virginia: 2000-2009



Chad Efaw
Projected Coordinate System: NAD 1983 UTM 17N
Source: West Virginia Department of Environmental Protection

Figure 8: The ANN statistic suggesting the spatial clustering of coal mines (2000-2009)

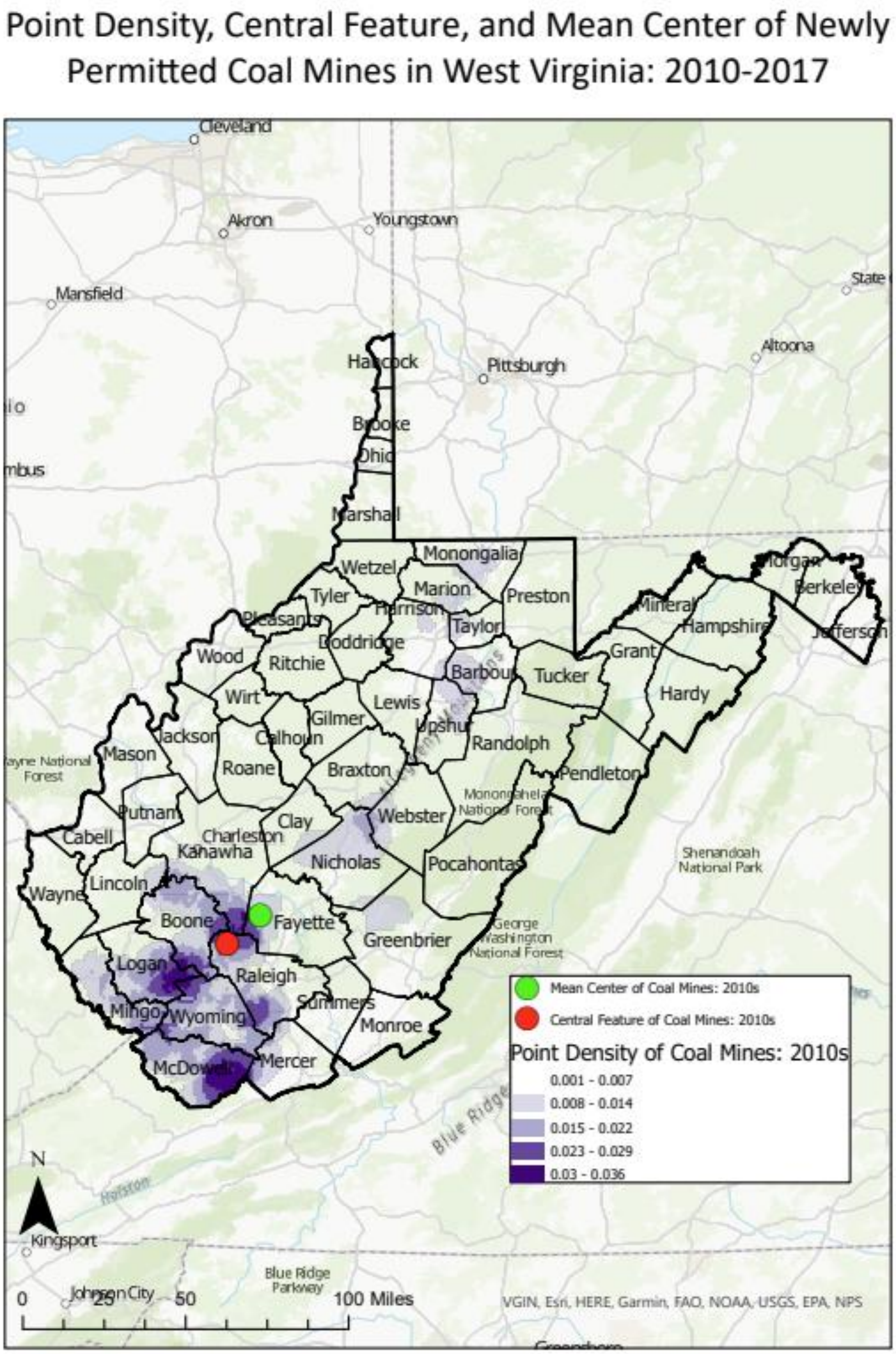


Given the z-score of -28.837748, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Average Nearest Neighbor Summary	
Observed Mean Distance	2963.9634 Meters
Expected Mean Distance	8028.7245 Meters
Nearest Neighbor Ratio	0.369170
z-score	-28.837748
p-value	0.000000

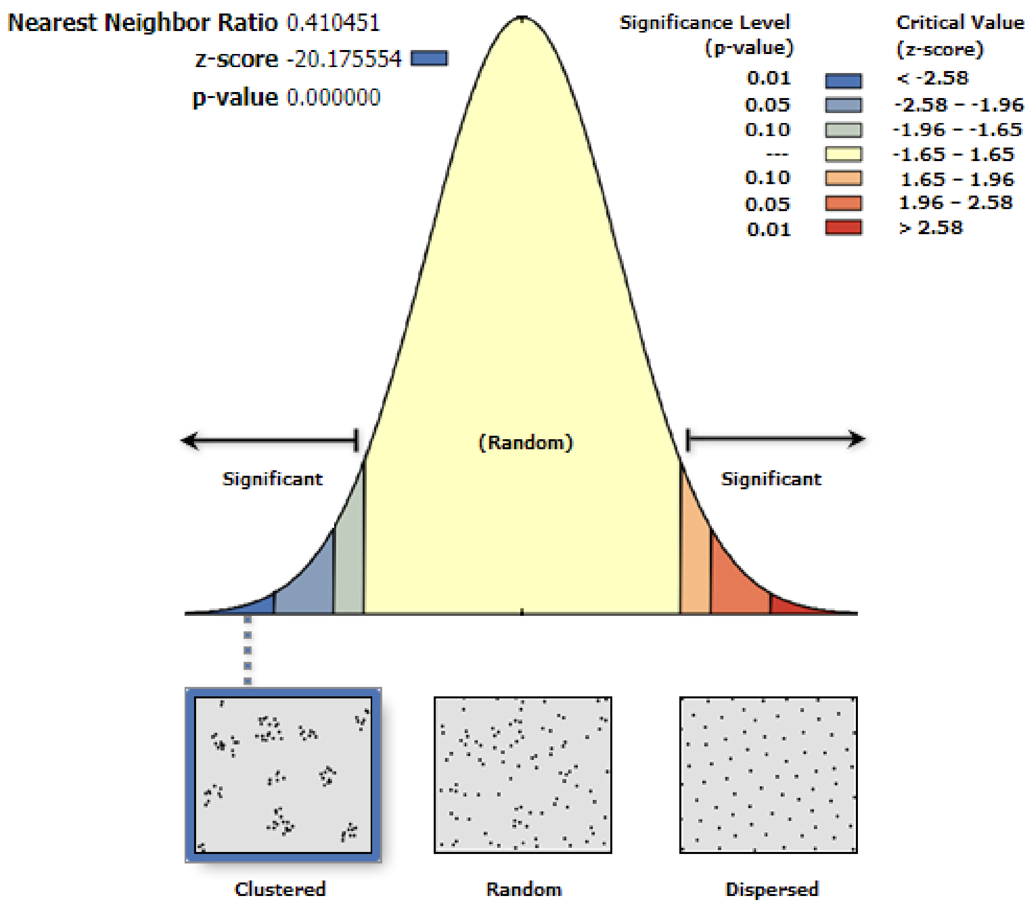
Dataset Information	
Input Feature Class:	Mines Permitted in 2000s

Figure 9:



Chad Efaw
Projected Coordinate System: NAD 1983 UTM 17N
Source: West Virginia Department of Environmental Protection

Figure 10: The ANN statistic suggesting the spatial clustering of coal mines (2010-2017)

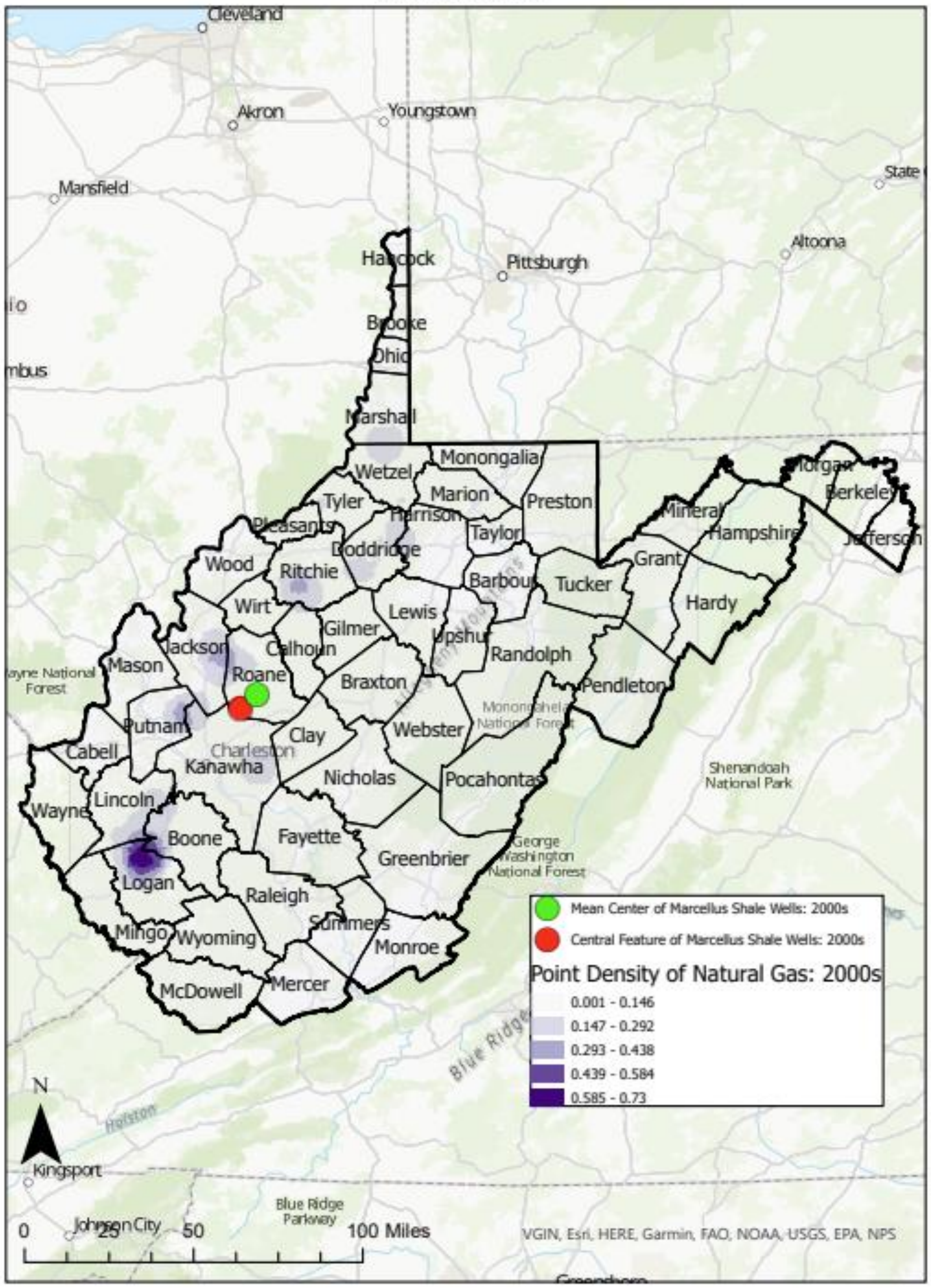


Given the z-score of -20.175554, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Average Nearest Neighbor Summary	
Observed Mean Distance	4220.8171 Meters
Expected Mean Distance	10283.3535 Meters
Nearest Neighbor Ratio	0.410451
z-score	-20.175554
p-value	0.000000
Dataset Information	
Input Feature Class:	Mines Permitted in 2010s

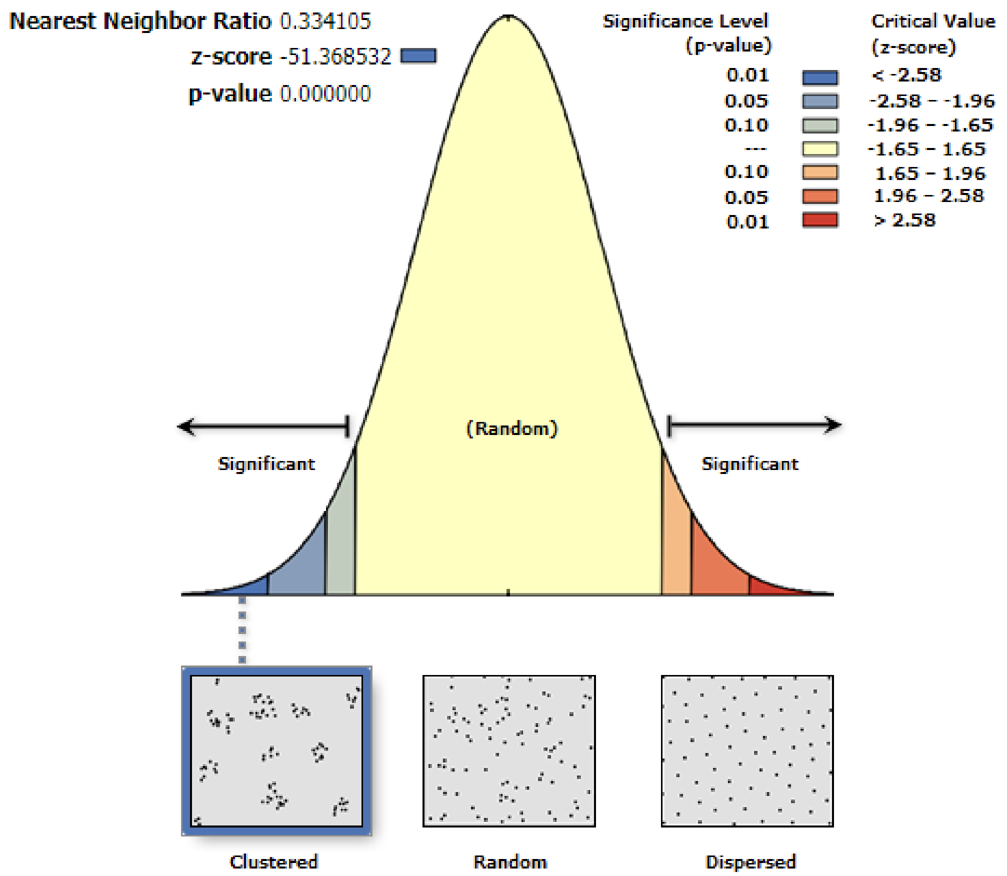
Figure 11:

Point Density, Central Feature, and Mean Center of Newly Permitted Marcellus Shale Wells in West Virginia: 2000-2009



Chad Efaw
Projected Coordinate System: NAD 1983 UTM 17N
Source: West Virginia Department of Environmental Protection

Figure 12: The ANN statistic suggesting the spatial clustering of natural gas wells (2000-2009)



Given the z-score of -51.368532, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Average Nearest Neighbor Summary

Observed Mean Distance	1174.6081 Meters
Expected Mean Distance	3515.6895 Meters
Nearest Neighbor Ratio	0.334105
z-score	-51.368532
p-value	0.000000

Dataset Information

Input Feature Class:	Permitted Wells 2000s

Figure 13:

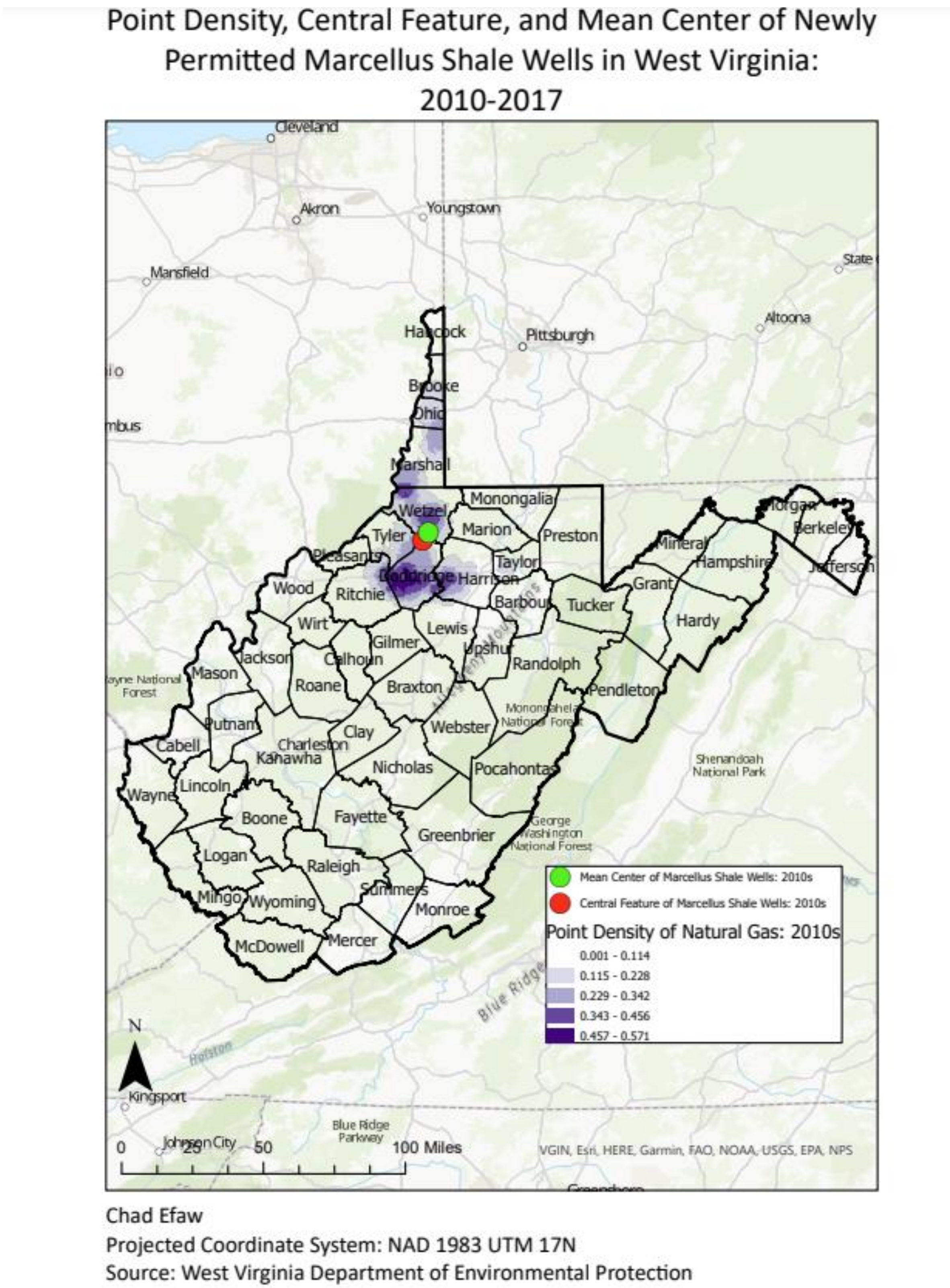
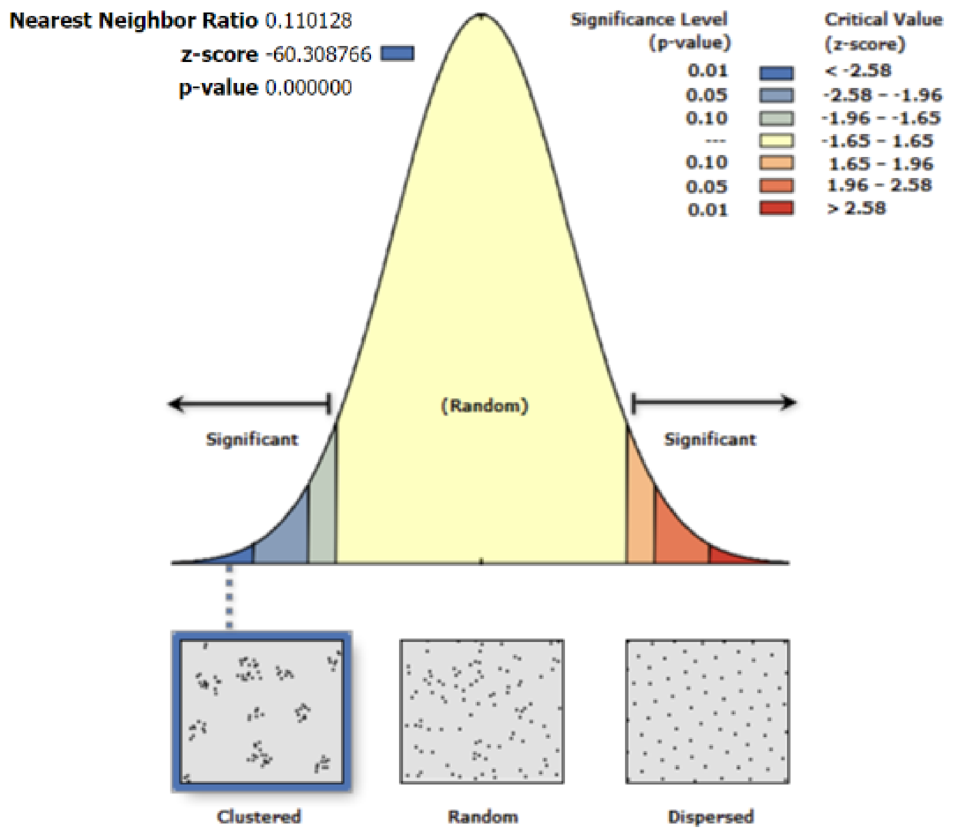

Point Density, Central Feature, and Mean Center of Newly Permitted Marcellus Shale Wells in West Virginia: 2010-2017
Mean Center of Marcellus Shale Wells: 2010s
Central Feature of Marcellus Shale Wells: 2010s
Point Density of Natural Gas: 2010s
0.001 - 0.114
0.115 - 0.228
0.229 - 0.342
0.343 - 0.456
0.457 - 0.571
0
25
50
100 Miles
VGIN, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS
Chad Efaw
Projected Coordinate System: NAD 1983 UTM 17N
Source: West Virginia Department of Environmental Protection

Figure 14: The ANN statistic suggesting the spatial clustering of natural gas wells (2010-2019)



Given the z-score of -60.308766, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.

Average Nearest Neighbor Summary

Observed Mean Distance	297.0029 Meters
Expected Mean Distance	2696.8957 Meters
Nearest Neighbor Ratio	0.110128
z-score	-60.308766
p-value	0.000000

Dataset Information

Input Feature Class:	Permitted Wells 2010s