SpAM

SpAM (Spatial Analysis and Methods) presents short articles on the use of spatial statistical techniques for housing or urban development research. Through this department of Cityscape*, the Office of Policy Development and Research introduces readers to the use of emerging spatial data analysis methods or techniques for measuring geographic relationships in research data. Researchers increasingly use these new techniques to enhance their understanding of urban patterns but often do not have access to short demonstration articles for applied guidance. If you have an idea for an article of no more than 3,000 words presenting an applied spatial data analysis method or technique, please send a one-paragraph abstract to ronald.e.wilson@hud.gov for review.*

Modeling Population Settlement Patterns Using a Density Function Approach: New Orleans Before and After Hurricane Katrina

Fahui Wang
Weijie Wang
Louisiana State University

Introduction

Before Hurricane Katrina, New Orleans had an estimated population of 454,863. More than 400,000 residents were displaced by the hurricane (Geaghan, 2011). After several years of recovery, the 2010 census reported a population of 343,829, that is, a decline of nearly 25 percent. The population change provides a glimpse of the effect Hurricane Katrina had in terms of population loss and its potential for reshaping the urban structure of the metropolitan area. Using 2000 and 2010 tract-level data from the U.S. Census Bureau, we model changes of population settlement patterns in New Orleans before and after Hurricane Katrina with a density function approach to determine if New Orleans has become a more polycentric city.

Population Density Models

Two models are used for city structures. The first model is *monocentric* (Mills, 1972; Muth, 1969), in which a city has only one primary economic activity center, the central business district (CBD). The monocentric model assumes the population distribution is affected in such a way that settlement patterns symmetrically radiate outward from the city center, decreasing in density the further away from the CBD. The second model is *polycentric* (Berry and Kim, 1993; Ladd and Wheaton, 1991), in which cities have several smaller secondary economic activity centers, or subcenters, along with a CBD. With polycentric models the population distributions are affected with settlement patterns concentrating around multiple subcenters and the CBD. The population decreases in density away from each subcenter, sometimes converging between them (Small and Song, 1994). The underlying assumption of both models is that people value proximal access to economic activity centers to reduce commuting and transportation costs to workplace, shopping, and service activities.

Density functions are commonly used to examine the validity of these two models and measure residential settlement density patterns over time. Changes in the intercept and gradient across time from a monocentric model can indicate whether areas close to the CBD have lost population and whether areas toward the edge of the region have gained population; that is, suburbanization. On the other hand, the polycentric model can identify which centers exert influence on citywide population density patterns and whether the influences of one subcenter have weakened or strengthened over time. We analyze both models to detect changes in settlement patterns to determine if Hurricane Katrina had an effect on the urban structure of New Orleans.

Data Sources

We use two primary sources of data in this analysis. First, we use census demographic data (by residence) for 2000 and 2010 to analyze population changes at the tract level.[1] Tract centroids were weighted on population data at the census block level to better represent a tract's actual center of population. We converted the population data in the 2010 census tracts (source layer) to 2000 tract boundaries (destination layer) by spatial interpolation because several census tracts had different configurations in 2000 and 2010.

Second, we used the Census Transportation Planning Package (CTPP) Urban Element Part 2 data (by workplace)[2] for defining employment. Employment centers were identified solely from the 2000 data, because the 2010 CTPP data were not yet available. To determine the validity of using only 2000 data to represent 2010 employment patterns we conducted fieldwork and used another employment data source. Fieldwork indicated that no significant new employment centers emerged in 2010. Our fieldwork was then verified using the 2010 Longitudinal Employer-Household Dynamics (LEHD)[3] data.

[1] http://www.census.gov/geo/www/tiger/.

[2] http://www.transtats.bts.gov/tables.asp?DB_ID=630.

[3] http://lehd.did.census.gov/.

We used only the urbanized parishes[4] in our analysis to represent the New Orleans Metropolitan Area, which consisted of Orleans, Jefferson, and St. Bernard.[5] Exhibit 1 shows the population data by parish. All three parishes lost population, with Orleans and St. Bernard Parishes losing substantial amounts, an indication of Hurricane Katrina's effect.

We mapped the 2000 and 2010 population densities separately to examine the differences in geographic distributions. Exhibits 2 and 3 show that census tracts away from the CBD became more scattered in population densities in 2010, with several tracts consolidating around the CBD.

Exhibit 1

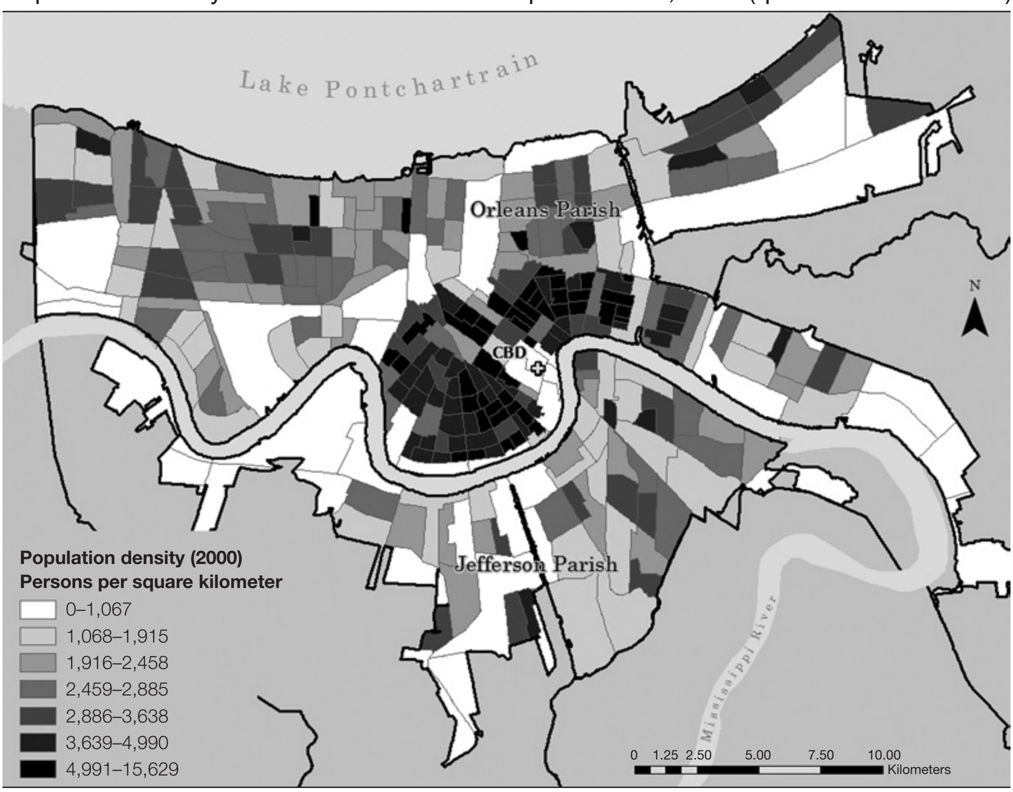
Population Change by Urban Parish in New Orleans, 2000 Through 2010

	Orleans	Jefferson	St. Bernard	Total
2000 population	484,674	455,466	67,229	1,009,369
2010 population	343,829	432,552	35,897	814,288
Percent change	– 29.1%	– 5.0%	– 46.6%	– 19.3%

Note: N = 200 census tracts.

Exhibit 2

Population Density in the New Orleans Metropolitan Area, 2000 (quantile classification)



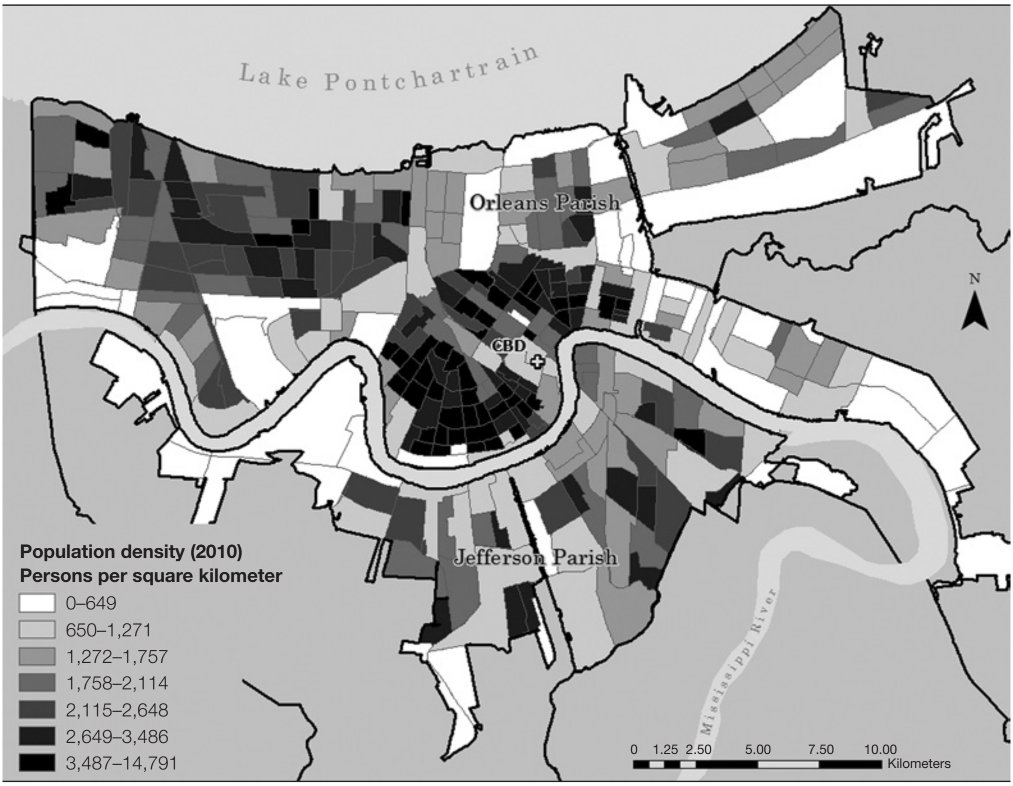
CBD = central business district.

[4] A parish in Louisiana is equivalent to a county in other U.S. states.

[5] The original spatial layers included major water and wetland areas, which were excluded to contain only the land area for subsequent area calculation and density computation.

Exhibit 3

Population Density in the New Orleans Metropolitan Area, 2010 (quantile classification)



CBD = central business district.

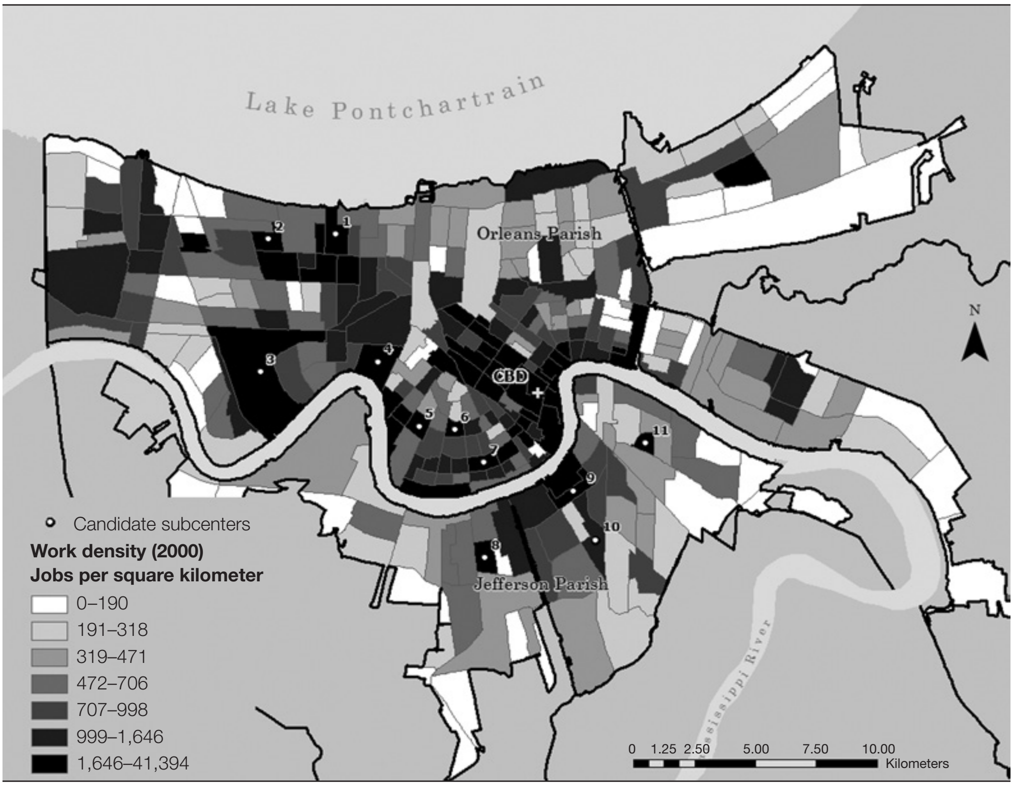
We next identified the CBD and other centers of economic activity through an analysis of employment distribution patterns with the 2000 CTPP Urban Element Part 2 data (see exhibit 4).

Exhibit 5 shows the employment density distribution from the LEHD data and confirms that our use of the 2000 data to represent economic centers in 2010 is valid.

Using a surface model in ArcGIS, we identified candidate employment centers by identifying peak density areas (exhibit 6). Candidate employment centers were indexed from 0 to 11, with 0 indicating the CBD and 1 to 11 indicating smaller subcenters.

Exhibit 4

Employment Density in the New Orleans Metropolitan Area, 2000
(quantile classification)

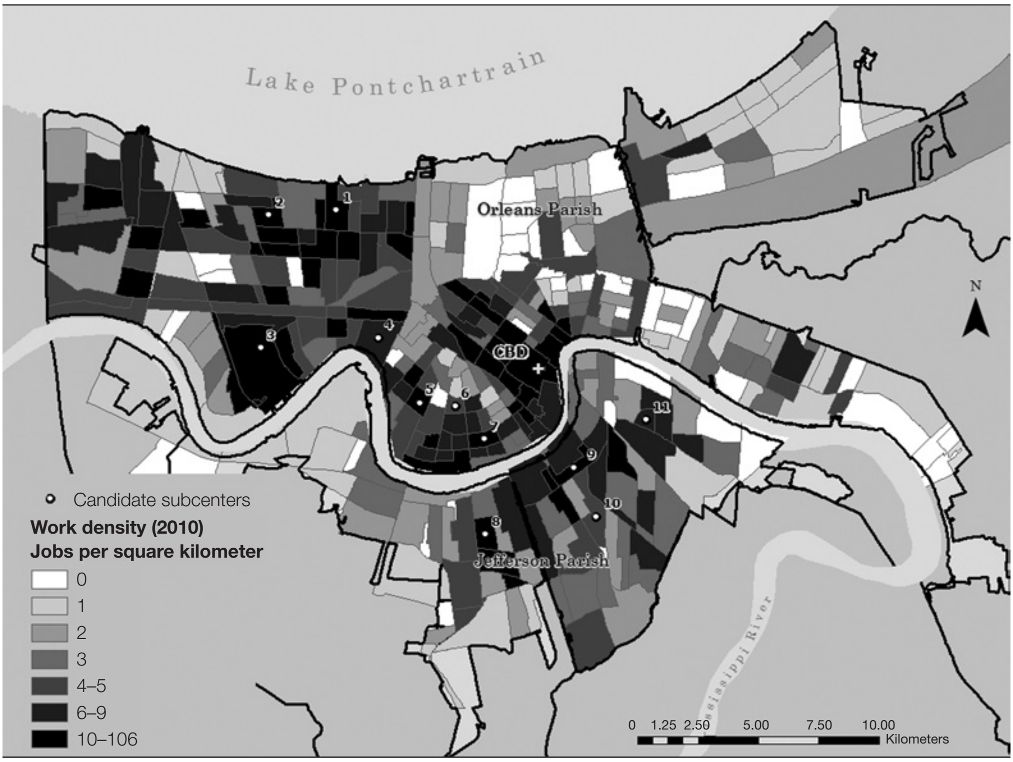


CBD = central business district.

We then ranked the 12 candidate subcenters based on estimated employment densities within 0.7-, 1.0-, and 1.5-kilometer radii from each subcenter tract. We chose an employment density threshold, with at least 10,000 jobs within 1 square kilometer qualified as a job center. Under these two criteria, four subcenters were retained as candidate subcenters (which we numbered 0, 1, 2, and 3, 0 being the CBD). Because of the low density of subcenter 2 and its proximity to subcenter 1, we eliminated this subcenter as a candidate. Subcenters 1 and 3, to the northwest and west of downtown, respectively, and the CBD (0) remained for analysis (see exhibit 6).

Exhibit 5

Employment Density in the New Orleans Metropolitan Area, 2010 (quantile classification)



CBD = central business district.

Modeling Change With the Monocentric Model

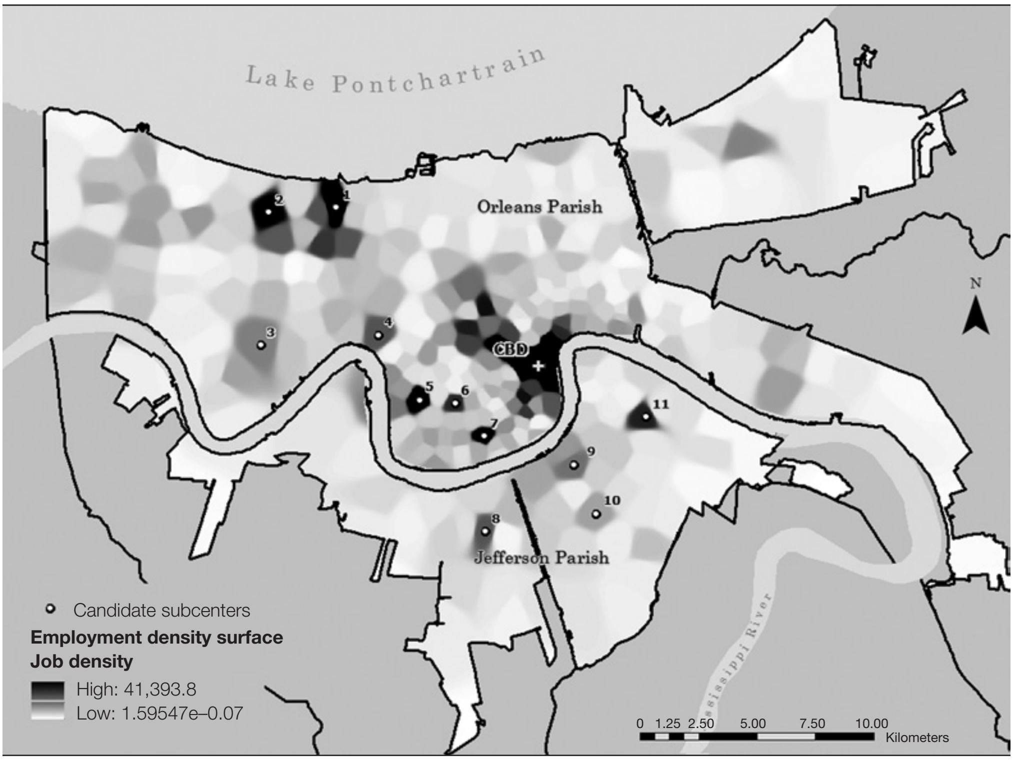
Monocentric models assume population densities symmetrically change at concentric distances away from the CBD only. We employed the four most common bivariate functions to test the relationship between population density (D_r) and distance (r) from the CBD (see exhibit 7).

For all four functions, the regression results of the monocentric model are subpar. The fitting power (R^2) for all four functions is less than 0.30 for 2000 and even less for 2010. The exponential function performed best, with the R^2 having decreased from 0.2935 in 2000 to 0.0775 in 2010. The intercept a decreased from 5,215.8 in 2000 to 2,931.2 in 2010, and the density gradient b (in absolute values) decreased from 0.109 to 0.088. Lower intercept values indicate a declining density around the CBD in New Orleans. Smaller (flatter) density gradients signify a slow (gradual) decrease of population density with increasing distance from the CBD, which reflects a general trend of population loss in the central city and growth in suburbia; that is, *suburbanization*.

The poorer fitting power by the monocentric functions is consistent with most other findings (McDonald, 1989). Nevertheless, all the models are statistically significant and the results are largely valid. The lower fitting power by the exponential function (R^2 = 0.0775) against the logarithmic function (R^2 = 0.1310) is abnormal with respect to model results for other western cities and indicates that Hurricane Katrina created a significant disturbance to the population settlement patterns of New Orleans.

Exhibit 6

Interpolated Employment Density Surface in the New Orleans Metropolitan Area, 2010



CBD = central business district.

Exhibit 7

Regression Results for Monocentric Functions in New Orleans Based on Population

Year	Model		*a*	*b*	R^2
2000	Linear:	$D_r = a + br$	4,218.40	– 149.20	0.21
	Logarithmic:	$D_r = a + b \ln(r)$	5,277.60	– 1,233.00	0.21
	Exponential:	$D_r = ae^{br}$	5,215.80	– 0.11	0.29
	Power:	$D_r = ar^b$	7,269.80	– 0.66	0.17
2010	Linear:	$D_r = a + br$	2,838.00	– 77.44	0.02
	Logarithmic:	$D_r = a + b \ln(r)$	3,531.70	– 712.80	0.13
	Exponential:	$D_r = ae^{br}$	2,931.20	– 0.09	0.08
	Power:	$D_r = ar^b$	3,887.00	– 0.55	0.04

Modeling Change With the Polycentric Model

We examined three density functions that correspond to three assumptions about polycentric population densities proposed by Heikkila et al. (1989), which are that (1) residents value access only to their nearest economic subcenter in a city made up of multiple monocentric subregions; (2) the influences of all subcenters are *complementary* to each other, and access to each center is needed (McDonald and Prather, 1994); and (3) the density of any tract is the result of the effect that cumulative distance decay from each subcenter has on that tract. We used a series of regression models to test each assumption.

To test the first assumption, we used a monocentric density function for several subregional divisions across the metropolitan area, each containing census tracts distributed around their nearest economic center (that is, proximal area). Monocentric density functions are estimated for each subregion. The model is written as

$$InD_{r_i} = A_i + b_i r_i \ (i = 1 \ldots n), \quad (1)$$

where r_i is the distance of a tract from center *i* within the subregion *i*, Dr_i is the population density of that tract, *n* is the number of centers, and A_i and b_i are parameters to be estimated by a bivariate regression.

Exhibit 8 shows the regression results for the first assumption. In the subregion (proximal area) around the CBD, the exponential density function is statistically significant in capturing the pattern of declining population densities with distance in both 2000 and 2010, which is similar to the regionwide monocentric model reported in exhibit 7. The function, however, is not statistically significant in the two subregions around the subcenters 1 and 3 in 2000 or 2010, indicating minimal influences of these subcenters on the population density patterns.

To test the second assumption, we used a multiplicative function that models subcenters as *complementary*, implying that access to all centers is needed (McDonald and Prather, 1994). The model is written as

$$InD = A + \sum_{i-1}^{n} b_i r_i (i = 1 \ldots n), \quad (2)$$

Exhibit 8

Regression Results for Polycentric Model, Assumption 1

Center *i*	2000 Sample	2000 A_i	2000 b_i	2000 R^2	2010 Sample	2010 A_i	2010 b_i	2010 R^2
	$InD_{r_i} = A_i + b_i r_i$ for Center *i*'s Proximal Area							
0 (CBD)	223	8.6118 (– 74.96)***	– 0.1375 (– 8.79)***	0.259	216	8.0647 (– 60.44)***	– 0.1051 (– 6.00)***	0.144
1	44	7.8476 (– 69.96)***	– 0.0077 (– 0.32)	0.0024	46	7.8411 (– 23.57)***	– 0.0808 (– 1.13)	0.0282
3	51	7.4986 (– 28.61)***	– 0.0318 (– 0.68)	0.0093	52	7.3234 (18.73)	– 0.0478 (– 0.69)	0.0096

CBD = central business district.
****Significant at 0.001. t values in parentheses.*

where r_i is the distance of a tract from center *i* within the whole study area, *D* is the population density of that tract, and *A* and b_i $(i = 1, 2 \ldots)$ are parameters to be estimated by a multivariate regression.

Exhibit 9 shows the regression results for the second assumption. The model in 2000 indicates that the population densities decline significantly at increasing distances from the CBD and from subcenter 1 across the whole study area. Densities, however, tend to increase with distance from subcenter 3 in 2000 but not as significantly as the decline from subcenter 1 and the CBD. The positive density gradient from subcenter 3 in 2000 is counterintuitive and raises suspicion of the validity of this assumption. In 2010, the model suggests that only the distance decay in population density is significant with distance from the CBD, and neither subcenter seems to influence the areawide density pattern.

Exhibit 9

Regression Results for Polycentric Model, Assumption 2

$lnD = A + \sum_{i-1}^{n} b_i r_i$ for the Whole Study Area				
Center *i*	**2000**		**2010**	
	b_i		**b_i**	
0 (CBD)	– 0. 06422 (– 6.39)***	A = 8.75485 *** (65.25) R^2 = 0.23 Sample size = 318	– 0.04563 (– 3.60)***	A = 8.31883 *** (49.36) R^2 = 0.11 Sample size = 314
1	– 0.09011 (-4.67)***		– 0.03030 (– 1.23)	
3	0.03942 (2.26)*		– 0.02092 (– 0.95)	

CBD = central business district.
****significant at 0.001. **significant at 0.01. *significant at 0.05. t values in parentheses.*

To test the third assumption, we used an *additive* distance decay function from each center. The model is written as

$$D = \sum_{i-1}^{n} (a_i e^{b_i r_i}) \ (\mathrm{i} = 1 \ldots \mathrm{n}), \qquad (3)$$

where r_i is the distance of a tract from center *i* within the whole study area, *D* is the population density of that tract, and a_i is a constant specific to center *i*. The function is estimated by a nonlinear multivariate regression.

Exhibit 10 shows the regression results from the third assumption, which most researchers consider reasonable. The model indicates that both the CBD and subcenter 1 are significant in influencing a declining density pattern in 2000, but only the CBD is significant in 2010. These results suggest that New Orleans regressed from a dual-centric structure in 2000 to a monocentric form in 2010, as indicated in the comparison of exhibits 2 and 3, thus reflecting the major effect of Hurricane Katrina on the population settlement patterns in New Orleans.

Exhibit 10

Regression Results for Polycentric Model, Assumption 3

Center i	$D = \sum_{i-1}^{n} a_i e^{b_i r_i}$ for the Whole Study Area			
	2000		2010	
	a_i	b_i	a_i	b_i
0 (CBD)	3,981.44 (8.09)***	– 0.1572 (– 3.00)**	2,451.2 (5.53)***	– 0.2111 (– 2.57)*
1	2,518.57 (3.70)***	– 0.0432 (– 2.61)**	– 883.59 (– 0.10)	0.0087 (0.10)
3	– 1,828.16 (– 1.15)	– 0.5262 (– 0.98)	3,185.91 – 0.37	– 0.0209 (– 0.29)
R^2	0.36		0.25	

CBD = central business district.
****significant at 0.001. **significant at 0.01. *significant at 0.05. t values in parentheses.*

Conclusion

In this research, we measured the spatial distribution of population density changes in the New Orleans Metropolitan Area from 2000 to 2010 to examine the effect of Hurricane Katrina in 2005. This analytical approach enabled a spatial examination of the effect a natural disaster had on the region and its postdisaster recovery. The regressions based on the monocentric model indicated a general trend of population loss in the central city and growth in suburbia, attributable to a combination of suburbanization that began before Hurricane Katrina and the uneven recovery afterwards. The regression results from the polycentric model indicated that the CBD had significant influence on the citywide population density pattern in both 2000 and 2010, but one subcenter declined in influence from 2000 to 2010. The results show that New Orleans has regressed from a polycentric (two-center) structure in 2000 to a more monocentric structure in 2010, which is contrary to many other North America cities. This finding signifies a major effect on city structure by Hurricane Katrina.

Acknowledgments

The authors acknowledge the editorial help of Ron Wilson.

Authors

Fahui Wang is a professor in the Department of Geography and Anthropology at Louisiana State University.

Weijie Wang is a master’s student in the Department of Geography and Anthropology at Louisiana State University.

References

Berry, Brian J.L., and Hak-Min Kim. 1993. "Challenges to the Monocentric Model," *Geographical Analysis* 25 (1): 1–4.

Geaghan, Kimberly A. 2011. Forced To Move: An Analysis of Hurricane Katrina Movers—2009 American Housing Survey: New Orleans. SEHSD Working Paper Number 2011-17. Washington, DC: U.S. Census Bureau. Available at http://www.census.gov/hhes/www/hlthins/publications/HK_Movers-FINAL.pdf.

Heikkila, E., P. Gordon, J.I. Kim, R.B. Peiser, H.W. Richardson, and D. Dale-Johnson. 1989. "What Happened to the CBD-Distance Gradient? Land Values in a Polycentric City," *Environment and Planning* A 21 (2): 221–232.

Ladd, Helen F., and William Wheaton. 1991. "Causes and Consequences of the Changing Urban Form: Introduction," *Regional Science and Urban Economics* 21 (2): 157–162.

McDonald, John F. 1989. "Econometric Studies of Urban Population Density: A Survey," *Journal of Urban Economics* 26 (3): 361–385.

McDonald, John F., and Paul J. Prather. 1994. "Suburban Employment Centers: The Case of Chicago," *Urban Studies* 31 (2): 201–218.

Mills, Edwin S. 1972. *Studies in the Structure of the Urban Economy*. Baltimore: Johns Hopkins University Press.

Muth, Richard F. 1969. *Cities and Housing*. Chicago: University of Chicago Press.

Small, Kenneth A., and Shunfeng Song. 1994. "Population and Employment Densities: Structure and Change," *Journal of Urban Economics* 36 (3): 292–313.