West Nile Virus in Chicago, IL, 2002: A Multidimensional GIS-based Analysis

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During the active mosquito season of 2002, Chicago, Illinois experienced an outbreak of West Nile Virus (WNV) that was unprecedented in the United States. A disease that three years previous had been virtually unknown became a hot spot for renewed fears of global emerging pathogens. Questions remain regarding the explosion of cases in this urban metropolitan region during one of the worst epidemics of WNV in the country. The purpose of this research is to analyze the varying effects of environmental and sociopolitical factors on the uneven geographical distribution of human WNV cases in the Chicago metropolitan region using a multidimensional approach that combines GIS and spatial statistics with qualitative methods

Although GIS research typically involves quantitative data and methods, there is a growing interest in linking GIS with qualitative data and methods. Researchers are exploring the incorporation of qualitative data in GIS (Rocheleau 1995, Al-Khodamy 1998), the use of GIS in participatory research (Harris and Weiner forthcoming, Ellwood 2002), and the role of GIS in mixed methodologies that combine quantitative and qualitative research strategies (Kwan 2002). This research describes an empirical example of the latter strategy. Using WNV as an example, it is demonstrated how GIS can be used to inform the more qualitative analysis of political and social factors, and how the results of qualitative analyses can be used to enhance our understanding of information in GIS. The findings provide a clearer picture of how environmental and sociopolitical forces affected the spread of WNV in the Chicago region.

BACKGROUND

West Nile Virus (WNV), a newly emerging infectious disease, was first discovered in the United States in New York City in 1999 (Nash et al 2001). The disease spread rapidly through bird populations (mainly crows), and mosquito populations on the east coast and was found in humans in other eastern states the following year. The disease also spread westward from the east coast and first appeared in bird populations in Illinois by 2001. At that time, around 100 dead birds had tested positive for WNV, but no human cases were reported. By 2002, the state recorded 884 human cases and 66 deaths from WNV, mostly concentrated in the region around Chicago (Cook and Dupage counties) (IDPH 2003). Examination of the spatial distribution of human cases within the counties shows that there is a non-random geographical pattern or clustering of the disease (Ruiz et al 2004).

While there has been a surge in research on the biology of WNV and, the entomology and biology of mosquitoes and birds (Andreadis et al 2000; Peterson and Roehrig 2001; Nasci et al 2001; Marfin et al 2001; Kulasekera et al 2001), there is a dearth of information regarding the ecology of the disease within human populations, and the social epidemiology of the disease within communities. Additionally, few studies have incorporated GIScience to predict or explain the occurrence of cases in urban areas (Ruiz et al 2004). WNV is a mosquito-vectored disease, and its occurrence in humans reflects the interactions between environmental conditions, human behaviors and socio-political factors that affect control and prevention efforts. Though some predictive models have been used to define potential “at-risk” areas for WNV (Theophilides et al 2003), the models focus mostly on dead bird reporting, and fail to take other factors into consideration. Studies examining health risk perception are common, though few studies have explored risk perception and practices for mosquito-vectored diseases like encephalitis and WNV (Herrington 2002). Also, most studies focus on the prevention of mosquito bites, or the public knowledge of disease rather than community or place based risk.

Macintyre et al (2002) admit that epidemiologists, medical geographers, and medical sociologists tend to ignore the importance of place in their examination of disease. Only recently have studies begun to explore the impact of the local physical and social environment on health and the interactions, at a variety of spatial scales, between health and place (Kearns 1993). . There seems to be a clear need for research that directly examines features of the local social and physical environment affecting the health of a community. "Despite pleas from several quarters to do so, few investigators have attempted to hypothesize what features of the local social or physical environment might influence health, and then tested these hypotheses" (Macintyre et al 2002, 129). An emphasis on place may even result in faster, better targeted, and more effective public health interventions.

Increasingly, public health researchers are utilizing GIS in understanding geographical variation in disease incidence. Rushton (2003) argues that Geographic Information Systems (GIS) and spatial analysis can be beneficial to public health by examining key relationships that exist between human and environmental characteristics that impact health. Authors have likewise noted the benefits of GIS as a tool for the study of disease (Cromley 2003; Rushton 2003; Krieger 2003). Many studies demonstrate how the spatial analysis and overlay capabilities of GIS can be used to better understand the ecology of disease and to model disease spread (Cromley and McLafferty 2002). At the same time, there is a growing body of literature on the integration of GIS and social research. Geographers researching community phenomena (Ellwood 2002; King 2002; Harris and Weiner forthcoming) and social dynamics (Kwan 2002) have begun combining GIS analysis with participatory techniques and qualitative methods of analysis. These mixed methodologies have great potential to inform our understanding of how and why diseases like WNV emerge and spread, emphasizing the importance of place characteristics.

Chicago's WNV outbreak provides an exciting opportunity to study the place-based human, social and environmental risk factors involved in WNV as expressed in the unique geographical pattern of human cases, as well as a chance to exploit GIS technology to define which of these factors are impacting disease incidence.

.. Several overarching themes could have influenced the severity of the WNV outbreak in Chicago such as the environment and how it favored mosquito activity, mosquito control policies and their impacts on the spread of WNV, and the community response and perceived risk of both the virus and mosquito control effort. Important questions yet to be answered are, what factors led to the cluster patterns of WNV in Illinois, specifically in Cook and DuPage counties, during the outbreak of 2002? Why did mosquito control policies differ so widely among communities via the Mosquito Abatement Districts (MADs), independent geopolitical units designed to combat both nuisance and disease carrying mosquitoes, and how did such differences affect risk for WNV? How did communities' social or political actions influence risk for the disease?

To better understand the epidemiology of the greater Chicago WNV outbreak of 2002, this study uses a mixed methods approach to explore both the quantitative and qualitative aspects of disease clustering (Creswell 1999, Creswell 2003, Tashakkori and Teddlie 2003). In the first phase of the project, GIS and statistical methods are used to visualize and analyze spatial patterns and to explore the associations between disease clusters and environmental and social characteristics. The results show that although attributes of the local population and environmental strongly affect WNV occurrence, in two Mosquito Abatement Districts WNV risk was significantly higher than expected. The second phase of the project examines the reasons for WNV clustering in these two districts. This paper focuses primarily on the quantitative portion of the study. Key interviews with health department and MAD managers, and selected community members help explain why some MADs had more human cases than others.

DATA AND METHODS

PHASE 1

Human case data for WNV was supplied by the Illinois Department of Public Health. Point data for all confirmed positive cases of WNV were geocoded based on an individual's home address. All confirmed cases of WNV are required by law to be reported to the state health department, so all known confirmed cases were included in the data set. Some reporting bias may exist where undocumented cases occurred. Because of privacy and confidentiality restrictions, all analysis was performed on census tract level using a GIS.

An examination of the population densities in Chicago and the surrounding areas shows that WNV cases are not clustered in the most densely populated areas (Figure 1). This indicates the influence of other factors contributing to the potential exposure of the population. There were many potential variables that may have contributed to the occurrence and outbreak of WNV in Illinois, but the most plausible factors, based on previous WNV outbreaks in other locations, were narrowed down for assessment (Table 1). These include socioeconomic, demographic and environmental characteristics. Socioeconomic data was derived from the 2000 Census.

Socioeconomic variables examined included the percent of the population that is white, median age, median household income, and the housing age. Historically, WNV outbreaks have occurred in mainly white populations, possibly because of reporting bias – whites have better access to health care and are thus more likely to be diagnosed with WNV, or for some other reason that is still unclear. Therefore, a positive association between the percent white and WNV is expected. Median age has been an important factor in other WNV outbreaks as well with the majority of cases occurring among older populations, so a positive association is expected there as well. Median household income was tested as a basic social and demographic indicator. There may be a positive association between higher income areas due to reporting bias, the neighborhood design (landscaping, parks, etc.), or neighborhood politics and increased awareness. This data was transformed by taking the log to allow for a linear relationship between the data. It was expected that housing age may have played a role in the high rates of WNV. In some neighborhoods, houses built just after WWII have poorer drainage systems and water catch basins that may provide excellent mosquito breeding habitats. It was hypothesized that these neighborhoods have higher prevalence of WNV.

Other variables include the percent of vegetation, and the mosquito abatement districts. Vegetation is expected to have a positive association with WNV because vegetated areas have better mosquito habitats and more breeding sites. Percent vegetation was derived from several land use/land cover images obtained from satellite imagery to determine the best possible vegetated/non-vegetated classes. The percent vegetated was calculated using a GIS.

Geopolitical factors are one of the least recognized but potentially important factors in WNV incidence. The state of Illinois has districts that run mosquito control programs, which can impact the intensity of WNV in a given area. Within the Cook County area there are four Mosquito Abatement Districts (MADs), North West, North Shore, Des Plaines Valley, and South Cook (Figure 2). These MADs are independent agencies supported mostly by local property taxes (Fowler 2003). All four are politically autonomous and there is no coordination between them. Following the 2002 outbreak, questions were raised as to how well these agencies did their jobs at controlling mosquito populations, and whether some MADs were better equipped to handle the crisis than others (Fowler 2003). These districts are also separate from the city of Chicago and Dupage County, which have contracted out their mosquito control to independent companies such as Clarke Mosquito Control (Fowler 2003). Dummy variables were created for each of the four MADs as well as one for Dupage County, and one for the area of Cook County that does not fall into any other MAD, mostly because it is urban and considered to be the Chicago region. All six regions are distinct with no overlap between them. The North West MAD was used as a baseline for the dummy variables due to its very low disease prevalence and its comparable size.

The first statistical analysis performed on the data was a test of spatial autocorrelation using a local Moran's I test with the software ClusterSeer. Next, logistic regression, using the presence or absence of a WNV case in a census tract as the dependent variable, was used to determine the importance and significance of the different independent variables discussed earlier in this section, and to determine a model that could be used to partially explain the clusters seen in the 2002 outbreak.

The GIS and statistical results indicated that two MADs had unusually high disease incidence. To explore the reasons for such high incidence, newspaper archival information about the communities and public reactions to the outbreak were collected. In addition, in-depth interviews were conducted with managers and key community members to determine why incidence of WNV was higher than expected in these two districts.

RESULTS

To identify spatial clusters of WNV in the Chicago region, the Local Indictor of Spatial Association, (LISA) statistic was calculated by census tract using the age-adjusted WNV rate per 10,000 people. Tracts with high local Moran's I values at the $p<.05$ significance level were considered to be spatial clusters – that is, areas where high rates of WNV were reported (Figure 3). Next, it is necessary to try and determine why those patterns exist and what factors contributed to the outbreak in those areas.

Several logistic regression models were run to determine the effects of the independent variables on WNV clustering. The dependent variable was presence/absence of a human WNV case in a census tract. Two basic approaches were taken, resulting in two primary models. Model 1 included all census tracts within the study site with n = 1479. Preliminary results showed strong evidence of multicollinearity. A backward stepwise approach was used to eliminate variables with multicollinearity. Wald Chi squared tests showed the model was significant to the p=.000 level. The Nagelkerke r^2 value was .200, which was relatively high considering the many factors that influence WNV. The model correctly predicted the presence/absence of WNV 78% of the time, a statistically significant percentage (Table 2). The percentage of tracts that were correctly predicted for tracts with a WNV case was rather low at 28.2%; though this is not surprising considering the far larger number of tracts with no cases.

Six independent variables were statistically significant in this model: median age, percent white, housing age, and three MADs – Des Plaines, North Shore and South Cook (Table 3). All of the variables had a positive influence on the slope with the exception of Des Plaines Valley, meaning there is less risk in this MAD. Vegetation, median household income, Dupage County, and the Chicago region were not found to be significant factors at the .05 significance level. A comparison of the odds ratios shows that a census tract located in South Cook is almost 3 times more likely to have a case of WNV than a tract in the baseline district of North West MAD. In addition, a tract in North Shore MAD is seven times as likely to have a WNV case, while Des Plaines Valley is 1/2 as likely to have a case. This fits the cluster results that show hot spots for cases in the North Shore and South Cook MADs.

Model 2 focuses on the Chicago suburbs only, since the vast majority of WNV cases occurred in the suburbs. The number of tracts examined fell from 1479 to 663, with the same variables entered into the model. This model fit better than the previous one – the Nagelkerke R^2 increased from .200 to .220 (Table 4). The correctly predicted percentage dropped slightly to 72%, but among tracts with cases, the percentage that were predicted correctly increased to 41.5% (Table 5). Also, there was a slight difference in the statistical significance of variables, with median age no longer significant. Vegetation, median household income and Dupage County also failed significance tests. In other models tested, housing classes representing the percentage of housing built during a given time was substituted for the median housing age. Housing in Chicago proved to be significant, but the age range varied from 1940-1959, whereas the years 1950-59 were significant in the suburbs. Other models were run to test for multicollinearity, which was found between several of the social variables, creating the need for a stepwise addition of variables into the models. Another test using interaction variables for MADs and median age resulted in a correlation between age and South Cook and Des Plaines Valley MADs. Regarding the MADS, Des Plaines Valley continued to have lower risk as the odds ratio dropped to 1/3 that of the baseline, and North Shore and South Cook continued to have an increased risk.

Because most of the WNV cases and clustering occurred in suburban areas outside of the central Chicago area, it makes more sense to use Model 2, which focuses on these suburban areas. It is important to note that the variables percent white, North Shore and South Cook MADs were highly significant in every logistic model. It is unclear if race itself determines risk for infection or if it is a confounding factor that is linked to reporting bias, or a descriptor of the underlying social segregation phenomenon in the Chicago suburbs. There is a wide body of literature focusing on the composition and dynamics of suburban communities in the United States, and the ethnic, racial, and economic segregation that has occurred within them (Farley 1986; Massey and Denton 1988; Davis 1990). Chicago's history of suburbanization is no different.

North Shore is the MAD with the highest prevalence rate, and should be examined further to identify why this location is important as a focal point for WNV spread. North Shore has a large elderly population which may explain the increase in cases, though it is surprising that median age was not statistically significant in the second model. It is somewhat surprising that vegetation did not appear to be a significant factor, though many of the cases in the suburbs have been linked to storm drainage systems, catch basins and backyards where wet organic material has accumulated. Housing age did prove to be a significant positive factor, which suggests that the theories of poor drainage in post-WWII housing are correct. This is a topic that could be investigated further as more detailed analysis could determine which types of housing and what drainage systems are most at risk.

One limitation of the statistical analysis is that it only focuses on known reported cases. Scientific evidence shows that 1 in 100 cases of WNV are reported (Nash et al 2001). Biases in reporting or undiagnosed cases in areas outside the clusters of this study may skew the results. Because of reporting bias, the models may show cases occurring in more affluent areas where access to health care is high, or to places where public awareness about WNV is high. However, from several interviews with health professionals, it seems that the cases reported were severe enough to necessitate health care of some sort. It has been suggested by several health professionals that the cluster areas would have only gained more cases had there been a bias in the reporting. Another potential limitation was with the variable Housing Age. By aggregating the data to the single measure, average housing age per tract, the post-WWII period is not captured. This was partly corrected in alternative models that included percentage of housing from three specific age classes (1940-1949, 1950-1059, and 1940-1959) as independent variables, and these models showed the 1950s time period to be important. However, we still do not know what about the post-WWII structures affects WNV risk. This will need to be examined more closely in the future.

The quantitative models generated through GIS and spatial statistics confirm that unique factors in certain MADs influence the disease prevalence in those areas. Neighborhood dynamics and ecological, social and political factors play an important role in disease. The models indicate a significant increase in risk within the North Shore and South Cook MADs. Mosquito abatement procedures vary greatly across MADs, which may have had an impact on disease risk. The second phase of this study delves into this question further by examining differences in mosquito control policies and politics across the study region and the impacts on spatial clustering of WNV. Newspaper archival research and in-depth interviews with managers and community members in each of the two high-risk MADs were conducted to better understand these differences.

MOSQUITO CONTROL AND WNV CLUSTERING

Preliminary findings suggest several important factors: political decision-making; poor communication/education, leading to skewed views of risk perception; and overall differences in abatement procedures including surveillance, control and planning. While some districts exhibited signs of mismanagement and decreased surveillance and control practices, the summer season of 2002 was worse than most professionals had anticipated. As one health worker stated referring to all WNV officials, "I don't think we were really prepared and really knew exactly how bad it could get". From the qualitative research, it was found that Dupage County and the Chicago region were less controversial and had less of a complex political mosquito control and surveillance system in place than the four designated MADs. Therefore, the focus of the research was narrowed primarily on North West, North Shore, South Cook and Des Plaines Valley MADs.

Both North West and Des Plaines Valley were praised highly by local and state health officials, community members, and other MADs for their forward thinking and planning, their public relations and education campaigns, their cutting edge surveillance and their vigilant control efforts. Conversely, blame fell on North Shore and South Cook for their lack of these efforts. In some cases, neighborhoods with very similar socioeconomic and demographic make-ups that had very different WNV outcomes depending on which MAD they were located in. Those in North Shore or South Cook often had many WNV cases, while those in North West or Des Plaines Valley had few or none. These differences may be related to bird migration routes (the reservoir species for WNV), or the presence of mosquito habitats that are very difficult to measure, such as backyard catch basins, or other ecological factors. However, political factors stemming from the management of mosquito control by the local districts most likely had some impact on the number of cases of WNV.

North Shore MAD had problems communicating effectively. The districts made minimal attempts at public education about effective self-protection techniques. They also failed to implement necessary control programs, such as timely adulticide spraying to reduce the population of positively infected mosquitoes. There is also a questionable amount of surveillance and control that occurred prior to the first human case of WNV. Unlike Des Plaines Valley and North West MADs, North Shore and South Cook MADs had far fewer mosquito traps, especially ones that capture the Culex species which is responsible for WNV transmission. They did not have the correct tests to monitor for presence of the virus in mosquitoes, and they did not treat suspected breeding sites as early, as often, or in as great a number as the other two districts. Once humans are infected, breeding sites have well been established and it becomes very difficult to eliminate infected mosquitoes. Conversations with health officials and local scientists suggest that North Shore MAD waited too long before it began looking for diseased mosquitoes and larvae and treating them. There also seemed to be a lack of direction and management within the North Shore district. The media and several interviewees mentioned poor staffing and weak leadership as critical to all other resulting problems.

South Cook has been criticized extensively in the media and from various health and community officials for its inactivity during the 2002 mosquito season. The South Cook MAD has a different philosophy of mosquito abatement which runs contrary to other districts and to national and statewide health directives. While their environmentally sensitive techniques have been praised in the past, South Cook has been criticized heavily for their poor response to the 2002 outbreak, and the subsequent large number of clustered cases in their region. The district argues that the increased number of cases in their region was due to the environmental factors that favor the presence of Culex mosquitoes in their area. They argue that this ecological phenomenon is partly due to the numerous cemeteries nearby, and could possibly be linked to a bird migration route, bringing may infected birds into contact with a susceptible mosquito population. However, it is clear that there was far less surveillance occurring, if any, within this region, and control efforts started later than in other districts. In addition, the district has negative opinions about the success of larviciding catch basins, a technique that is favored across the board in other districts and by health departments. Finally, adulticide spaying for positively infected mosquitoes did not occur in South Cook MAD until the state health department stepped in and threatened to pull emergency funding from the district. These and other leadership differences caused an extreme amount of anger and frustration between local leaders, residents and health departments and South Cook MAD. It is important to note however, that South Cook does have the largest MAD in the state, with a budget that is smaller than some. Managers at the South Cook MAD expressed their frustration over financial difficulties, and lack of money may have contributed to the inadequate mosquito control efforts. Yet it is evident from the interviews that the control and surveillance philosophies of managers in South Cook also affected mosquito control and disease outcomes.

Many of those interviewed mentioned silence and the lack of transparency among South Cook managers for their actions to combat WNV – a frustrating situation for the local and scientific communities. Several mayors and health department employees expressed dismay with South Cook's virtual disappearance during the mosquito season. There was little to no contact between the MAD and local villages. Some cities began their own abatement programs in response to the outbreak, because little was being done at the district level. Financial arguments became a hot topic as towns dug deeper into their pockets to cover the costs of mosquito control, when their taxes had already been sent to South Cook for the very same control. This continues to be a sensitive issue in many villages within the South Cook district. One health worker commented that:

> The main cause of clustering …may have been a combination of things. I think a lack of education amongst, probably everyone really. The MADs were more used to dealing with nuisance mosquitoes. Now they have this whole other realm to deal with. Now they have diseased mosquitoes. I think there was a lack of knowledge there. At least in the North Shore. And a lack of direction. In the South, it was just a lack. I think there was a huge mismanagement of money in that district, different philosophies, lack of surveillance. Just an overall lack of everything.

Illinois public health agencies were in a state of shock following the WNV outbreak in 2002 which resulted in a series of district meetings across the Chicago suburbs, and a lot of discussion regarding how to improve mosquito abatement. All MADs have increased their summer seasonal staff, added traps and increased their surveillance, though South Cook has done less to change its program than the other districts. In addition, a bill has been proposed by state legislatures which would alter the structure of all four MADs, essentially absorbing South Cook and North Shore into Des Plaines Valley and North West. The status of this bill is yet to be determined. If adopted, this legislation would result in more uniform mosquito control policies across the Chicago region, thus reducing the policy-based spatial clustering of WNV related to inadequate mosquito control efforts. GIS and spatial analysis methods can be used to determine if these trends occur in future WNV outbreaks.

CONCLUSIONS

As various forms of spatial analysis and GIS become a mainstream part of public health research, it becomes crucial to create linkages with other social and health science disciplines. GIS has been steadily gaining importance in public health applications (Cromley and McLafferty 2002) while a parallel development has been the rise in discussion of GIS and society. As community and participatory GIS, and mixed method GIScience research continues to grow and gain respect, new collaborative and interdisciplinary research opportunities should be established. The Chicago WNV outbreak was an ideal opportunity to combine technical visualization and spatial statistics with community level in-depth qualitative assessments. Meanwhile, while emphasizing the geographic nature of the study, focus remains on the importance of place and the impacts and consequences of local level decision-making on the health of a community.

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Table 1: Variables used in logistic regression.

Dependent Variable	
Presence (1) or Absence (0) of WNV case	
Independent Variables	**Description**
Race	% of population, white
Income	Median household income (used LogMHHI)
Age	Median age
Housing Age	Weighted mean
Vegetation	% vegetated
Mosquito Abatement Districts (MADs)	dummy variable created for each MAD, Dupage County, or Chicago Region

Table 2: Percent of correctly predicted variables in the first logistic regression mode.

		Predicted WNV Cases		
Observed		0	1	**Percent Correct**
WNV Cases	0	1052	51	95.4
	1	270	106	28.2
Overall Percentage				78.3

p = .783

p* = .746 (Largest Group)

Z-test significant (.05)

Table 3: Model 1 – Logistic regression results for all tracts in the study area.

Variable	B	S.E.	Wald	Sig.	Exp(B)
Median Age	0.036	0.013	7.399	0.007	x
Housing Age	0.015	0.006	7.013	0.008	x
% White	0.014	0.002	35.159	0.000	x
North Shore MAD	2.155	0.308	48.989	0.000	8.625
South Cook MAD	1.206	0.167	52.026	0.000	3.338
Des Plaines MAD	-0.775	0.343	5.118	0.024	0.461

Overall Wald = 324
Overall model significant (.000)
Nagelkerke r^2 = .200

Table 4: Model 2 –Chicago area eliminated from logistic regression model.

Variable	B	S.E.	Wald	Sig.	Exp(B)
Housing Age	0.025	0.008	8.782	0.003	x
% White	0.015	0.003	18.19	0.000	x
North Shore MAD	2.088	0.337	38.405	0.000	8.068
South Cook MAD	1.043	0.231	20.417	0.000	2.836
Des Plaines MAD	-1.017	0.391	6.753	0.009	0.362

Overall Wald = 55.6
Overall model significant (.000)
Nagelkerke r^2 = .220

Table 5: Percent of correctly predicted variables in the second logistic regression model.

Predicted WNV Cases				
Observed		0	1	**Percent Correct**
WNV Cases	0	380	49	88.6
	1	137	97	41.5
Overall Percentage				71.9

p = .719

p* = .647 (Largest Group)

Z-test significant (.05)

Figure 1: Study site showing population density and WNV case locations.

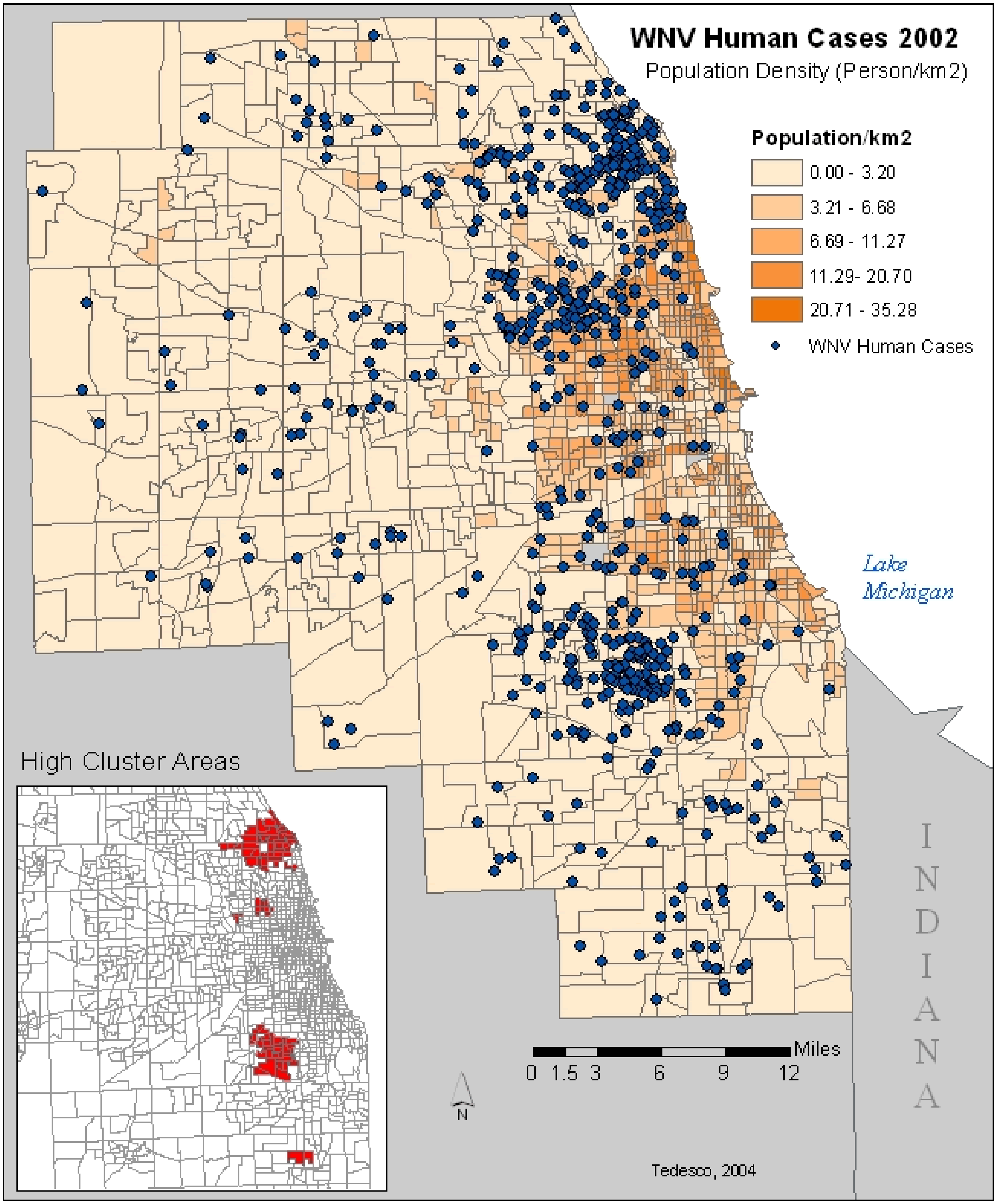

Figure 2: MADs and Cook and Dupage County locations with WNV cases.

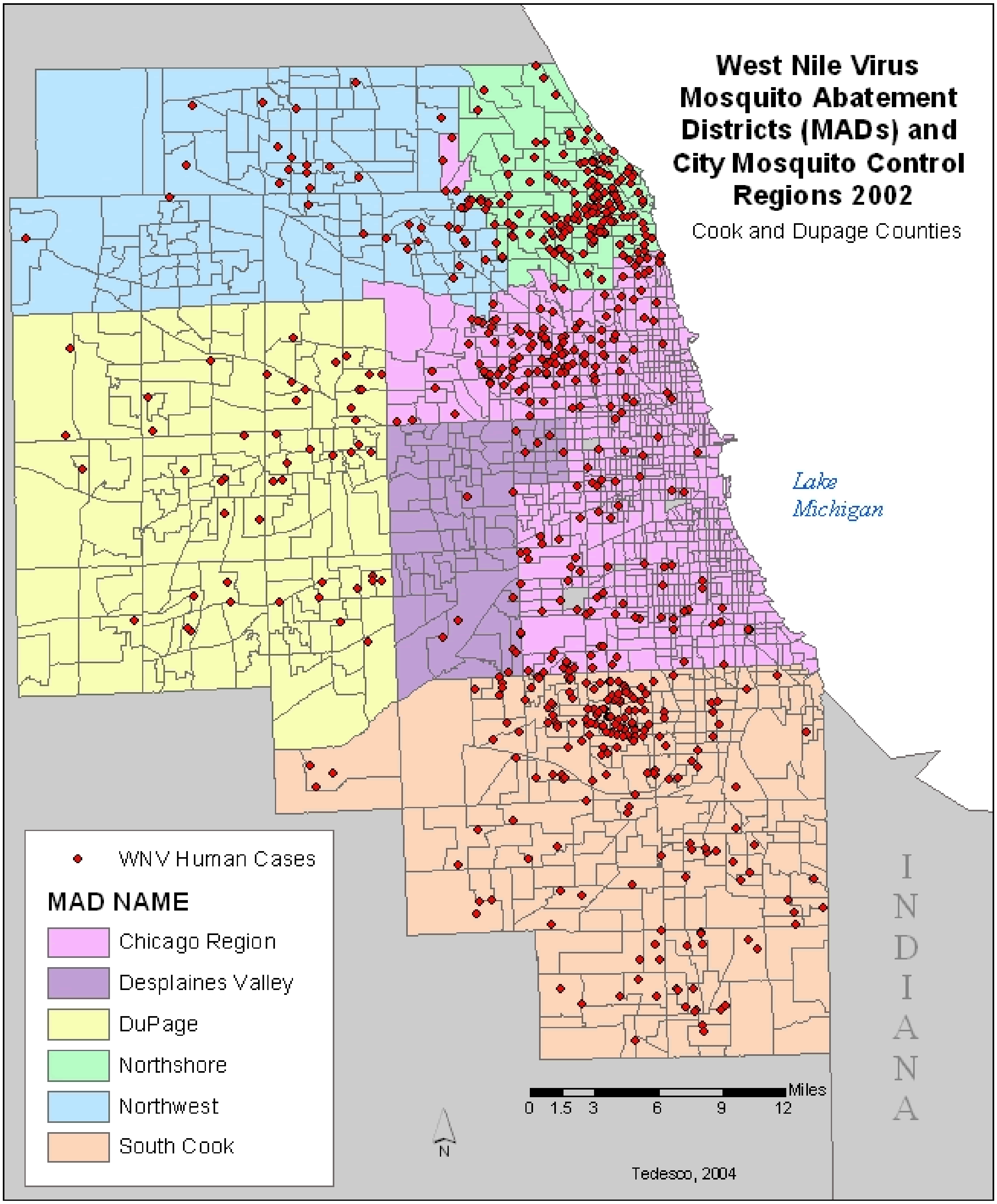

Figure 3: WNV cluster analysis using Local Moran's I and age-adjusted rates.