ABSTRACT

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Despite federal regulation, the sheer scale and poisonous quality of industrial pollution continues to pose an immediate threat to environmental and public health. However, the diverse study of degradation and toxins which are certainly not new phenomenon. The following inquiry compares the spatial distribution of four different types of hazardous waste (permitted landfills, national pollutant discharge elimination system, hazardous substances and national priority listed ‘superfund’) disposal sites and the associated risks throughout North Carolina. Increased dependence on space to accommodate pollution has produced a multitude of manufactured risks to environmental and public health which stretch through the entirety of the state. Current regulations rely on a site-based calculus to contain the varying types of pollution and often neglect the meso-level relational effects of waste management policy. In response, the following geographic information system (GIS) geospatial analysis tests for and seeks to model spatial inequality in relation to the particularity of place. Hot-spot and cluster functions also aid in identifying North Carolina communities disproportionately exposed to hazardous waste sites. Findings suggest strong support for the disproportionate patterns of pollution thesis throughout a range of environmental and social landscapes. Conclusions regarding methodological potential, spatial inequality and corresponding implications for environmental justice are discussed in tandem.

Patterns of Pollution: Spatial Inequality throughout North Carolina

by
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DEDICATION

I would like to dedicate the following inquiry to my mother and father, Neal and Lauren Thomson. I would also like to mention my grandparents Bill and Judy Santman as well as Danielle and Patrick Thomson. If it were not for my immediate family and their unrelenting support, I would never have been granted the opportunities and corresponding privileges which have propelled me to this point in my scholarship. My unrelenting appreciation to each of them can never be repaid. I have instead resolved to pay my debt forward to future generations by becoming an educator.

BIOGRAPHY

Ryan Thomson is a scholar-activist currently working toward a Ph. D in Sociology at North Carolina State University. His research interests include rural and critical globalization studies with an emphasis on public engagement. Ryan's current extension research with the North Carolina Environmental Protection Agency focuses on sustainable community development and accessibility to waste infrastructure. He currently sits on the Board of *North Carolina Waste Awareness and Reduction Network (NC Warn)* and remains dedicated activist within local environmental and social justice movements.

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Introduction

In the summer of 1978, Ward Transfer Company dumped roughly 30,000 gallons of toxic polychlorinated biphenyl (PCB) laced oil on 210 miles of roadside throughout 14 counties in North Carolina. Four years later the state of NC, aided by the Federal Environmental Protection Agency (EPA), began to clean up the spill to limit further contamination. After months of deliberation, Governor Hunt decided to bury the PCB in the predominantly black community of Afton in Warren County. Local residents immediately launched a grassroots movement that sought to raise awareness to what Dr. Reverend Ben Chavis termed 'environmental racism.' They laid in the streets to block the hazardous transport trucks, held sit-ins at regional EPA offices and marched countless miles throughout the campaign. This particular case of 'environmental racism' has been widely cited by numerous scholars as the birth of the environmental justice movement.[1] This unique grassroots movement successfully blended claims of social justice with environmental discrimination into a new framework for activism and scholarship. However, given the atheoretical nature of environmental justice research, a combination of supplementary theoretical structures from human ecology can aid in providing a comprehensive understanding of patterns of pollution. These include organizational studies from environmental sociology, disproportionality thesis from the rural sociology, and the

[1] Despite the common scholarly vernacular of 'environmental justice' to refer to the larger (global) movement and framework, the author insists on using the term 'ecological justice' (eco-justice) to refer to damages within local cycles of biophysical regeneration. This is done in order to immediately attribute these findings to the communities which rely on their material reproduction and experience the consequences of hazardous exposure first hand.

geographical technique from the newly emerging sociology of spatial inequality.[2] [3] Given the expansion of methodological opportunities and theoretical synthesis, this inquiry seeks to test for spatial inequality as it pertains to ecological equality while also investigating the nature of pollution throughout the state of North Carolina. In doing so, the following scholarship seeks to draw attention to the disproportionate protection of current environmental regulations and further advance local community dialogue.

Human Ecology and Pollution

The study of socio-ecological interrelations has become fragmented into countless disciplines and sub-disciplines yet all share in the same broad tradition of human ecology. Amos Hawley defined ecosystems as "an arrangement of mutual dependence in a population by which the whole operates as a unit and thereby maintains a viable environmental relationship." (Hawley 1950, 26) The general study of 'human ecology' thus sought to apply the symbiotic balance of nature to social relations and the fluctuating characteristics of a particular community (Park 1925, 1936). This conception presents ecology as an extension of biological economics and applies competitive succession to the social web of life. Thus, the adaptation of a population's behavior, economy or culture can best be defined as a constant and dynamic process rather than a static end state (Hawley, 1950; Duncan and Schnore

[2] Within sociology, it is worth mentioning that the emerging study of spatial inequality is largely an extension of previous rural research. This presents the geographical technique utilized in this study as immediately related to rural scholarship such as Freudenburg's disproportionality thesis.

[3] Catton (1994) makes the argument that sociology is in fact a specialty within ecology given the interdependence of humans on biological reproduction.

1959).[4] Duncan would further articulate that the ecosystem, as a conceptual scheme, is capable of indefinite expansion to comprehend virtually any problem of collective human life and that corresponding indicators of progress must be multifaceted and relationally reciprocal (1961). This understanding was most adequately applied to the historical evolution of humankind's niche expansion within the global ecosystem. In doing so, humans greatly altered the current flows and function of all ecosystems following our bipedal development, the specialization of the hand and ultimately with the emergence of agricultural societies (Duncan 1964). From these early human ecology writings emerged an ecological-evolutionary model that extended from these primitive agrarian techniques to larger exploitative technologies which characterize our current industrial society (Gerhard and Nolan 1984). Since these foundational studies, human ecology has splintered into numerous subdisciplines such as waste management, sociology, agriculture, geology, geography, toxicology and life sciences to name a few. No single approach has driven theory however, a number of competing approaches seek to inform the process by which policy is made.

Current Policy

Water contamination has a wide range of side effects on public health (ranging from mild irritation to lethal) and can have detrimental effects to ecosystem reproduction which echo throughout the interdependent food chain. The management of pollution risk reached a turning point with the Clean Water Act (CWA) of 1972, which permitted the EPA to regulate

[4] These early studies throughout the mid-twentieth century all had a particular concern for how to define ecological boundaries and oftentimes emphasized space.

point sources of pollution discharge in the form of National Pollutant Discharge Elimination Sites (NPDES) through the use of regional control boards. The 1976 Toxic Substance Control Act (TSCA) also granted the EPA the authority to require reporting, record keeping, testing requirements and restrictions relating to chemical production as well as certifying the importation and exportation of chemicals. This regulatory emphasis within production, importation, use and disposal of specific chemicals also included polychlorinated biphenyl (PCB), asbestos and lead-based paints. These sites tend to comprise manufacturing, mining, oil and gas extraction and service industries, municipal governments and facilities (military bases) and some agricultural facilities such as feed lots. All these industrial sites pose a serious risk of water contamination, thus threatening public and ecosystem health. These point source sites (also referred to as 'end of pipe') release vast amounts of pollution and are simply defined as 'externalities' by firms seeking to off put individual responsibility onto the grander public as a whole. Findings suggest that these threats are disproportionally distributed on a neighborhood micro-level basis yet remained far more common in urban fringe and rural communities even following the establishment of regulatory permitting.

In the winter of 1970, President Nixon created the Environmental Protection Agency which served as the vehicle to regulate ever–increasing material input (in both quantity and type) and supervise a diverse range of hazardous externalities (Priest 1988). The EPA is organized into 10 regions and on a state-by-state basis with a range of unique localized variations (relative to other federal bureaucratic institutions). This could be viewed as a technique to aid in the legitimation and normalization of the inherent risks associated with everyday pollution exposure. In accordance, the second regulatory policy response which sought to mitigate the deteriorating socio-ecological interrelations during the 'environmental decade' and proved equally (if not more) significant to the CWA was the Resource Conservation and Recovery Act (RCRA) of 1976. This legislation established a foundation for the creation of infrastructure (i.e. landfills and hazardous waste sites) and a number of general preventative regulatory departments. Under Subtitle D of RCRA, municipal and county solid waste landfills are subject to federal regulations that restrict locations, establish liner requirements, leachate collection and removal. The immediate effect of RCRA was the dramatic decrease in number of landfills and a centralization of leachate toxins to state certified sites (Tammemagi 1999; Yousuf and Rahman 2009). Water contamination proved so threatening to public and environmental health that liners and their upkeep have become central features of landfills throughout the United States. Leachate is any liquid that, in passing through matter, extracts solutes, suspended solids or other components of that material and is a serious risk to public health. This blanket term utilized by waste management was taken from toxicology which applies to all material containing elevated levels of undesirable material (often high ammoniacal nitrogen concentrations and low phosphorous content). These toxins pose a large risk to the contamination of groundwater and have been identified as a source of cancer clusters as well as other diseases related to contamination among residents near landfills (Goldman et al. 2010). In a similar manner, the same system of accounting has begun to select landfill sites with geographic information systems (GIS) which supply an insight to policy formation and risk distribution. It should be mentioned that industrial landfills differ from solid waste landfills and are primarily collected by the private sector by matter (construction and demolition waste, coal fly ash, medical waste) and tend to be disposed of through combustion facilities (Zhang et al. 2011). RCRA also managed to begin moderating the treatment, storage and disposal of hazardous waste scattered throughout the fringe areas of larger industrial centers. Shortly thereafter, the major amendments to CWA in 1972 managed to redistribute the risks to public health which were quickly accumulating throughout the state, primarily in rural municipalities. The large significant turning point to follow the environmental decade was the Comprehensive Environmental Response, Compensation and Liability Act (CERLA) of 1980 and the Superfund Amendments and Reauthorization Act (SARA) of 1986. These acts of mitigation created the national priories list and registry of hazards. In doing so, environmental legislation was largely a response to Love Canal and Valley of the Drums (United Church of Christ 1987, Bullard 1991) and established a special trust fund aimed at combating these socio-ecological failures. Superfund sites tend to be heavily industrialized facilities so polluted with public health risks as to be uninhabitable. NC contains 38 of these superfund sites on the priority list (with a national 1280 total sites as of 2011) that serve as constant reminders of social failures to protect the geophysical cycles of reproduction.

The system utilized by the EPA to calculate risk utilizes a Hazard Ranking System established in relation to “potential relative risk to public health and the environment” (EPA 2011). Of the 38 sites scattered throughout NC, the Warren County Roadside PBC spill has been the only instance of recovering socio-ecological relations largely in part to the national attention that sparked the current environmental justice movement.

ENVIRONMENTAL JUSTICE

Scholarly works such as Richard Bullard's *Solid Waste Sites and the Black Houston Community* (1983), *Dumping in Dixie* (1990), Adola (1994) and Faber (1998) aided in solidifying the environmental justice framework as a model for challenging environmental inequality. Bullard's case studies of the Mississippi Delta, downtown Houston and Afton North Carolina documented clear examples of hazardous exposure along lines of race and class. The documentation from universities, research institutes and numerous non-profits all utilize a similar ecological justice framework in which substantive claims are made by a community regarding unequal treatment. As a result of strictly making pointed assertions pertaining to environmental discrimination, the frame generally avoids the use of a theoretical paradigm or ideological approach which could undermine the objectivity of the claim-maker(s). Put simply, environmental justice research seeks to facilitate critical public engagement of policy (primarily relating to ecological inequality) and is only permitted to be interpreted by others in order to retain scientific sincerity in the political realm of decision making. Throughout the movements' emergence, environmental justice dialogue was often characterized by reductionist reviews suggesting simple cases of environmental racism and classism.

Environmental Sociology

Despite numerous theoretical alternatives, disproportionality and path dependency are the primary focus of this spatial analysis. However, future research could be used to investigate the theoretical applications of treadmill of production (Schnaiber 1980), ecological modernization (Rosa 2000),[5] metabolic rift (Foster, Clark and York 2010) and ecologically unequal exchange approaches (Bunker and Ciccantell 2005). Ecologically unequal exchange and the treadmill of production in particular hold immense potential given their understanding of ecological evolution and how it pertains to material output. The post-war boom in chemical synthesis has been referred to by Allen Schnaiberg as the treadmill of production (1980). In terms of pollution, the treadmill of production claims that the rate and toxicity of externalities will increase with time (Schnaiberg, Pellow and Weinberg 2002). This outcome of waste is often neglected and a ‘treadmill of pollution’ can be seen as a taken for granted assumption within the literature. When applied to the world system, there is significant empirical support given to the increased toxicity and volume of waste currently being exported to undeveloped periphery nations (Schnaiberg 1997; Basel Action Network 2002; Pellow 2007). Stemming from the dependency school of research, ecologically unequal exchange theory also asserts that the profit-motive of development will benefit some areas more so than others (Bunker and Ciccantell 2005). When pollution is applied to space, unequal exchange drives down the real value of a good (in this case land and surrounding ecosystem) to bear the burden of a particular hazard. This distributional process of unequal

[5] Both risk society as well as the kuznet’s curve of reflexive modernization.

exchange provides a conceptual framework for understanding how the socioeconomic metabolism (or material throughput) of one place can disproportionately develop at the expense of another place.

Firm Organization

Environmental justice and risk society literatures suggest these grander processes manifest within the particular organization of an economy and its independent firms. Perrow's *Normal Accidents* (1984) characterized high-risk facilities[6] as tightly coupled (independent and non-sequential) systems with complex (unfamiliar, non-linear and incomprehensible) interactions. Years later, risk society would come to refer to this "epoch in which the dark side of progress has increasingly come to dominate social debate" (Beck 1995:2). Like Bullard, Charles Perrow (1999) and Ulrich Beck (1999) share the realist structural approach that views people as being exposed to hazards based on the social position which they occupy within society. [7] Despite distinct origins, both eco-justice and risk society literature suggest that patterns of pollution are manifest along class and racial strata.[8] Gephart (2004) further elaborated that complex and tightly coupled systems of industrial production inherently produce high-risk situations as the result of their organization. Like Perrow, he argues that accidents are inevitable and occur with a sense of normalcy associated with economic expansion. Given the nature of risk management regarding pollution

[6] Figure 9.1 identifies nuclear plants, chemical plants and nuclear weapon bunkers as high-risk facilities (Perrow 1984:327)
[7] Referred to by Freudenburg as 'real risks' (1988).
[8] Specialized vocations such as waste management and toxicology also share in this realist camp.

exposure, this establishment of normalcy places the burden of proof on the victims of environmental or public health accidents (Cable 2008).

Grant, Trautner, Downey and Theibaud (2010) advanced this organizational discussion with their findings that a multitude of facility and community factors interact to produce ‘recipes of risk.’ Put simply, it is the notion that a combination of economic and community factors interact to prevent (or fail to prevent) the placement of hazards inherent in industrialization. These ‘recipes’ offer a relatively complex understanding of pollution and far exceed the paradigm currently directing waste management policies. These organizational studies in effect ‘bring the firms back in’ and attempt to situate a structural environmental critique within a particular form of organization.

Disproportionality and Spatial Inequality

The study of spatial inequality emerges from the well established scholarly traditions of rural sociology and geography. Early Cooperative Extension Services and later New Deal Programs (such as the Rural Electrification Administration and Tennessee Valley Authority) permitted rural sociologists to aid the physical sciences formulating agriculture policy while studying variations in natural resources (Taylor 1942). Given the dispersion of communities throughout rural areas, an emphasis on geography and space were integrated with a range of demographic and socioeconomic factors. Buttel has characterized the sociology of natural resources by its social science policy orientation, local landscape emphasis, rural community units of analysis and stress for conservation (1996; 2002). However, the patterns of uneven development brought with them an inherently disproportionate set of relations regarding access to resources and exposure to hazards. Freudenburg (1988) postulated that uneven development disproportionately disrupts rural ecosystems at the expense of local communities. Since numerous other theories approximate average figures for environmental impact, Freudenburg sought to characterize the high levels of inequality and particular accumulation of hazards (such as industrial pollution sites). Although similar to unequal exchange as well as risk society theory, disproportionate degradation emphasizes the particular clustering. This process occurs through what he refers to as a double diversion in which pollution is reframed as a non-problematic and economic issue while claiming public interest. Like the previously mentioned risk society scholars, he, too, points to institutions (such as the EPA) as sources of legitimation the plunder of natural resources and accumulation of hazards.

Other scholars (Labao, Hooks and Tickamyer 2007) have begun to cross-fertilize elements from rural sociology with research from geography to produce a new approach for studying spatial inequality. This theoretical approach is coupled with the methodological revolution currently surrounding geospatial information systems. This advancement in geospatial modeling and analysis techniques made available through GIS software and corresponding data sets has offered new opportunities to study spatial-temporal trends. Beyond this sociologists have only begun to tackle the spatial knowledge gap that is the sub-national unit of measurement.

The studies of geography and spatial inequality also provide an ecological frame embedding social organization within geophysical processes. Given the current insights provided by the treadmill of production and risk assessment, the following analysis tests for disproportionate clustering of hazards that exist beyond the concentrated populations in urban areas (Molotch and Logan 1987). As urban centers grew, the increased demand for space often times displaced accumulating pollutants from the cities to nearby communities positioned on the fringe of the city. This process is often referred to as path dependency in which a previous decision (e.g. the selection of a landfill location) has a significant influence on future environmental decisions regarding that community (e.g. the further location of a hazardous waste site). These trends are in many ways tied to the urban centers which seek to displace the burden of waste on nearby surrounding communities.

Much like rural research, pollution clusters tend to be highly descriptive and relational to the geography which it exists. However, this approach which dominates waste management policies falsely assumes a public solution to a problem which is created nearly entirely through private enterprise. Landfills, NPDES and hazardous waste sites are all maintained by public costs through the EPA despite their industrial origins within private firms (Grant et al. 2002). Ultimately, uneven exposure of pollution throughout a geographic landscape is a product of disproportionate power relations within the grander social organization of private firms and the state. The work of scholars such as Bevc, Marshal and Picou (2007) has already begun to lay the foundation for a bridge between spatial disproportionality of toxic exposure and the struggle for ecological justice.

Data

Over the past two decades, geographers and statisticians alike have compiled vast amounts of secondary data used to analyze social and ecological processes throughout every corner of the world. The data used in the following study was made readily available to the public through NC One Map Geographic Data Services,[9] a state-level project of the NC Geographic Information Coordinating Council started in 2003. These incredibly detailed virtual maps and corresponding metadata are downloadable as EPA (.shp) files which have become accessible to the public in recent years. Data regarding active landfills were collected through the EPA Landfill Methane Outreach Program in 2004 while permitted NPDES data were collected by the NCDENR Division of Water Quality in 2006. The NCDEHNR Division of Waste Management composed the National Priority List 'superfund' list in 2009 while the Hazardous Waste Section released the files of active sites in 2011. It should be observed that a number of sites are qualified by the state as constituting multiple permits, thus some overlap exists in housing and documentation of data.

Industrial hazardous waste sites contain a wide array of specialized chemicals including previously mentioned PCB oils at a commercial and residential micro-level. The bit-map obtained through NC One Map outlines the sites bringing in a land use element absent in the rest of the data. Exposure to these types of hazardous chemicals has been found to be cancerous (Brown and Mikkelsen 1997). Of the 883 total hazardous waste sites, all but a handful are not incorporated private entities. Such non-private sites include places such as NC State Universities (Lot 86 Farm Unit), the Department of Defenses base Sunny Point and

[9] http://www.nconemap.com/

Duke Universities Transformer Station. The larger majority of the permit list is comprised of industrial production sites, private dumps, coal and gas plants near urban areas. Sites such as Duracell international lithium production factories in Lexington, Miller Brewing Co. plant in Eden or Dow Chemical in Charlotte tend to be close to cities, while places like RJ Reynolds factory north of Winston-Salem and Pfizer southwest of Wilmington are intermittently scattered throughout the nearby countryside.

The data provided by the state is a coordinate for points and still serves to relationally assess the placement of landfills. Landfills bring with them the risk of leachate exposure which has been shown to be cancerous. Leachate is the blanket term used to describe a general mixture of waste which contains some level of hazardous waste as decay sets in. Research as recent as 2010 concluded that clusters of cancer outbreaks can and have occurred when leachate is not properly irrigated (Goodman, Hudson and Monteiro). The state of NC has spaced out a potential landfill per county and an additional 26 totaling to 126 total landfills. Larger urban areas tend to have an additional landfill while small rural areas use the closest drop site opportunity. These sites tend to be selected based upon the demand for disposal space as it relates to the availability of land. In order to decrease the chance of exposure, sites are often selected on the fringe areas surrounding urban areas but can become incorporated to the city limits as boundaries expand. Landfills tend to be viewed as the front lines of the waste crisis and have been forced to expand in area as well as number.

Section 312 of the Clean Water Act established a minimum level of water quality to be dumped into public waterways such as rivers, streams and the ocean. These NPDES are wastewater sites such as pesticides, vessel discharge, sewer sludge and animal feed operations which discharge into surface water. These 1477 permitted sites throughout the entirety of the state primarily embed these sites along sizeable rivers and streams (see Figure 5). Duke Energy Corporation has twenty-three total discharge sites while Carolina Power and Light (CP&L) (a subsidiary of Progress Energy) has sixteen. Now that Progress and Duke Energy have merged, Duke is now the single largest source of 'end of pipe' pollution into NC waterways. Behind the energy providers are a series of corporations, municipal and education institutions following with double digit permits. These sites (represented as points) seldom fall within urban areas in an attempt to avoid public health risks and a corresponding civil action.

The final form of pollution used in this comparison in many ways differs from permitted sites which seek to retain their standing with the state. Under the RCRA, the National Priority List 'superfund' sites are far more variable in terms of pollutants and range of environmental failures. These sites pose such a risk to public health that these areas are effectively abandoned and quarantined to the general population. Of the 37 sites (represented by their coordinates as points), each is unique to the incidents which occurred in failing to regulate pollution. Ward Transformer Corp. discussed in the introduction left behind a toxic legacy not only along the highway in Warren County but also at their factory in Raleigh. Sigmon's Septic Tank Service let a 'settlement lagoon' in Statesville get so out of hand the area was abandoned. The remainder of the list is dominated by contaminated chemical companies and pesticide contaminated farms. These sites tend to be located near large industrialized urban centers; however, a number of rural sites do exist. One instance is the Ore Knob mine of Ashe County which simply deteriorated as a result of the mineral extraction determined by geographical formations.

Methods

In accordance with a realist ontologically, GIS is used to assess the spatial distribution of toxins void of social perceptions associated with an idealist approach. The following study utilizes GIS for its structurally-oriented analysis of current patterns of pollution as they are spatially distributed. In order to compare the four types of pollution alongside one another, a range of spatial techniques will be used to analyze differing patterns. The investigation will utilize two mid-range geographical units, the state (as a collective space) and parcelized counties which embed pollution in the geographic and local details of geography. The particularities discussed at length are geography, access to labor, relation to urban centers and demographic details of neighborhoods regarding the selected case studies.

GIS software offers a range of tools, methods and highly specialized techniques developed specifically to assess spatial relationships. These tools model relationships, assess trends, and identify patterns by including space as a variable directly into the mathematical computation. In order to test for the existence of spatial inequality, Average Nearest Neighbor summary, High-Low Clustering (Getis-Ord General G), and Spatial Autocorrelation (Global Morans 1) will all prove insightful in assessing geographical patterns. Secondary investigation will utilize a Hot-Spot Analysis (Getis-Ord G*) and the aggregate point function to assess between county patterns of exposure. All analysis utilized a Euclidean distance (strict distances between places) rather than accommodating inequality along Manhattan distances which would include city blocks. Average nearest neighbor assesses the general dispersion of pollution sites throughout the entirety of the state. Spatial autocorrelation (Moran 1950) will also be used to assess the level of pollution dispersion on a county-by-county basis. The study will overlap these findings with a hot-spot analysis of each type of pollution to identify counties suffering from increased environmental discrimination. In doing so, the aggregate point function will identify targeted areas at the local level. All analysis utilizes a Euclidean distance (strict distances between places) rather than accommodating inequality along Manhattan distances which would include city blocks and roads.[10]

Hypothesis: Does spatial Inequality Exist?

- $H_{0:}$ Variations within the location of pollution sites are dispersed in a random (or evenly distributed) pattern and do not constitute unequal risk exposure. ($p > .05$)
- $H_{a:}$ Significant clustering exists (between or within counties) which constitute disproportionate exposure to nearby residents. ($p < .05$)

The benefit of triangulating methods permits verification as to the reliability of state data as well as grant a deeper understanding of the role of the county in altering the distribution of pollution. It is immediately apparent to viewing the distribution of the data that the process of human niche expansion, having been forced by the treadmill of pollution, is directly affected by demographic as well as geographic characteristics. In terms of human ecology, this

[10] Having used Manhattan Distance would in some instances radically alter the findings of the study. However, since pollution contaminates ecological resources directly (and by no means travels along streets) a Euclidean distance best represents the spatial model of pollution. It should be mentioned however that exposure has been known to be subject to a multitude of interaction effects.

expansion would indicate that the process of uneven development is a driven by the emphasis the particularity of place across multiple types of pollution.

Findings

Not only did clustering appear highly significant at the .01 level for between counties (landfills, npdes and industrial hazards) as well as within counties (for industrial, npdes and superfund sites), but evidence of high-clustering was found, further demonstrating that areas unaffected by pollution do not cluster together. There exists overwhelming evidence of spatial inequality which further support the disproportionate patterns of pollution and dependency thesis. This clustering is in contradiction with the hot-spot analysis (seen in figures 3, 4 and 5) that identify the northeastern part of the state as being spared the burden of environmental pollution from these four types. Hazards (aggregated to ten miles shown in figure 2) appear to travel along the larger interstate highways linking the core metropolitan areas. These sites are sporadic and tend to cluster most densely within urban centers (see figure 3).

The average-nearest neighbor comparison output table for each type of analysis suggests spatial inequality clearly exists both between as well as within counties. It is apparent that these dense clusters prove highly significant and exist for npdes, superfund and hazardous waste sites irrelevant of county lines. However, landfills prove to be the exception to this rule and show a random dispersion throughout the state. This is largely due to each county having a landfill permitting the distribution of dumps to spread out between counties.

The following autocorrelation output for comparing counties suggests that pollution exposure also tends to differ between counties. Given the distribution provided by the NC EPA, we would expect this distribution of landfills, npdes and hazardous waste sites to randomly occur less than .01% of the time. However, superfund sites falls .346 standard deviations from the expected equal distribution and does not constitute a form of environmental inequality between counties given the random dispersion.

Furthermore, the high-low cluster method seeks to test these clusters to see if areas tend to accumulate pollution sites and/or non-polluted sites. As the findings suggest, landfills, npdes and hazardous waste sites tend to cluster high levels of pollution together and few pockets exist of unaffected pollution. Given that superfund sites were deemed insignificant by the autocorrelation, we can presume that no high or low clusters are apparent in the random dispersion. The side by side comparison of spatial autocorrelation and average nearest neighbor, the data exhibit a transition for both landfills and superfund sites when controlling for county lines which parcel the state. However, these fascinating findings have radically different interpretations. Landfills on the one hand exhibit a transition from random to cluster spacing. This suggests that given that each county has a landfill the entirety of the state exhibits a random pattern, yet certain counties (Wake, Durham, Johnson and Jackson) contain more sites than others. Wake and Durham suggest a population complication while Mecklenburg County remains strangely absent. Johnson County nestled in the Appalachian Mountains likely distributes its waste in such a way due to the high transport costs trash pickup.

Referring back to the second shift, superfund sites become randomized when county lines are controlled for. Perrow (1988) would likely suggest that complex and tightly coupled organizational ‘accidents’ tend to occur in heavily industrialized clusters along county borders. These areas tend to be rural or partially suburbanized areas which develop outward in from the city and accommodate a decades old industrial site of some sort. In terms of ecologically unequal exchange, rural communities existing (or newly developed suburbanized areas) on the fringe areas overflow ever closer towards pre-1980’s industrial areas or industrial parks.

When viewing the hot-spot and aggregated point outputs, pollution appears to accumulate into clusters and patterns differently depending on the type of waste. This is not to say that there is no overlap between types of pollution, rather each different type of pollution is confined by a particular social policy and geographic context. The aggregated points of hazardous waste sites appear to disseminate outward from the industrialized sectors of urban areas. This is also supported by the hot-spot analysis (figure 3) which identities the metropolitan areas of Charlotte, Raleigh and Winston-Salem as areas with heighted levels of hazards waste sites. The northeastern part of the state exhibits little pollution throughout two hot-spot analysis. Although one would assume this ability to limit state defined pollution sources, this could also suggest that a lack of industry has left the coastal plains without a source of income. Given the poverty which tends to characterize the farmers of the area, access to landfills and jobs appear to be an alternative type of harm entirely.

This radically differs from counties with increased levels of landfills (figure 4) as well as the absence of sites throughout the northeastern part of the state. Again Raleigh and Winston-Salem appear to have disproportionate numbers of sites to accommodate the large populations but Charlotte remains mysteriously absent. This may be due to Mecklenburg counties ability to place its landfill in Gaston County to the west. The Asheville area is also identified as a hot-spot likely due to the geographic limitations of transportation trash throughout the mountainous region.

National pollution discharge elimination sites appear in many ways to be a combination of the patterns observed with landfills and hazards. Npdes are willing to locate themselves within cities however; the need for access to a moving water source forces the distribution out into the rural areas. These sites however are disproportionately not present in the northeastern part of the state. In addition, all previously mentioned urban areas are identified as hot-spots for npdes but also effect surrounding counties such as Union, Forsyth and Durham.

Finally, the superfund hot-spot analysis (despite not significantly clustering along county lines at the .05 alpha level) identifies a range of disproportionate areas throughout the state. These areas include Mecklenburg, Wake and Asheville as well as nearby (partially) industrialized counties such as Haywood and Carrabus. It is strange that Hoke County just southwest of Fayetteville as well as Brunswick falls three standard deviations above the expected mean. This is hardly a surprise given the long term health effects which have recently been discovered relating to the military infrastructure throughout the area. The rurality of the military bases suggests a lack of adequate oversight.

Given the immense potential of GIS research, future inquiry should make use of hydrological mapping, geological soil specifications and climate patterns in order to best model the distribution of pollution with corresponding interaction effects. The methodological advancements within this field will continue to grow as more detailed data is made available and triangulated with grassroots community level data. Although this study chose not to test Bullard's environmental racism theory directly, future inquiry could easily model rates of ecological injustice by racial or class category. Such research could lead to a more thorough understanding of environmental inequality and discrimination. Given the racial pollution patterns exhibited throughout the counties of Gaston, Warren and Chatham, it is apparent that 'environmental racism' is still having an effect on the health qualities of NC communities. Future research should further investigate Bullard's spatially, alternative theoretical frameworks as well as test the Reverend Chavis's claim of environmental racism.[11]

Given the development of NC industry since its establishment as a colony of Great Britain, the particular manifestation of pollution presents a pattern which is historically contingent on prior decisions. The textile mills which stretch from the southeastern port of Wilmington form a trade route which had previously been known as the 'textile crescent.' These mills, in many ways similar to more modern sources of pollution, were subject to

[11] Possibly with a time order or comparative element between areas.

geographic as well as social influences. Hence, the establishment of large roads followed previous routes in order to best serve the trade interests which had previously been established. This is readily apparent when reviewing the particular location of large firms, industrial hazards and npdes in particular. This notion of path dependency largely informs the spatial process by which pollution clusters in one place rather than another. Textile firms, despite a lack of state regulation, were (and are) largely similar to private industrial npdes since they required access to flowing water. They also remain subject to the need for cheap labor so locating a textile firm between the triangle, the triad and Charlotte was seen as profitable. As a result, the textile crescent led to a series of decisions which led the further concentration of pollution clusters in and around the larger urban centers and secondary municipal townships.

Conclusions

The spatial inequality throughout North Carolina environmental quality is clearly a complex phenomenon which exists at varying degrees throughout the state.[12] Urban areas tend to centralize hazardous waste sites while transporting vast amounts of waste to landfills often beyond the city limits. 'End of pipe' npde sites also exist within urban centers but since law requires disposal into running water, most of these industrial sites relocate to suburban and rural communities. Large rivers such as the Upper branches of the Cape Fear and Neuse river basins appear to be the primary centers for these sites. The port of Wilmington on the

[12] Future research will further elaborate on how ecological justice can operationalize its relation to inequity.

coast also houses a disproportionate number of these large industrial sites. Superfund sites tend to occur in smaller communities which heavily rely on the industrial (e.g. General Electric in Hendersonville) or resource extraction sectors (e.g. Ore Knob Mine) of the economy. Extractive industries and heavily industrialized business parks show strong support for ecologically unequal exchange.[13] Gaston County to the West of Charlotte and Research Triangle Park in Wake County both import and retain vast amounts of waste. Communities which share a water table or are positioned downstream of these areas ultimately face the largest risks associated with economic development. It should be mentioned that the case of Gaston County is likely the most drastic case of meso-level environmental discrimination in the entirety of the state. In every single hot-spot analysis as well as aggregation, the predominantly black community of Gastonia (located in the center of the county) is targeted for heighted levels of pollution. Beyond this, a multitude of micro-level examples of injustice exist from Rogers road landfill in Orange County to the contaminated groundwater in Concord and Aberdeen. Each and every site (shown in figure 1) constitutes a health risk to the surrounding public and ecosystem. The repercussions of each site bring with them the potential for illness for surrounding residents which can lay dormant for years before being exposed as a health risk. Despite being added to the superfund national priority list in 1987, community members surrounding Camp Lejeune Marine Base in Jacksonville requested a formal investigation into the multiple instances of leukemia in October 2009. Today, this

[13] One prime example is Charlotte's pollution of South Carolina's Lake Wylie which turns into the Catawaba River. However, heavy industrialization already aligns the banks of this river so cross-over effects are seldom discussed.

particular incident is garnering serious attention throughout a state which knows pollution all too well.[14]

The treadmill of pollution certainly appears to be at work given the increased number of permits over the last twenty years. Policy has primarily responded with environmental health initiatives void of any industrial discussion or possibility for more stringent regulatory policy. Nevertheless, the number of superfund sites has strangely slowed since the expansion of the list throughout the 1990's. This could in part be seen as the drying up of federal funding which enlarges the priority list or possibly the appearance of an alternative approach which decreases public coverage of such issues in order to prevent alarm. Landfills open and close with some regularity so little can be inferred regarding the meso-level assessment of residential waste. The process of path dependency can further be interpreted as a historical process which builds on previous sites of pollution with time. Hazardous waste sites and landfills will often draw the other form of pollution to the already devalued pieces of property when conveniently located on the fringe of urban centers. This process of uneven development can ultimately be seen as a dialectical process which requires labor in combination with the geographic availability of a disposal site.

In terms of redistributing pollution and its associated risks, environmental justice consistently gets caught in a reactionary position in which novice activists seek to defend themselves from the placement of toxic waste. This 'Not In My Backyard' (NIMBY) approach, although efficient at the city and township levels of governance, fails to go on the

[14] In reference to the early environmental justice movement as well as the infamous 'hog wars' which dominated the coastal region of the state. The research and grassroots movement has been well documented by Edwards and Driscoll, 2008.

offensive when dealing with policy reform. Since federal environmental reform appears to be a distant hope at the current political moment, the state of NC could greatly benefit from a renewed state-generated dedication to environmental quality. Such a renewal would not only boost state sector jobs (cut during the recession), it could also aid in the creation of new private industries beyond that of simple recycling. Alternative energy production would likely be the first step to decreasing the number of npdes (and not to mention coal ash ponds). Beyond this, tourism and leisure activities would likely see a boost in profits. Although state legislative reform currently seems like a distant idea, it is not impossibility. The state of North Carolina has undergone significant environmental reform before (e.g. decreasing incinerators from over 200 down to nine over the past two decades) and repeating this process is conceivable. Another and equally proactive alternative would be to strictly target the largest sources of pollution: the previously discussed collection of state owned facilities and Duke Energy.

These results clearly suggest that environmental inequality exists within and surrounding the cities which serve as the primary space of capital accumulation and path dependency. However despite the systemic nature of pollution, these findings suggest that environmental justice exists at the grassroots level. Rather than emphasizing the entire environment, localized resistance focuses on protecting their immediate surroundings and nearby community.[15] Although not the primary emphasis of this inquiry, future research could use GIS methodology to test for pollution as it directly correlates with race, class and

[15] This suggests the possibility for environmental justice to exist at the larger theoretical movement level while the struggle for equity advocates ecological justice.

ultimately poverty. This technique has proven incredibly useful when seeking to identify and empower particular communities as they seek to establish claims of unequal exposure to hazards. Secondly, GIS holds immense potential for mapping the diffusion of pollution throughout the state's rivers and streams as well as denote which aquifers face the highest risks. Furthermore the macro-theoretical structures previously mentioned could likely use GIS methods to advance a meso-level relational understanding of space, place and ecological degradation.

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Appendix

APPENDIX A

(Table 1) - AVERAGE NEAREST NEIGHBOR ANALYSIS (between all sites in the state)

Unit of Pollution	Observed Mean	Expected Mean	Nearest Neighbor Ratio	Z-Score	P-Value	Conclusion	Cluster / Random / Dispersed
Landfills	18821.908	19574.145	.096157	-0.825255	.409227	The pattern does not appear to be significantly different than random	Random
Industrial Hazards	0.000559	0.001367	0.409273	-33.600357	0.000000001	There is a less than 1% likelihood that this cluster would appear by random	Clusters
NPDES	0.000584	0.001087	0.5374	-34.02169	0.000000001	There is a less than 1% likelihood that this cluster would appear by random	Clusters
Superfund	0.002875	0.004957	0.579936	-4.957	0.000001	There is a less than 1% likelihood that this cluster would appear by random	Clusters

(Table 2) - SPATIAL AUTOCORRELATION (Global Moran 1) (between Counties)

Unit of Pollution	Moran's Index	Expected Index	Variance of County Pollution	Z-Score	P-Value	Conclusion	Cluster / Random / Dispersed
Landfills	0.269946	-0.007874	0.004825	3.99546	0.000063	There is a less than 1% likelihood that this cluster would appear by random	Clustered
Industrial Hazards	0.253211	-0.000308	0.005283	3.608716	0.000308	There is a less than 1% likelihood that this cluster would appear by random	Clustered
NPDES	0.397884	-0.007874	0.004497	6.050781	0.00001	There is a less than 1% likelihood that this cluster would appear by random	Clustered
Superfund	0.01519	-0.007874	0.0044435	0.3464465	0.7290008	The pattern does not appear to be significantly different than random	Random

(Table 3) - HIGH-LOW CLUSTERING ANALYSIS (Getis-Ord General G) (between Counties)

Unit of Pollution	Observed Gen. G	Expected Gen G	Variance of County Pollution	Z-Score	P-Value	Conclusion	High / Random / Low
Landfills	0.009342	0.007874	0.0001	33.333991	0.000856	There is a less than 1% likelihood that this cluster would appear by random	High-Cluster
Industrial Hazards	0.01454	0.009091	0.00002	4.064664	0.000048	There is a less than 1% likelihood that this cluster would appear by random	High-Cluster
NPDES	0.011264	0.007874	0.0001	5.276294	0.00000001	There is a less than 1% likelihood that this cluster would appear by random	High-Cluster
Superfund	0.008574	0.007874	0.000012	0.199915	0.841547	The pattern does not appear to be significantly different than random	Random

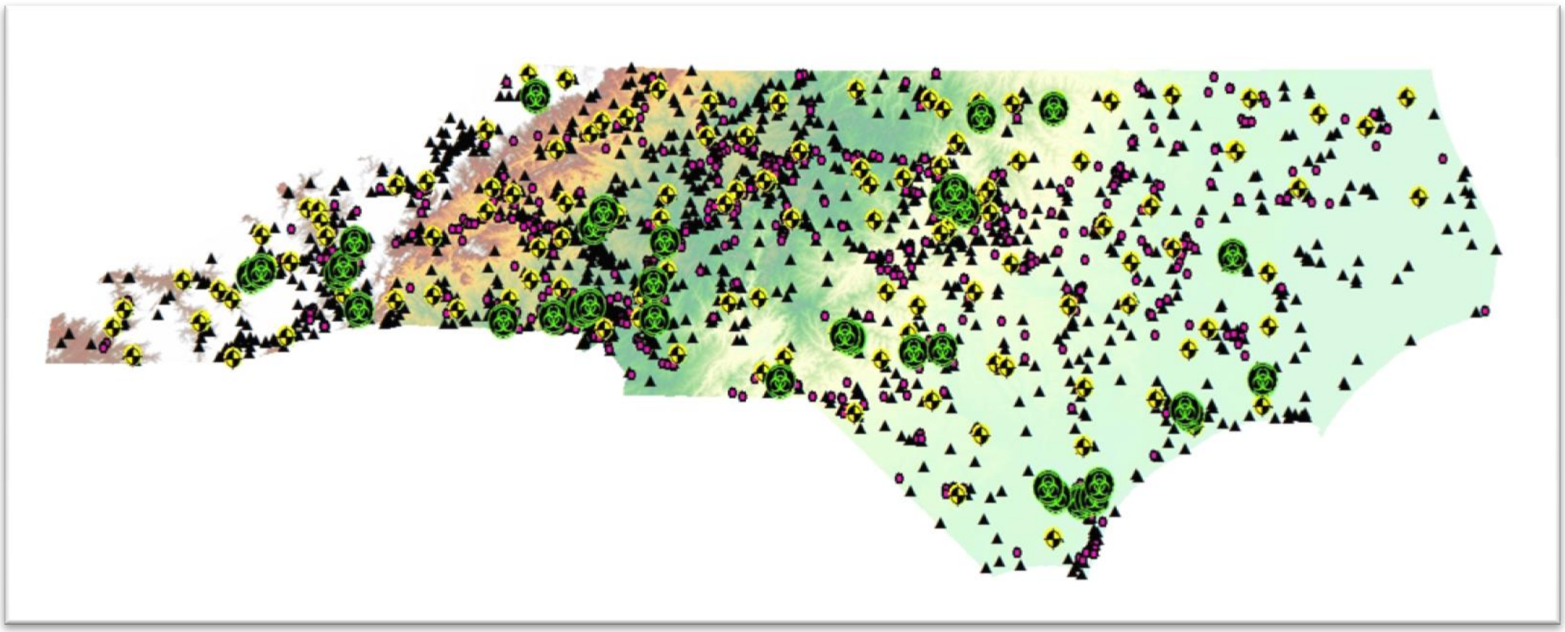

Figure 1 - NC Distribution of All Four Types of Pollution Over Elevation

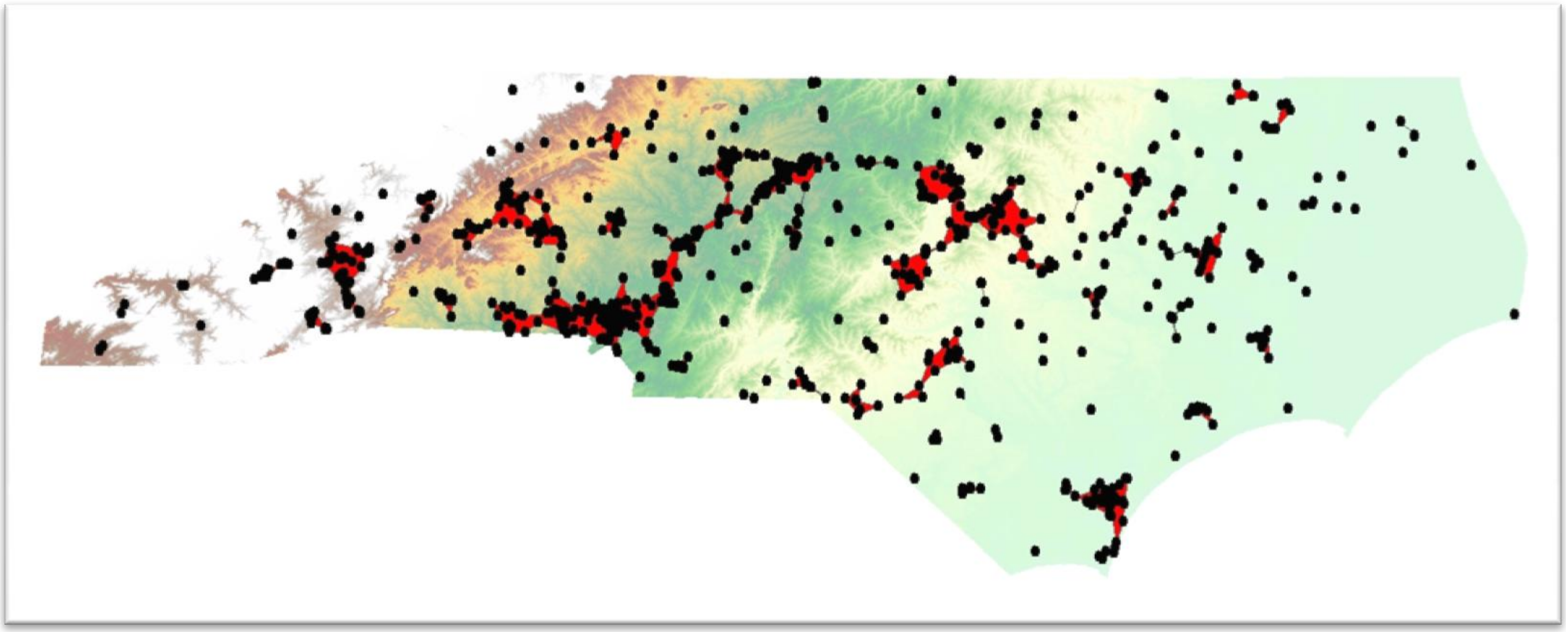

Figure 2 – 10-Mile Range of Hazardous Industrial Site Clusters

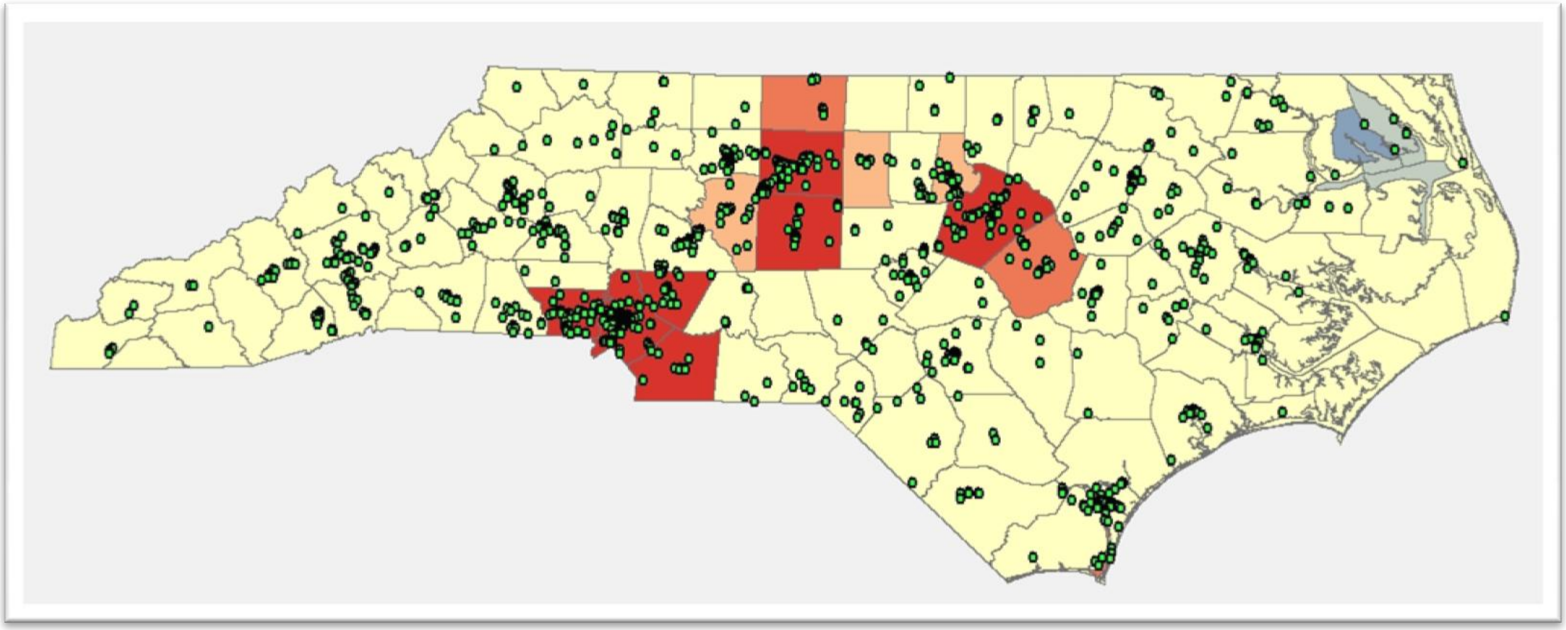

Figure 3 - Hot-Spot Analysis Output of Industrial Hazards Sites (shape converted to a point file)

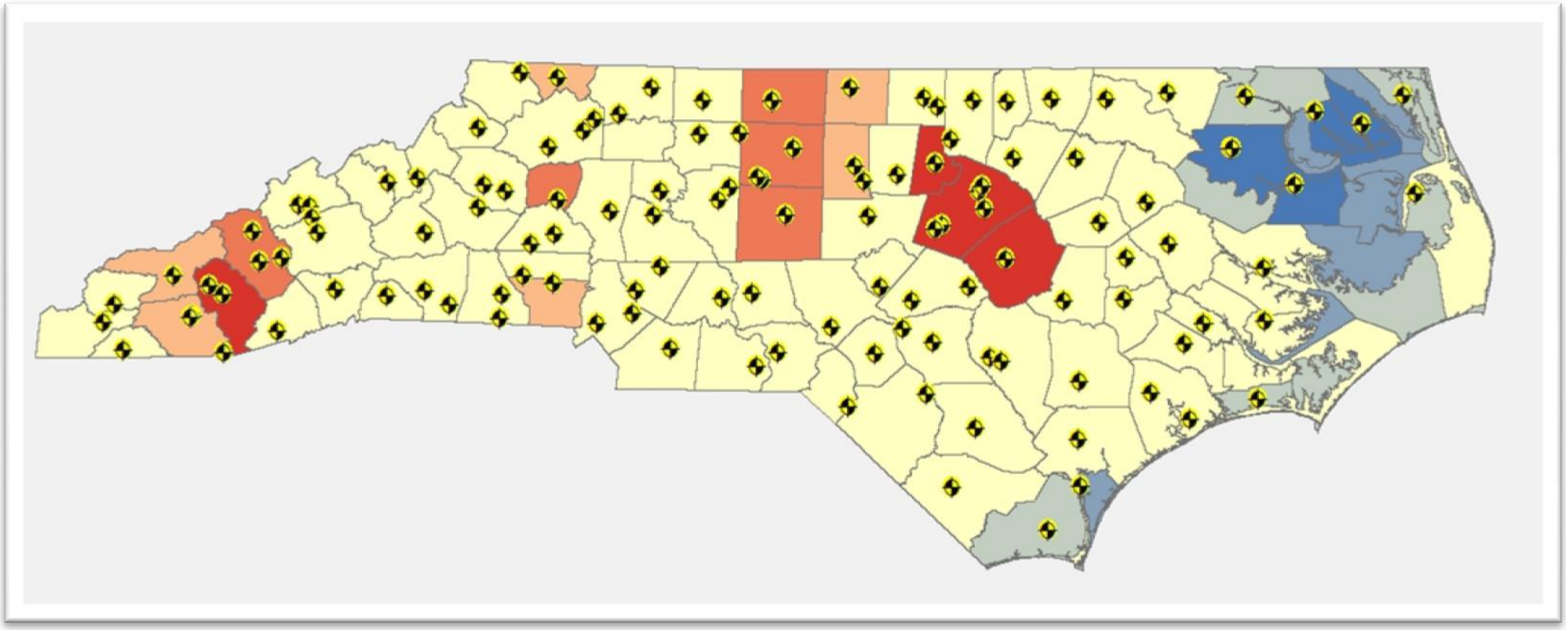

Figure 4 - Hot-Spot Analysis Output of Landfill Sites
(data collected by EPA Landfill Methane Outreach Program)

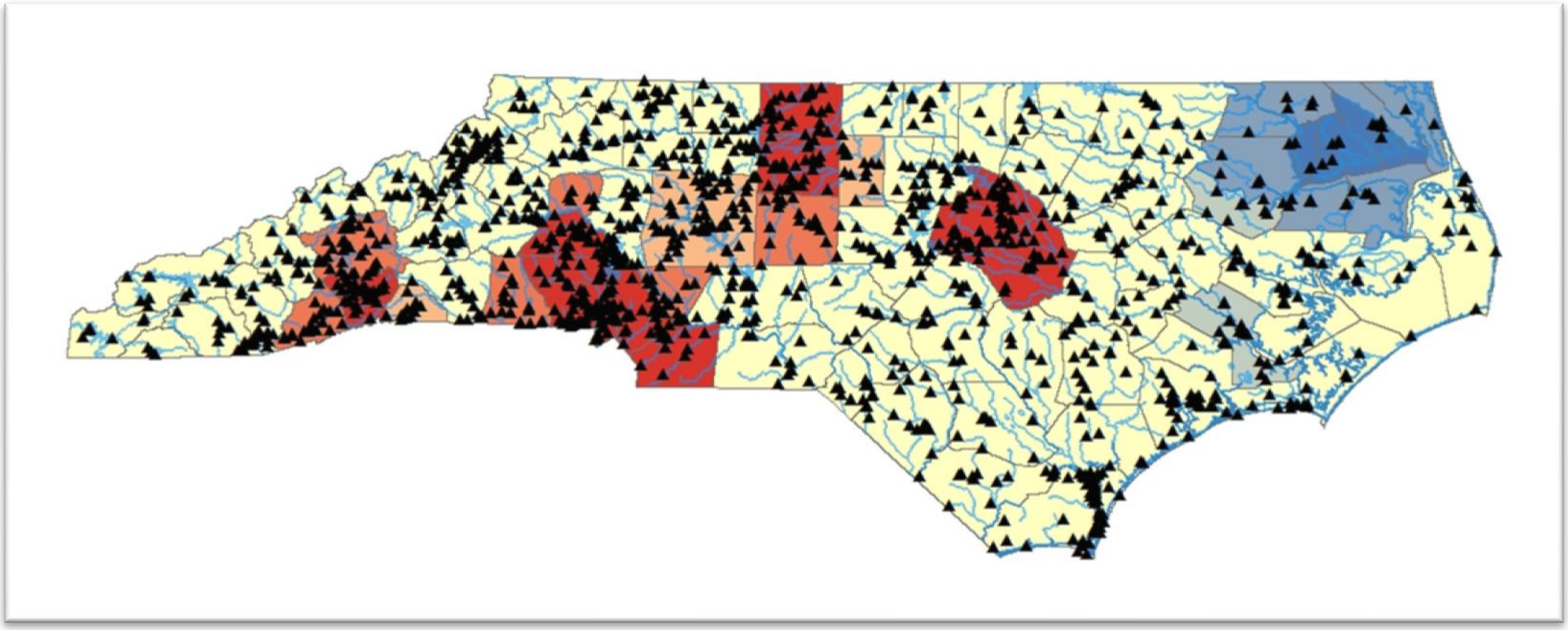

Figure 5 - Hot-Spot Analysis Output of National Pollution Discharge Elimination Sites
(data collected by NCDENR Division of Water Quality)

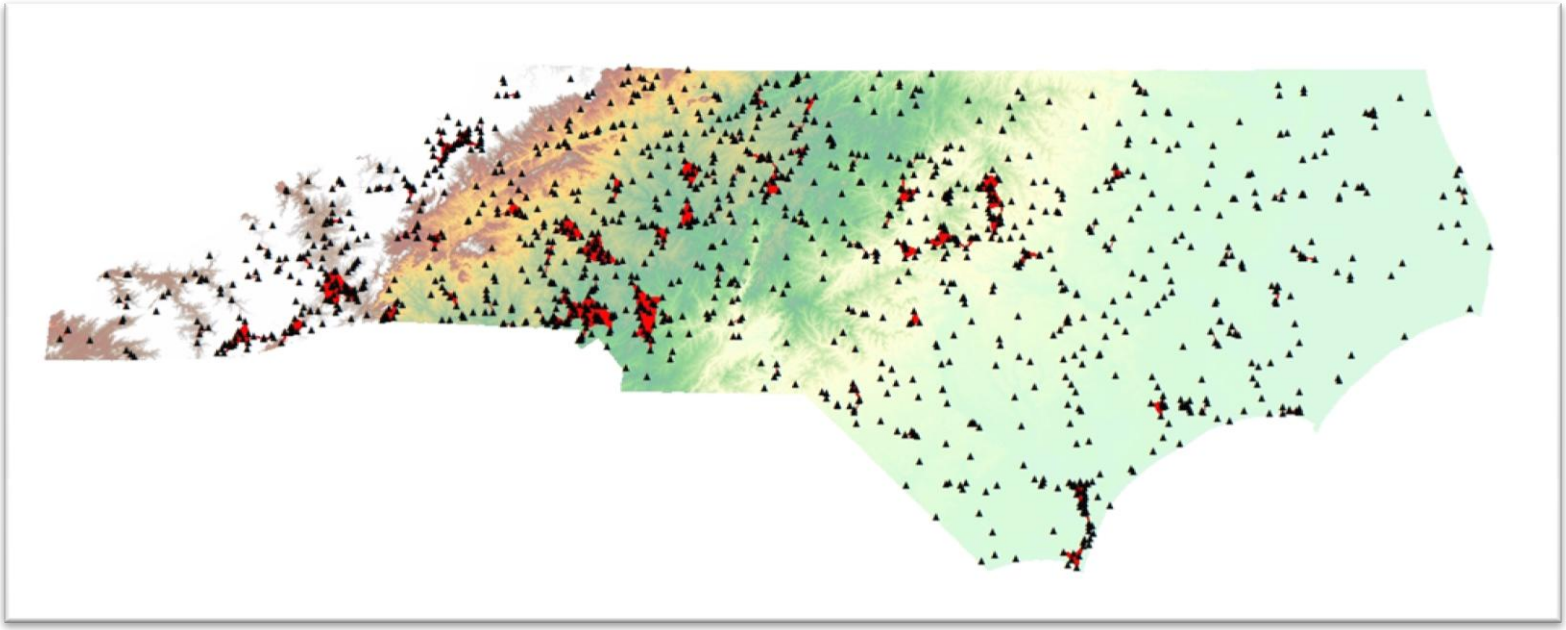

Figure 6 – 5-Mile Aggregation of National Pollution Discharge Elimination Site Clusters (data collected by NCDENR Division of Water Quality)

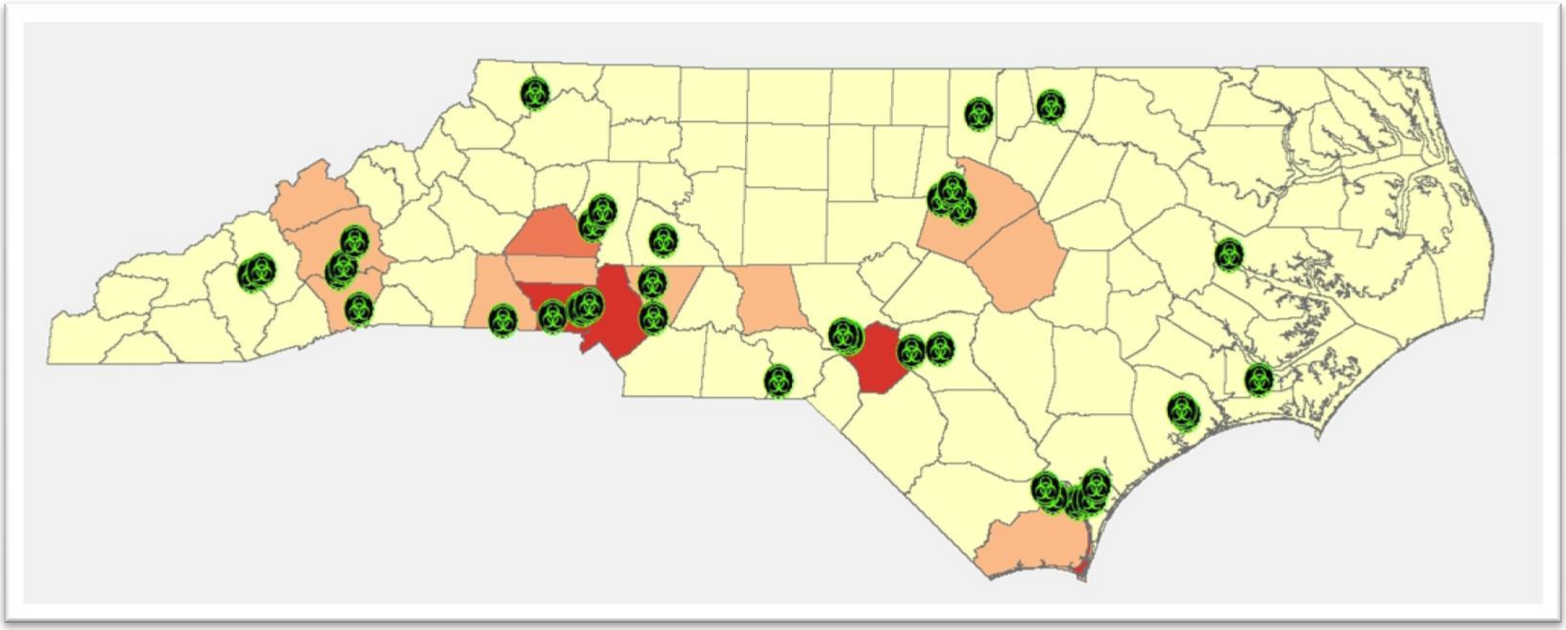

Figure 7 – Hot-Spot Analysis Output of National Priority List Superfund Sites (data collected by NCDEHNR Division of Waste Management)

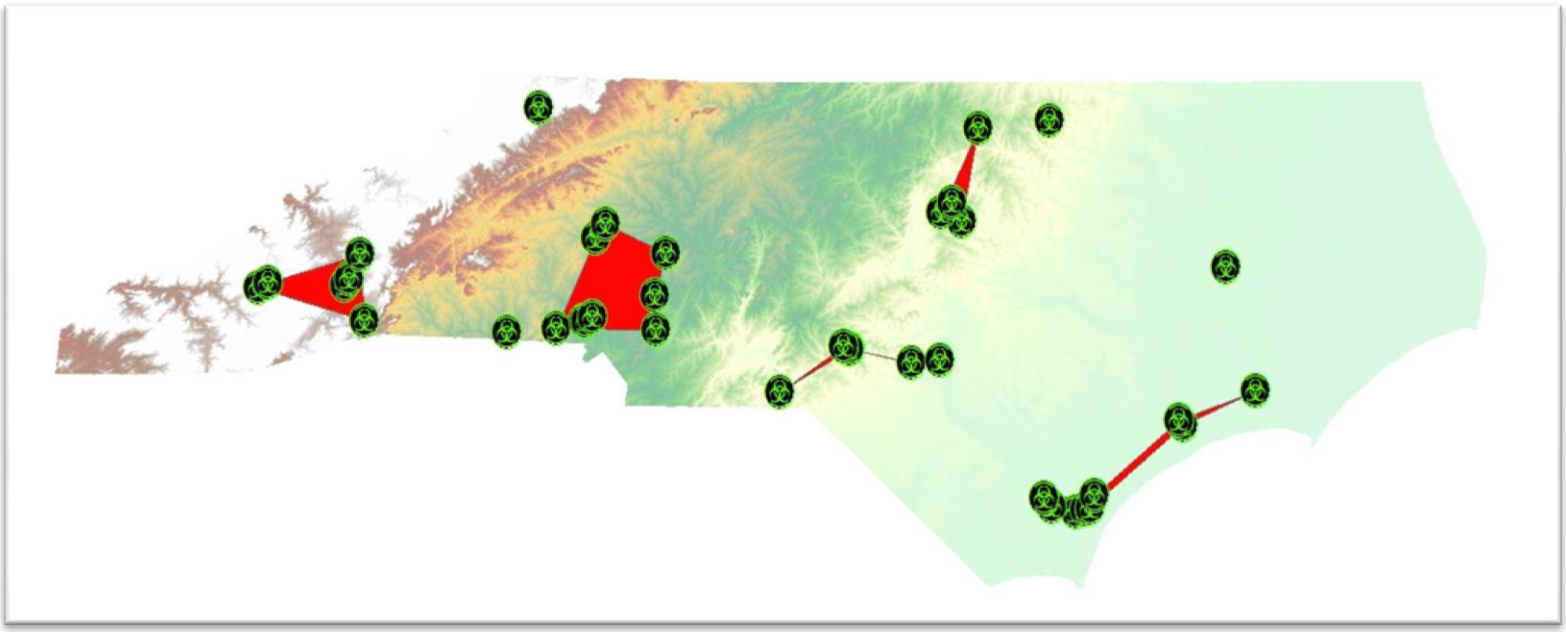

Figure 8 – 50-Mile Aggregation of Points of National Priority List Superfund Site Clusters (data collected by NCDEHNR Division of Waste Management)

APPENDIX B

Figure 9 - Global Moran 1 Formula

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

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

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:

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} \tag{2}$$

The z_I-score for the statistic is computed as:

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

where:

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

$$\mathrm{V}[I] = \mathrm{E}[I^2] - \mathrm{E}[I]^2 \tag{5}$$

Figure 10 – Average Nearest Neighbor Ratio Formula

The Average Nearest Neighbor ratio is given as:

$$ANN = \frac{\bar{D}_O}{\bar{D}_E} \tag{1}$$

where $\bar{D}_O$ is the observed mean distance between each feature and their nearest neighbor:

$$\bar{D}_O = \frac{\sum_{i=1}^{n} d_i}{n} \tag{2}$$

and $\bar{D}_E$ is the expected mean distance for the features given a random pattern:

$$\bar{D}_E = \frac{0.5}{\sqrt{n/A}} \tag{3}$$

In the previous equations, d_i equals the distance between feature i and its nearest feature, n corresponds to the total number of features and A is the total study area.

The z_{ANN}-score for the statistic is calculated as:

$$z_{ANN} = \frac{\bar{D}_O - \bar{D}_E}{SE} \tag{4}$$

where:

$$SE = \frac{0.26136}{\sqrt{n^2/A}} \tag{5}$$

Figure 11- High-Low Clustering Formula

The General G statistic of overall spatial association is given as:

$$G = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} x_i x_j}{\sum_{i=1}^{n} \sum_{j=1}^{n} x_i x_j}, \ \forall j \neq i \tag{1}$$

where x_i and x_j are attribute values for features i and j, and $w_{i,j}$ is the spatial weight between feature i and j.

The z_G-score for the statistic is computed as:

$$z_G = \frac{G - \mathrm{E}[G]}{\sqrt{\mathrm{V}[G]}} \tag{2}$$

where:

$$\mathrm{E}[G] = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j}}{n(n-1)}, \ \forall j \neq i \tag{3}$$

$$\mathrm{V}[G] = \mathrm{E}[G^2] - \mathrm{E}[G]^2 \tag{4}$$