A GIS CLASS EXERCISE TO STUDY ENVIRONMENTAL RISK

Meg E. Stewart
Department of Geology and Geography, Vassar College, Poughkeepsie, NY 12604,
 mestewart@vassar.edu

Jill S. Schneiderman
Department of Geology and Geography, Vassar College, Poughkeepsie, NY 12604,
 schneiderman@vassar.edu

Stephanie B. Andrews
Department of Geography, University of Hawaii at Manoa, Honolulu, HI 96822,
 andrewss@hawaii.edu

ABSTRACT

Geographic Information System (GIS) software can be used to determine the spatial distribution of environmental hazards. The ability to look at multiple layers of information on one map enables investigators to visually compare areas that contain high numbers of hazardous industries with variables such as socio-economic status and race. We used GIS in a classroom exercise to examine the distribution of toxic release sites in Queens, New York. Using 1990 U.S. Census tract data along with Toxic Release Inventory (TRI) sites registered by the Environmental Protection Agency (EPA) for Queens in 2000, we created a series of maps to examine the relationships between the locations of known toxic releases and demographic factors such as race, education, income levels, and linguistic isolation. By using readily available digital data like TRI sites and census tract data this classroom project shows students the utility of GIS for analysis of environmental hazards. Our in-class exercise revealed 1) distinct divides between neighborhoods by race; 2) an association between the locations of TRI sites and Asian and Hispanic linguistic isolation; 3) correspondence between the locations of TRI sites and limited level of education; and 4) overlap between the locations of TRI sites and neighborhoods of low income. Although not a definitive environmental risk study, these findings suggest that neighborhoods with limited resources to prevent the siting of undesirable technologies in their communities or to move out of harm’s way may be disproportionately subjected to environmental risks. Exercises of this sort are easily carried out by students with access to GIS. Such studies demonstrate to students the societal importance of integrating natural and social sciences.

Key words: environmental risk, GIS, Geographic Information System, Queens, New York, education - computer assisted, environmental justice.

PURPOSE

When discussing environmental degradation and pollution in geology classes, the question arises whether low income and minority communities are disproportionately subjected to environmental risks than are higher income and primarily white communities. In fact, numerous studies support such a correlation (U.S. GAO, 1983; UCC, 1987; Bullard, 1990; Mohai and Bryant, 1992; Pollock and Vittas, 1995; U.S. GAO, 1995; Mohai, 1996). As a result, the high ratio of toxic sites to low income and minority communities has led social justice activists to define a new kind of environmental advocacy, one that demands “environmental justice for all” (Bullard, 1994). Our class exercise engages such concerns about environmental issues and social justice; it uses a Geographic Information System (GIS) as a teaching tool to examine and encourage discussion of environmental risk in Queens County, New York. Though not a definitive study of environmental justice in Queens, the exercise demonstrates how educators can use GIS technology to urge students towards consideration of the distribution of environmental risk.

The Environmental Protection Agency’s (EPA) Office of Environmental Justice defines environmental justice as: “the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. Fair treatment means that no group of people, including racial, ethnic, or socioeconomic group should bear a disproportionate share of the negative environmental consequences resulting from industrial, municipal, and commercial operations or the execution of federal, state, local, and tribal programs and policies” (U.S. EPA-OECA, 2000). Despite the EPA’s awareness of what might be termed environmental injustice, as well as former President Clinton’s Executive Order 12898 which addresses the EPA’s responsibilities and strategies concerning environmental justice (U.S. EPA-OSWER, 2000), poor and minority neighborhoods are more likely to receive society’s toxic wastes (UCC, 1987; Bullard, 1990; Mohai and Bryant, 1992). Also, waste incinerators, sewage treatment plants, petrochemical facilities, and landfills are disproportionately located in these types of communities (Bullard, 1994). This situation has resulted from effective NIMBY (not-in-my-backyard) campaigns in financially well-off, politically well-connected, and educated communities (Mazmanian and Morell, 1990; Kraft and Clary, 1991; Lavelle and Coyle, 1992).

A GIS is a computer-based system of hardware and software useful for analyzing and interpreting spatially referenced digital datasets; these may be geographic maps, georeferenced aerial photographs, land-use information, or community demographic data. These data can be imported into a GIS software program as layers and then analyzed to answer land-use questions (Star and Estes, 1990).
GIS may be extremely useful for assessing the distribution of environmental hazards; it is relatively easy to use and the maps generated furnish a visual aid for determining possible environmental hazard relationships. For our class exercise we used low priced or free data that we downloaded from the World Wide Web.

Although GIS is used routinely by geologists and other earth scientists for mapping the distribution of natural resources and hazards (for example, Hillman, 1995; Hilley and Pollard, 1996; Vanderwall et al., 1996; Corwin et al., 1997; Lasserre et al., 1997; Freeman and Miller, 1998; Franck et al., 1999; Lewis, 1999; Livingstone et al., 1999), GIS has been applied only in a few instances by earth scientists to examine the distribution of environmental risks in relation to demography (Schneiderman, 1997; Boer et al., 1997; Sadd et al., 1997; Sadd et al., 1999). The technology holds tremendous potential for communities concerned about the distribution of environmental risks and offers earth scientists the opportunity to apply our knowledge for purposes beneficial to whole communities.

Any major city in the U.S. would be suitable for such a class GIS project. We chose Queens, one of the five boroughs of New York City. Initially settled in 1637 by Dutch colonists, it is densely populated today--nearly two million people live within its approximately 112 square miles (Seyfried and Peterson, 2000). We focused on Queens for our class exercise because it has a long history of industrial activity, consists of mostly working class communities, and comprises an ethnically diverse population. It also contains within its borders two major airports, La Guardia and John F. Kennedy.

In order to examine the distribution of environmental hazards in Queens (Figure 1), we used GIS to look for correlations between the locations of EPA toxic release sites and demographic variables, such as race, education and income levels, and primary language spoken in the home. The EPA defines the Toxic Release Inventory (TRI) database as containing “information from companies and government facilities that report their air, land, and water releases and other waste management activities” (U.S. EPA-OPPT, 2000). Some previous GIS-based environmental risk studies have utilized TRI data exclusively (Cutter and Soeleck, 1996; Pulido et al., 1996; Sadd et al., 1999; Sheddard et al., 1999) while others have also used the EPA’s RCRA (Resource Conservation and Recovery Act) sites (Ahearn and Osleeb, 1993; Cutter et al., 1996; Boer et al., 1997; Pulido, 2000). RCRA sites, generally termed hazardous waste sites, are facilities that generate, transport, treat, store, and dispose of hazardous waste; such facilities must provide information about their activities to state environmental agencies (U.S. EPA, 2000). An early version of our class exercise utilized RCRA sites for the purpose of analyzing the distribution of environmental risk (Stewart and Andrews, 1999). Dry cleaners, gas stations, and auto mechanic shops are typically found on RCRA lists. Seemingly innocuous RCRA sites hold a potential danger for a neighborhood, otherwise there would not be a need to list them with the EPA. However, we chose to map TRI sites for the class exercise because of the more immediate threat that a toxic release has on a neighborhood. In Queens County there are 59 toxic release sites. Likewise, there are over 1,600 RCRA sites of which approximately 45 percent are gas stations or dry cleaners (U.S. EPA-Region 2, 2000).

In our exercise GIS visually showed students that environmental hazards associated with incinerators, landfills, or sewage treatment facilities in Queens occur especially in low-income areas, neighborhoods populated by people with limited education, or those where English is not the primary language.

**METHODS OF MAP CONSTRUCTION**

We obtained demographic data from the 1990 United States Census and examined tract-level data. Tracts are sections of counties that generally contain approximately two thousand to four thousand people (Peters and Larkin, 1997). We chose tract-level data because: 1) tracts are the standard unit of comparison (for instance, Bowen et al., 1995; Pollock and Vittas, 1997; Sui et al., 1995; Cutter et al., 1996; Pulido et al., 1996; Boer et al., 1997; Sadd et al., 1999); 2) tract-level data are readily available; and 3) the geographic scale is appropriately large. One could use smaller or larger geographic scales, such as country, state, metropolitan region, or neighborhood areas, for similar environmental hazard analyses. Also, data of different resolution can be organized by county, zip code, block groups or individual blocks (McMaster et al., 1999). In fact, choice of scale and resolution are major methodological issues in the environmental risk assessment literature. Ideally for environmental risk assessment, researchers would use a coarse-resolution analysis—the use of county or tract boundaries—for small-scale studies. For larger scale studies, block groups or block boundaries would be used for fine-resolution analysis (McMaster et al., 1997).

We used GIS software to analyze the data and construct our maps. At least 18 different types of GIS software can be used in a desktop environment (Somers, 1999) and the approach we used should apply similarly to other GIS software. Students used 1992 Tiger Line files (tract boundary and landmark files), 1990 U.S. Census Tract data (Summary Tape File 3 data for Queens County, New York), and current EPA TRI site data for Queens County, New York to construct their maps.

Students constructed their maps in the following manner. First, Tiger line files, which are in table format, are opened in the GIS software. Tiger files are map data (in polygons) used by the U.S. Census Bureau in street-level mapping of the United States (Clarke, 2001). Figure 1 shows the tract boundary and landmark Tiger files used for this exercise. Second, census tract data are extracted from a larger database, which are on CD-ROMs and available at government data repository libraries. Each separate variable (i.e., race, sex, income level) is saved as a file with a *.dbf (database file) extension. The census tract files are opened in a spreadsheet program and a new database is saved that contains all of the desired variables. The finalized database is imported into the GIS and has a column in common with the Tiger line file; the common column links the two tables and is used for mak-
Figure 1. Location of the class exercise in Queens County, New York, one of the five boroughs or counties of New York City. The enlarged map shows Queens divided into tracts (a Tiger line file) that were the boundary areas used for the 1990 U. S. Census. Water bodies adjacent to Queens are shown in the darker shaded areas and the lighter shaded sections are landmarks such as airports, parks and cemeteries.
ing thematic maps (Figure 2). Third, TRI sites for New York are downloaded from the EPA’s Region 2 web site (U.S. EPA-Region 2, 2000). Region 2 covers New York, New Jersey, Puerto Rico and the U.S. Virgin Islands. (Note that one can download data by state or territory. Among other monitoring data available on this web site are Superfund and RCRA sites. The sites are georeferenced in longitude and latitude.) The EPA gives a choice of two GIS export formats and the file that is compatible with the GIS software is downloaded. A translation of these downloaded data into the GIS is necessary but is not difficult if the data projection is known. From the TRI database for New York, sites for Queens are extracted and a new file is created. Fourth, users create thematic maps (Figure 3) using the Tiger line file and the census data table. The thematic map is a color-coded map showing shaded gradations that increase with numbers of people or higher percentages of a variable. Since census tract data are presented as absolute numbers, data must be converted to a percent of the population. This is nothing more than simple division and multiplication (for example, [# people with less than a 12th grade education / total persons] * 100). Finally, once a thematic map is created, users overlay on it the georeferenced locations of TRI sites. Much like analyzing an aerial photograph, we used visual interpretation to compare locations of TRI sites with high densities of a demographic variable. According to Clarke (2001) the “plot and look” method “should never be skipped in GIS analysis, at the risk of using complex methods to prove the geographically obvious” (p. 183). Each demographic variable was analyzed in this manner.

To test the results of our visual analyses we did simple single variable calculations for each of the variables that we mapped by choosing all tracts that contained within their boundaries one or more TRI sites (Table 1). We combined all the tracks with a TRI site and compared these to all the tracts that did not contain a TRI site to see if a particular demographic variable might correlate with increased risk of exposure. This methodology follows standard environmental risk spatial analyses (for example, Cutter et al., 1996; Boer et al., 1997; McMaster et al., 1997) and is used to examine the characteristics of the population surrounding the locations of environmental hazards. There are 673 tracts in Queens, 39 tracts contain at least one TRI site and ten tracts have no residents. One TRI site is within a tract that has no residents. We eliminated tracts without residents from our analyses. We analyzed single demographic variables in two classes: TRI-present tracts and TRI-absent tracts. For each variable—except population and income—in both classes we totaled the variable, divided by the population total, and multiplied by 100 to obtain a percent. To calculate the population variable we summed the populations of tracts with TRI sites and divided by 38 and summed the populations of tracts without TRI sites and divided by 625. We also determined the median household income variable in this manner.

### RESULTS

Our computer-generated maps displayed 1) population density; 2) racial composition; 3) non-English speakers, including linguistically-isolated Hispanics and linguistically-isolated Asians; 4) household income levels 5) persons living below the poverty level; 6) people on public assistance; and 7) individuals with less than a 12th grade education. We examined these maps visually to search for associations between the demographic data and the locations of toxic release sites.

Although TRI sites are scattered throughout the borough, TRI sites cluster in the upper northwest corner of Queens (Figure 3). The clearest visual association of TRI sites associated with a particular demographic parameter

<table>
<thead>
<tr>
<th>Variables</th>
<th>TRI-present tracts</th>
<th>TRI-absent tracts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population per tract</td>
<td>2,753</td>
<td>2,962</td>
</tr>
<tr>
<td>Non-white (%)</td>
<td>36.7</td>
<td>42.3</td>
</tr>
<tr>
<td>Black (%)</td>
<td>17.2</td>
<td>22.1</td>
</tr>
<tr>
<td>Hispanic (%)</td>
<td>22.7</td>
<td>18.8</td>
</tr>
<tr>
<td>Isolated, non-English speakers (%)</td>
<td>5.8</td>
<td>4.9</td>
</tr>
<tr>
<td>Median household income ($)</td>
<td>31,971</td>
<td>37,030</td>
</tr>
<tr>
<td>Below poverty (%)</td>
<td>12.6</td>
<td>10.7</td>
</tr>
<tr>
<td>Public assistance (%)</td>
<td>3.3</td>
<td>2.7</td>
</tr>
<tr>
<td>Less than 12th grade education (%)</td>
<td>57.6</td>
<td>47.2</td>
</tr>
</tbody>
</table>

Table 1. Single demographic variables analyzed as two classes: tracts that contain a TRI site and tracts that do not contain a TRI site.
is shown in Figure 3: communities with households earning less than $35,000 (1989 dollars) host a disproportionately larger number of TRI sites when compared to communities with higher incomes. Although not presented here because of space limitations, our map showing the locations of TRI sites and communities in which 25 to 100 percent of the population has less than a twelfth grade education shows a distinct association. This education demographic cuts across all races. Also not given here, neighborhoods of non-English speaking Hispanic and Asian people overlap with concentrations of TRI sites. There also appear to be only slight correlations between locations of TRI sites and population density. Interestingly because this runs contrary to many previously published reports, the maps we generated that display the distribution of people in Queens by non-white race (including black, Hispanic, and Asian) show no correlation between race and toxic releases but do demonstrate the segregated nature of the borough.

Our single variable analyses shown in Table 1 concur with what we see on our maps. Populations more likely than not to live near a TRI site include Hispanics, isolated, non-English speakers, persons living below poverty level, persons on public assistance, and those with less than a 12th grade education. The median household income is also significantly lower in tracts that contain a TRI site.

The data for our classroom analysis came from two different time periods: the U.S. Census data are from 1990 and the toxic release sites are current and were downloaded from the web in February 2000 (U.S. EPA-Region 2, 2000). However, 2000 U.S. Census data will be available online beginning June 2001 (U.S. Census Bureau, 2000) and will provide the opportunity to update these maps.

Although our classroom exercise allows us to suggest some potential demographic characteristics that lead to increased exposure to environmental risk in Queens County, this project is not a definitive environmental risk study for Queens, NY. For more conclusive evidence for environmental risk, we would need to 1) statistically prove or disprove greater risk of exposure to toxic materials for certain populations; 2) ground truth—visit—each TRI site; 3) examine different geographic scales and bordering counties for so-called edge effects; 4) include additional hazardous facilities, such as Superfund sites, RCRA sites, or incidents of diseases such as cancer (using cancer registry data); 5) scrutinize the amounts, types and local distributions of released toxins; 6) use 2000 U.S. Census data; and 7) investigate the historical land use in the area. Nonetheless, this is a useful class exercise for examining correlations between environmental risk and demographic variables and for teaching the power of GIS.

The single variable analysis shown in Table 1 provides a way to test what we see on the maps. Limitations with this method include an inability to track the realistic distribution of a toxin, whether by wind, spill surface, or underground plume. This method also assumes that a risk decreases or stops at an arbitrary geographic boundary, such as a tract boundary line. However, for a class exercise this simple cal-
calculation is sufficient to test visual interpretations. For more detailed and rigorous environmental risk studies, we suggest a buffer or plume analysis (Chakraborty and Armstrong, 1997, McMaster et al., 1999; Sheppard et al., 1999) that uses the GIS to map, for example in the case of buffer analysis, a specified distance around the risk site. Or, in the case of plume analysis, the use of prevailing wind directions to map a plume direction for the toxin.

CONCLUSIONS

GIS is a fast, easy-to-use tool that can be employed to examine the distribution of toxic release locations, hazardous waste sites and other environmentally problematic areas. Visually striking, GIS examinations are likely to engage students interested in environmental issues. As a result of our class exercise, students saw clearly that in Queens, NY, communities of individuals with a low median household income (Figure 3) and without a high school diploma are more likely to live in close proximity to toxic sites. In general, such maps illustrate the fact that communities with fewer resources to mobilize against the concentration of undesirable environmental technologies and materials in their communities, end up harboring them.

This classroom project follows approaches of previous GIS environmental risk studies. As in those studies, we used TRI sites and census tract data to look for associations between environmental hazards and community characteristics. Note, however, that comprehensive risk studies use statistical analysis, field checks of EPA data, multiple geographic scales, and include study of edge effects and historical contexts. This study does not attempt to explain patterns or processes of risk potential. Rather, it demonstrates the utility of GIS and real data in the classroom to engage and inform students interested in environmental risk.

ACKNOWLEDGEMENTS

Funding for development of this class exercise came from the Andrew W. Mellon Foundation through Vassar College's "Mellon Teaching With Technology in the Undergraduate Curriculum initiative (ADD) to Meg Stewart and from a National Science Foundation grant (DUE9653266) to Jill Schneiderman. We thank Yu Zhou for her helpful comments on an earlier draft of this paper. Reviews from Ryan Jensen, Gary Rosenberg and an anonymous reviewer significantly improved the paper.

REFERENCES


Francek, M., Klopcic, J., and Klopcic, R., 1999, You can’t put that here!: GIS helps return sewage sludge to soils where nutrients can be recycled: GIS World, v. 12, n. 4, p. 52-54.


Sui, D. Z. and Giardino, J. R., 1995, Applications of GIS in environmental equity analysis: A multi-scale and
multi-zoning scheme study for the City of Houston, Texas, USA: Proceedings, GIS/LIS '95, Annual Conference and Exposition, Nashville, Tennessee, p. 950-959.


http://www.epa.gov/region02/gis/atlas/online.htm (February 28).


About the Authors

Meg E. Stewart is the Vassar College GIS Technology Consultant and is an adjunct faculty member at Dutchess Community College, in Poughkeepsie, NY. She has a BS degree in Geology from California State University, Hayward and an MS in Structural Geology from the University of Nevada, Las Vegas.

Jill S. Schneiderman is an Associate Professor of Geology at Vassar College and the editor of The Earth Around Us: Maintaining a Livable Planet (W.H. Freeman, 2000). She teaches geology, environmental studies, and women’s studies.

Stephanie B. Andrews received her BA in Geology from Vassar College in 1999. This project was the result of her senior independent work. She is currently a graduate student at the University of Hawaii.

As human expansion and influence have grown to levels that challenge the stability of the entire terrestrial environment, we have discovered how the origin and persistence of life owes much to an unseen balance that is deep and delicate. Ironically, many aspects of this balance have become known to us only through our unwitting displacement of them.