International Journal of Mass Emergencies and Disasters
March 1997, Vol. 15, No. 1, pp. 135–146

The Use of Geographic Information Systems in Disaster Research

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In the last ten years, Geographic Information Systems (GIS) have slowly crept their way into the everyday methodological discourse in areas such as geography, urban planning, and emergency management. However, GIS has yet to be integrated into social science research on disaster. This paper uses examples of GIS use in emergency management to help inform the future direction of GIS use in disaster research. While computers and software and, for that matter, data are vital to the development of an effective system, more important are researchers who can generate theory-based uses for the technology that offer new understandings of disaster phenomena. Only through research teams that include both researchers (idea generators) and technicians (idea "implementers") can GIS be effectively used in disaster research.

A little less than a year after Hurricane Andrew (1992), I had the unique opportunity to work on the ground floor of the implementation of the Federal Emergency Management Agency's (FEMA) use of Geographic Information System (GIS) in a Disaster Field Office (DFO). The DFO after Hurricane Andrew was one of the first large-scale uses of GIS by FEMA in the aftermath of a major disaster. While GIS is far from being a new technology, it is only in the last five to ten years that it has become part of the everyday discourse in geography, urban planning, and emergency management , to name a few disciplines. GIS has yet to become a part of the methodological discourse in the social sciences generally, and in social science research in disaster specifically.

When I was first asked to contribute to this special edition, I was convinced that I could separate the issues of GIS in disaster research and GIS in emergency/hazard management. As I continue to think about the future of GIS use in disaster research, however, I realize that to a large degree the two issues are somewhat tied together, particularly in the case of applied research. This article, then, will use lessons learned from GIS in emergency management to help define the direction of GIS use in disaster research.

Space can be defined in a multitude of ways: social, political, or spatial, for example. The power of a GIS is that it allows us to link these different definitions together in one all-encompassing system. In disaster research, the ability to link social, economic, and political data with geographic or spatial data is extremely important. Various researchers such as Britton (1986), Dynes (1970), Kreps (1984), Streeter (1991), Pelanda (1982), and Quarantelli (1987) have struggled to define disaster. Disaster is seen as an unpredictable event which renders a social unit unable to cope with previously normal activities. By nature of this definition, disaster occurs in some type of space. This space can be defined geographically.

Simple geography, however, does not define disaster. Rather, disaster occurs in social, political, and economic space. And it is within this space that individuals, families, businesses, and communities must cope with hazardous events. The implication is that social, political and economic space have inherent power structures that create conditions of discriminatory and unequal distribution of resources. Both on a micro level and a macro level, the outcome is that some social units have the resources to better mitigate against and prepare for disaster. The power and strength of a Geographic Information System is its ability to integrate geographic, physical, social, economic, and political data.

What Is a GIS?

A GIS is an "organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information" (ESRI 1993, pp. 1–2). A GIS uses both geographic data (a digital census tract coverage) and nongeographic data (a spreadsheet with census tract numbers and populations), and it includes the ability to tie these two datasets together. A GIS integrates geographic or spatial data and other information into a single integrated system. The key feature to a GIS is that it also includes operations which support spatial analysis. Additionally, it allows for the manipulation and display of geographic knowledge in new ways. These new ways include large-scale maps in addition to standard tables and charts. A GIS, then, can be more broadly defined as "a system of hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling, and display of spatially

referenced data for solving complex planning and management problems" (NCGIA 1990, pp. 1–14). This system taken as a whole can be a tool in disaster research and emergency management by helping users answer various spatial questions.

These questions can be simple or very complex (DeLiberty 1995). A GIS can be used to answer questions of location. These questions include determining "what is at" a specific location. Determining what house is on the southwestern corner of a specific intersection is one type of location question. Second, a GIS can be used to answer conditional questions. In other words, it can help us determine locations that meet certain criteria, such as how many schools are within 10 miles of a nuclear power plant. Third, a GIS can help us determine trends. Using data from different periods of time, we can determine what has changed over time. For example, by comparing housing coverages from 1990 and 1995, we can determine the housing density change over time. Fourth, spatial patterns can be found by using a GIS. Patterns of damage, for example, can be determined by analyzing the spatial distribution of damage over a specific geographic area. We can determine whether damage is worse in areas of poverty. Finally, a GIS, as its most complex function, can help us model possibilities. For example, if we add a road to a neighborhood, will egress evacuation times be significantly altered? If Hurricane Andrew's track were 20 miles to the north, what types of damage could we expect from wind, rain, and surge?

In order to answer these questions, the geographic data necessary to represent the map features can broadly be in three forms. *Point data* are specific location data such as the coordinates of schools or homes. *Line data* are used to represent information such as roads or narrow rivers. *Polygon data* represent areas such as city boundaries, wetlands areas, or census tracts. Any given project can include all three types of data. A GIS stores data as individual coverages that are layered to answer the various questions. As we will see, GIS can be a powerful tool in emergency/hazards management and an important future methodological direction for disaster research.

GIS and Hazards

In 1995, Chartland and Punaro argued that in order to further improvements in disaster mitigation, preparedness, response, and recovery, emergency managers need "advanced, technology-supported information handling systems for collecting, indexing, storing, processing , retrieving and disseminating essential data" (p. 1). One such system is a GIS. By allowing emergency managers to incorporate spatial analysis and modeling into their everyday decisions, they are better able to plan for potential disaster. In addition, GIS can be implemented in the wake of a disaster. The ability to spatially analyze data allows emergency managers to better plan and coordinate their recovery efforts.

In one of the most recent works on GIS and natural hazards, Coppock (1995) attempts to assess the use and development of GIS in helping to reduce the impact of natural hazards. He finds the literature connecting GIS and natural hazards to be scarce. In part, this is due to the multidisciplinary nature of both GIS and natural hazards. However, even when looking at the two fields independently, the search for literature yields similar findings; it does not exist. Furthermore, Coppock states that "it is not known how many operational GIS's for mitigating the impact of natural hazards exist" (p. 26). Coppock concludes that GIS does not appear to have lived up to its expectations. In fact the International Decade for Natural Disaster Reduction (IDNDR) Science and Technical Committee has "called for better coordination in the technologies such as remote sensing and GIS" (p. 27). However, the failure of GIS to live up to expectations is not a function of GIS itself, but rather a failure to implement a functional system with appropriate data and personnel.

Emergency managers and community leaders are under increasing pressure to be prepared for all types of potential hazards (Wolensky and Wolensky, 1990). In recent years, the federal government has pushed states and localities to take a greater role in disaster preparedness and response. One example of GIS use in a coastal disaster context is the State of Florida's Florida Marine Spill Analysis System (FMSAS). Up until a short time ago, according to ARC/News (ESRI 1995), officials responding to oil spills had to use old paper maps as their primary data source. In order to create a system that would be readily available if a spill occurred, the Florida Marine Research Institute developed a GIS application that would use digital data to give real-time current maps and on-line spill-response ability. The system was developed by incorporating satellite imagery, basemaps, and intensive field observations to create a system that could produce customized maps identifying vulnerable habitats during the various states of an oil spill. The system was put to a test in August 1993 when 300,000 gallons of fuel spilled into Tampa Bay, Florida. The FMSAS system was able to, within hours, produce maps for Coast Guard officials detailing the extent of the spill. The process was as follows: helicopters monitored the spill; the boundaries were mapped; and maps showing the movement of the spill were furnished that determined the most vulnerable areas. This oil spill model is one small example of how GIS can be used to assist emergency response. A broader

example is the use of GIS after Hurricane Andrew. Unlike the oil spill model, the Hurricane Andrew case shows us how a GIS can be used when real time information is not as critical.

Hurricane Andrew: A Case Study in the Application of GIS

At the end of August 1992, Hurricane Andrew swept through southern Florida, leaving a path of destruction throughout the region. With the physical and emotional devastation to the area and people came a large, somewhat unmanageable response and recovery phase. In areas like Florida City, a poor Black neighborhood, not one house was left unscathed. After the initial shock, leaders in the federal, state, and local governments converged to begin the paramount process of "Hurricane Andrew Recovery." The initial use of GIS was in mapping damage and analyzing community demographics. Later, as the potential of GIS was better understood, its use grew in areas like Public Assistance and Hazard Mitigation.

The Federal Emergency Management Agency committed to setting up a GIS after Hurricane Andrew. The FEMA system was a multiplatform, Unix-based Apple Computer networked system with a 13 gigabyte hard-drive system partitioned into distinct nodes: a data node that housed all new incoming data; a GIS for working files; and a raster node where all rasterized (digital output file) maps were stored. Map output was not sent directly to the networked plotter, but rather was output as a file that could then be stored for repeated printing. At the Hurricane Andrew DFO, and consequently, by FEMA as a whole, MapInfo has been adopted as the GIS software package. In part, MapInfo was chosen for its relatively low learning curve. While its analysis features are not as sophisticated as upper-level systems such as Arc/Info, it does have a strong data engine that is able to complete sophisticated and complex data linkages both on spatial and attribute data.

More important than the hardware and software in this GIS were the datasets. The FEMA GIS department attempted to support various departments within FEMA, the State of Florida, and the local government, measure impact and recovery, and set up a system that could be in place the next time a disaster happened. Projects included tracking (1) debris and debris removal, (2) clean and secured abandoned damaged homes, and (3) the location of trailers used for temporary housing. Damage assessments were geo-referenced to allow these data to become a digital coverage. In addition to basic basemap data such as street coverages, zip code boundaries, community boundaries, hydrology, and census tract boundaries, emergency-specific data were gathered. These data coverages included Dade

County evacuation zones, hurricane shelters, and Turkey Point Nuclear Power Plant evacuation zones. FEMA's GIS also included data that could assist in measuring impact and tracking recovery. These data included Florida Power and Light electric service disconnect data at four points in time, United States Postal Service (USPS) forwarding address data, USPS undeliverable address data at two points in time, FEMA public assistance data, and the Dade County tax assessment database. It is important to note that none of the data for tracking recovery was in a digital format. Yet, with all these data, the majority of products produced by FEMA GIS after Hurricane Andrew required little spatial analysis.

What did we learn from Hurricane Andrew with regards to GIS, and how can we use it to inform the future direction of GIS as a methodology in disaster research? I think one of the most important lessons that was learned from Hurricane Andrew is that postimpact is not the ideal time to set up a GIS system to address the needs of an impacted community. The first "GIS" product produced after Hurricane Andrew was not produced for at least four months. The first problem was a data problem. Getting data is much easier said then done. Once the data were received and processed, the first reports were produced. The first report presented damage, assistance, and demographic data for communities in southern Dade County. While the report was informative, it failed to use the power of a GIS system, which is analysis. The actual printed map product is a by-product of the analysis, not the main object. However, the majority of requests received after Hurricane Andrew were specifically for maps showing specific data, not maps that answered any of the five questions a GIS can help answer.

The problem is that GIS is a very expensive graphics tool. On the other hand, it is a powerful analysis tool. New technologies can be powerful if they are integrated into the planning of emergency response. Likewise, GIS can be a very effective tool in disaster research. However, to effectively use it requires not only computers and data but, more important, a person actually "thinking" about the issues to properly utilize its integrative powers.

GIS and Disaster Research: Future Directions

As discussed earlier, disaster by nature of its definition occurs in social, economic, and political space as well as in geographic space. Geography, however, can not alone define disaster. The power of GIS in disaster research is its ability to bridge these different disparate types of data. In other words, the future of GIS in disaster research is in taking the type of work FEMA was doing after Hurricane Andrew to the next level. This level

is one that not only looks at disaster phenomena such as damage, but rather examines the distribution of phenomena in social, economic, and political space.

In order to understand this social distribution, researchers must look for data sources that can be used in spatial analysis. Understanding that data can always be aggregated up (i.e., to more inclusive units) but never down, the best data are point-specific data. Tax assessor's databases, for example, are an excellent source of data. These databases include data on land value, real property value, age of home, and size of home. Understanding how damage correlates not only to the eye of a hurricane or the epicenter of an earthquake, but also to housing value allows us to look at the effects of stratification on the distribution of damage. Again, GIS allows us to integrate social and geographic data in order to understand disaster as a social phenomena.

However, as simple as this may seem, the most crucial element of a GIS is the data. The data drive the system. Bad data yield bad results. As the saying goes, "Garbage in, garbage out." But even knowing this, processing and ultimately using data is a complicated endeavor. More often than not, data are in the wrong form. In order to link or match data, data must be in a form that a GIS can understand. For example, in order to reference an address in real space requires that the address be given an X,Y coordinate. In order to do this, most GIS software packages require that the address be in a standard form. However, this standard form is rarely the form the data are in. Additionally, data need to be at the correct scale and aggregation. Most GIS data are from secondary sources such as the Census Bureau or local government; thus, it can be expected that the data will require time-consuming cleaning in order to link or overlay them with data from other sources. Again, data drive a Geographic Information System and need to be the primary concern of researchers.

The future of GIS in disaster research is not one of a linear direction. Rather, disaster researchers must look at GIS as an emerging technology with major implications for not only researchers but also emergency managers. GIS, however, must be understood before it can be utilized. Besides needing to understand GIS in order to integrate it into research projects, researchers need to begin looking at the use of GIS (and other technologies) in disaster management. Following are some future agendas for disaster research, in no particular order.

Disaster Researchers Need to Study the Use of GIS in Emergency Management

Too often, GIS is seen as an end and not as a means. GIS is a decision-making tool. We have yet to develop technology that can on its own make decisions for a community. The presence of a GIS does not in and of itself make a community better prepared for a hazardous event. With the heightened emphasis on GIS in emergency management, disaster researchers have an opportunity to better understand technology use within emergency management. Indeed, much has changed since Drabek (1991) investigated to what extent microcomputers were being used in emergency management.

When Hurricane Felix was approaching the East Coast of the United States during the 1995 hurricane season, I was called by the Emergency Operations Center (EOC) in one of the affected states. I previously had consulted with this state to discuss their GIS system and data. They asked if I would like to come in and observe the EOC. When I got to the EOC, I was lead to a computer and was asked to tell them what data they had available. I ended up spending the next two days in the EOC working with their GIS data. In fact, there was very little I could offer this state, because their system consisted of GIS software and Army Corp of Engineers/FEMA data. They had no plan of implementation. They had no idea what they even had available. As I sat in the EOC, I realized that, while they thought they had a GIS, they actually did not. Somehow this system, all on its own, was supposed to answer questions that no one knew to ask.

While some states such as California use GIS effectively, researchers clearly do not know enough about the technology or its use. Nor do we understand the possible implications of the technology. Questions that remain are (1) to what extent are GIS and other "decision-making" technologies being implemented; (2) how are these systems being used as decision-making or information-dissemination tools; (3) how are these new technologies being implemented (i.e., do they have dedicated employees assigned to them); and (4) is a "techno-elite" being created on a local or state level creating a new type of technology-based stratification system.

Applied Researchers Need to Begin to Look at GIS as a Valuable Tool to Understanding Disaster-related Phenomena

We need to begin to incorporate GIS into our research agendas. After the Kobe Earthquake in 1994, researchers in the March 1995 edition of the *Natural Hazards Observer* made 12 observations on what the United States could learn from Kobe's disaster. In one of their observations, they argued that "a GIS-based model can give city officials a rapid sense of the scope of damage and point to neighborhoods or facilities that are most likely to be in need of assistance" (NCGIA 1995, p. 5). In addition, they argued that "cities with a history of seismic activity, or in a recognized seismic hazard zone, should begin to identify hazardous existing buildings and establish a program to strengthen or remove those structures" (p. 5). While they did not sight GIS as a specific tool for this, a GIS is an ideal tool for such inventories.

In addition, remote sensing or satellite data can be used to offer more prediction and planning information. In California, for example, digital data of fault lines with buffer zones around the faults can be used in conjunction with property tax data to not only predict those properties at greatest risk but also to tag empty lots as hazardous. With this information in a digital form, builders and zoning departments can begin to plan ahead for buildings most at risk. Additionally, a GIS can be used for modeling. Scenarios can be built to better understand what happens in an earthquake, hurricane, flood, or other hazard. As Streeter (1991) argues, disasters are not random events since some regions are more prone to disaster than others. Hurricanes, for example, do not pose a threat to states in the central plains of the United States nor, for that matter, do they affect inland cities in coastal states to the same degree that they affect coastal cities. Our propensity to develop beaches and flood plains significantly contributes to the progression of weather situations from natural acts to highly destructive human disasters. While a GIS cannot eliminate natural or technological hazards, it can be a valuable tool to understand the social, economic, and political implications both before and after an event.

Survey Researchers Should Use GIS to Test the Representativeness of Survey Results

GIS can be used to test the representativeness of survey research responses, particularly mail surveys. More often than not, survey research is done in areas with cultural diversity. As we know, not all people experience events such as disasters equally. Culture, position in regional stratification systems, and gender, for example, can significantly affect individual, family, or business disaster impact and recovery. In order for us to understand how social position affects disaster experience, it is vital that our samples and responses are representative of the social geography of our population.

A GIS can be an effective tool in tracking survey responses without violating subject anonymity. By creating a geo-referenced database of all mailed surveys, each survey can be tied to demographic data. In addition, the database would simply include a data field that would indicating whether a survey was returned. This database would be independent of the survey results, used solely as a means of testing result representativeness. A GIS allows researchers to analyze the spatial pattern of responses and nonresponses. For example, in an area such as Los Angeles, Anglos, African Americans, Hispanics, and Koreans need to be represented in survey results because each group is embedded in a unique culture with unique perspectives and experiences. By tying each address in a sample to its demographic characteristics we can analyze our responses on any one of a number of dimensions. We can query the dataset to obtain a subset of all surveys returned from block groups that are predominantly African American, for example. Likewise, we can determine return rates from areas with large proportions of single mothers. Understanding these patterns allows researchers to concentrate follow-up efforts in underrepresented areas. Additionally, researchers can understand the limitations of their work.

All too often, researchers are more concerned with overall return rates rather than the overall representativeness of their returned sample. The use of a GIS allows for the simple tracking of survey returns. Similar methods can be used to determine the representativeness of phone surveys. Researchers need to incorporate new technologies such as GIS into their overall sample framework allowing for tracking and representativeness of the returned sample.

GIS Should Be Used to Better Understand the Social Aspects of Disaster

We know disaster occurs in a specific geographic area, but it is not defined by geography. Researchers need to use GIS to analyze the social distribution of disaster effects and recovery. The ability to look at the spatial-social distribution of a disaster allows us to better understand populations at risk. GIS allows us to overlay vastly different datasets that without GIS would require large amounts of time to compare. Damage data by address, for example, can be overlaid with census block group boundaries. Damage data can be aggregated to the block group level, and comparisons can be made to better understand the relationship between damage or recovery and socioeconomic status. While this can be done without GIS, it is labor exhaustive by requiring manual look-ups of each address on paper census maps.

However, we need to remember that GIS should not drive research. Just as a Geographic Information System, in and of itself, does not make an emergency management team better prepared for a hazardous event, it likewise cannot in and of itself generate research questions. Nor for that matter can GIS technicians, who understand the technology but not the theory, drive the use of GIS in disaster research. Rather, the only effective use of GIS is through research teams that include researchers who can generate ideas from theory and previous research and technicians who understand the use of the technology. Our experience needs to drive the use of GIS; it cannot be used merely because the technology exists.

Vulnerability Analysis: A Future Application

At best, GIS is being used in terms of hazard and risk mapping. Maps exist that show the location of earthquake faults, for example. Maps are also available that show coastal flood zones and areas at greatest risk from hurricanes. However, we are less likely to use GIS to analyze vulnerability, which is more than a geographic phenomena. GIS should be used to link the physical attributes of risk, such as earthquake faults and flood zones, with the social, economic, and political attributes that render individuals, families, businesses, and communities most vulnerable. Vulnerability is a function of power hierarchies within the social, economic and political spheres, not merely proximity to flood zones, fault lines, or hurricane-prone coast lines. Disaster researchers can use GIS as a tool to better understand these complex vulnerabilities.

Summary

While GIS is not a new technology, it is a technology that today is on the cutting edge in emergency management and in the future can be on the cutting edge in disaster research as well. Its use requires researchers to understand disaster in a spatial context, linking social indicators and geography. Researchers need to look at operationalizing variables differently to allow for spatial analysis.

Beyond incorporating GIS into disaster research itself, researchers must begin to look at the use of technology as a whole, concentrating on how it is being implemented and used. The use of GIS is not in and of itself a solution to emergency managers or researchers. Rather, it is a tool that, if used correctly, can offer new understandings of age-old problems.

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