Use of Geographic Information Systems in Trauma Research

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Abstract

The applications of geographic information systems (GIS) allow for the tracking and prediction of populations, locations, and infrastructure impacted by natural and man-made disasters and/or where emergency response efforts are needed. GIS also facilitates modeling for more successful disaster preparation and the maximization of resources to mitigate the deleterious effect that disasters have on the physical and mental health of the affected population. As it pertains to trauma research and response, especially with children and their families, when disaster strikes, there is no time to waste. Advanced technologies like GIS can inform decisions on where trauma centers are erected, where mental health first responders are stationed, where and how resources are allocated, and what more can be done in the crucial moments that immediately precede and follow the event. Although every scenario cannot be anticipated, models of previous disasters can be applied to potential future sites of terrorist attacks, hurricanes, floods, nuclear power accidents, and the like, so that fortifications can be constructed, plans can be drawn, and mistakes of the past are not repeated. GIS can also aid mental health researchers in the aftermath of disasters by measuring disaster exposure objectively. The level of exposure to disasters such as the 9/11 terrorist attacks on the World Trade Center, the movement of nuclear material in the air after the Fukushima Daiichi nuclear disaster, and the location and intensity destruction in war-torn regions, such as Syria and Nigeria, strongly affect physical and mental health outcomes of the population, and can be measured

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objectively with GIS. These and other examples will be discussed with an emphasis on the mental health of children and their families. Although children might not always have an explicit awareness of all factors involved in a traumatic event, they often shoulder a disproportionate burden of the stress. It is our contention that a more scientific, systematic, and objective approach to measuring direct exposure in future disasters will aid in the decision-making process for interventions and treatment to alleviate some of this burden.

13.1 Introduction

In recent decades, experts in a number of disciplines have increasingly focused their attention on solving issues related to large-scale disaster scenarios. Environmental changes and related weather phenomena have led to increased, persistent threats of natural disasters. At the same time, industrial accidents and terrorist attacks are on the rise. Together these trends have resulted in a growing global need for better vulnerability assessment and improved disaster response, particularly within geographical regions that are more prone to disasters and whose populations are at greater risk for both physical and mental harms (Bohle et al. 1994; Gabe et al. 2005; Torresan et al. 2008). Risk and vulnerability assessments of potentially dangerous areas are regarded as among the best means of crisis management and disaster mitigation (Curtis et al. 2007; Preston et al. 2011; Gruebner et al. 2015, 2016). In light of these developments, the present chapter reviews and highlights the applications of geographic information systems (GIS), including remote sensing technologies, in the various stages of disaster planning and response.

13.2 Geographic Information Systems (GIS)

Mapping of geographic phenomena was found in caves of primeval humans as early as 8200 years ago (Krebs and Krebs 2003). With rapid advancements in computer technology during the latter half of the twentieth century, several computer-mapping programs revolutionized cartography and brought forth the development of modern automated mapping procedures, allowing maps to be generated much faster and with greater precision. By the middle of the 1980s, computer mapping finally allowed descriptive, attribute data to be linked to geographical entities within digital maps, and the modern desktop-based GIS was born (Musa et al. 2013-b). A GIS is a computer system with the capacity to capture, store, analyze, and display geographically referenced information. These have been used widely in natural, social, and engineering sciences because they incorporate physical, demographic, economic, and disaster information (Mark et al. 1997). In the field of disaster planning, GIS has allowed for mapping the location of disasters and the populations at risk. This has enabled local and national governments to identify the extent of the physical damage caused by the disaster, identify the populations in harms' way, and pinpoint where outreach, rescue, and recovery efforts should be concentrated. Such applications of GIS, in combination with Global Positioning Systems (GPS), and remote sensing technologies (including light detection and ranging [LIDAR]), have been successfully employed in the identification of the extent of damage from both natural and anthropogenic (man-made) disasters (Clark et al. 2001; Huyck et al. 2003).

There are two traditional models of GIS: raster and vector. In the raster GIS model, geographic phenomena of a continuous nature (e.g., elevation, satellite imagery, remotely sensed data) are represented in grids of pixels similar to a digital photograph taken with modern-day cell phones. The size of the pixel determines the spatial resolution of the data, and the program stores the values of the geographic data being captured for each pixel, such as the elevation above sea level. This GIS model is ideal for mapping flood extent and determining which areas would be damaged, for example, by a Category 4 hurricane making landfall in a highly populated area, such as a national capital.

In the vector GIS model, discrete geographic phenomena are represented by a combination of points (location of health services, epicenter of an earthquake, etc.), lines (roads and transportation networks, storm paths, temperature isolines, etc.), and polygons (administrative units, census areas, building footprints, etc.). In each of these traditional GIS models, different data types representing various phenomena are layered or superimposed on top of each other, allowing the user to analyze them across different topologies. For example, one can overlay a raster satellite image, say of the plume of smoke emanating from the World Trade Center (WTC), atop the locations of schools (vector point data) and postal code boundaries (vector polygon data) which contain demographic attribute information, to assess both which schools were under the plume of smoke from the WTC attack and the demographics of those exposed (see Fig. 13.1). The schools shown were identified within certain neighborhoods (postal codes) for participation in an epidemiological representative study of NYC public schools designed to assess the impact of 9/11 on students' mental health (Hoven et al. 2005; Musa et al. 2003).

13.3 Assessing Risk

Ecological change and environmental crises have become increasingly prominent issues on the global scene (Kreft et al. 2015; Peduzzi et al. 2012). The 2016 Global Risk Report has ranked extreme weather events, failure to cope with climate change, and major natural catastrophes as three of the top five biggest global risks, supplanting failure of national governance and state collapse or crisis (World Economic Forum 2016). Unsurprisingly, a nation's vulnerability is heavily tied to its developmental level and capacity to mitigate risk, with the least developed countries bearing the lion's share of casualties from natural hazards (Peduzzi et al. 2009). In fact, the UN Global Assessment Report on Disaster and Risk Reduction states that natural disasters accounted for over 42 million life years lost, with over 80% of those

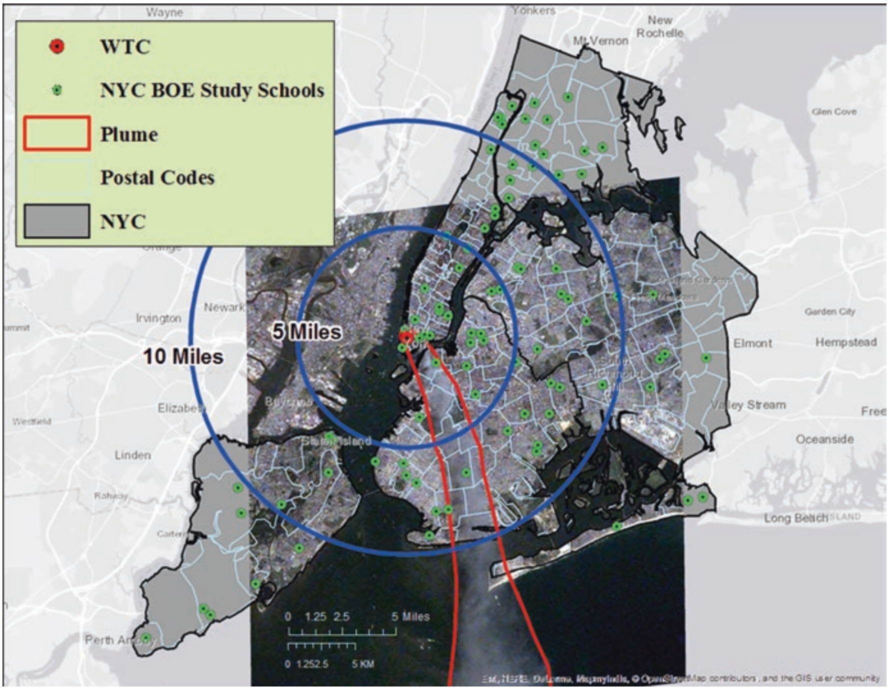

Fig. 13.1 NYC BOE study (Hoven et al. 2005) participating schools and NYC postal codes near and under the plume of smoke emanating from the WTC on September 11, 2001. Author: George J. Musa, PhD, Global Psych Epi Group, Columbia University—NYSPI, April 5, 2018, Projection: NY-LI State Plane (NAD83); Sources: NYC Dept. of City Planning, NYC Dept. of Education, International Space Station; ESRI, HERE, DeLome Mapping Inc., Open Street Map

lost years spread across middle- and low-income countries, with an estimated cost of $250 to $300 billion annually (2015). In light of these growing trends and increased regularity of natural disasters, emergency management, that is, pre-disaster preparedness as opposed to post-event disaster management, needs to be our policy focus if we are to minimize the social, financial, and infrastructural impacts of disasters (UN 2015).

13.4 GIS and Emergency Management

Emergency management is defined as the application of science, technology, planning, and management to prepare for and deal with large-scale disaster events that put large numbers of people at risk of injury or death (Cova 1999). The challenges brought on by these events, including preparedness, evacuation planning, post-disaster relief, and rebuilding efforts, are inherently geographic, and as such, GIS, with its versatility in the collection, organization, and assessment of spatial data, can aid in improving the inherently spatial decision-making process (Cova and Church 1997; Cutter 2006).

In the case of future natural disasters, GIS and modeling of spatial data can assess the probability of where events are most likely to occur and can aid in the assessment of which aspects of the disaster and its aftermath will be the most salient for the local population. These models can aid decision-makers in planning preventive and relief efforts, including which medical and mental health professionals will be the most pertinent to mobilize, and the most efficacious distribution of resources, both pre- and post-disaster. Through the careful aggregation of demographic and spatial information, the applications of GIS models to prediction of, and response to, natural and man-made disasters are limited only by imagination and the spatial data available. These applications involve visualization and analysis of spatial data from many different viewpoints, including those of researchers, policymakers, planners, managers of various programs, and professionals in public health and health care (Kurland and Gorr 2009). In the past, researchers and professionals from these various fields operated with disjointed visual representations of the geographical environments that inform the emergence of physical and mental health symptoms in the wake of disasters. Currently, relevant environmental factors can be layered on top of one another in clear and compelling spatial representations of events and their aftermath (Kurland and Gorr 2009). These maps can also be rapidly adjusted to fit the needs of the analyst, facilitating targeted, specialized analyses, and yet coupled with the ability to combine and share data with individuals from different disciplines. This dual strength is especially applicable in emergency response situations, in which many individuals from different backgrounds need to collaborate and communicate quickly to make vital decisions to mitigate damage and save lives.

Due to the growing regularity and intensity of disasters, effective disaster response must not only address immediate short-term challenges but also reduce systemic vulnerability and mitigate future crises (Aubrecht et al. 2013). Thus, the length of time for recovery after impact becomes a major component of disaster concerns. In this regard, GIS are less static projections of existing data and more dynamic tools that shape the way that decisions are made, which drive the aims of the scientists who create and use them (Koch 2005). Within this framework, GIS maps support evidence-based practices that could tip the scale in favor of prudent decisions both at the pre-disaster planning phase and at crucial moments during or after the disaster, when more urgent and reactive decisions are made. Several pertinent examples of these moments have already been conveyed in the chapters of this book. In the example of the ongoing conflict in Syria, El-Khani et al. (2017) put forth unconventional and insightful ways for maximizing the impact of mental health services for people on the ground in war zones, as well as in nearby refugee camps. Additional demographic and geographic data compiled and layered using GIS modeling might yield useful predictions of where community mental health clinics might be most accessible, what kind of mental and physical health specializations will be most useful, and how the topography of the landscape, weather patterns, and distribution of resources might affect access to mental and physical health care. Moreover, such systems could build on information already compiled about the local population to support a focused awareness campaign that is both accessible and culturally appropriate.

While there are many uses of GIS in disaster relief efforts, an equally compelling application lies in its predictive powers. Over a decade ago, Al-Adamat et al. (2003) used GIS technology to create a groundwater vulnerability map in Jordan to delineate the dearth of renewable freshwater resources which, even then, was severely strained by population growth due to refugees from Middle East zones of conflict. More recently, according to the UNHCR (2017), an additional 660,582 refugees have fled from Syria to Jordan since the start of the Syrian Civil War, which has undoubtedly continued to push Jordanian water resources to the breaking point. Risks for future conflict over water resources, as well as nearby countries' willingness and ability to absorb refugees, at the astounding rate that they are evacuating Syria, are creating a fragile geopolitical landscape.

Yet the roots of this crisis are deeper and go back a decade. Some researchers draw a direct link between earlier water scarcity and the onset of the conflict in Syria. A severe drought from 2006 to 2011 and a prolonged dry period that persisted afterward contributed to the collapse of the economy and societal structures (Gleick 2014). During this time period, approximately three million Syrians were affected by agricultural failure that included catastrophic losses in staple crops like wheat and barley and a decimation of livestock populations. The resulting food insecurity drove approximately 1.5 million people from rural areas to cities and camps outside these cities, putting an additional strain on the limited economic resources. Mismanagement of water resources by the Assad regime as well as an emphasis on outdated and damaging agricultural practices intensified this problem (Gleick 2014). GIS was utilized to create groundwater vulnerability maps during this time period (Kattaa et al. 2010), which identified specific practices, such as the use of certain fertilizers and pesticides, the dumping of solid waste, the improper disposal of wastewater, and the presence of olive mills as exacerbating factors in the contamination of groundwater, especially in the coastal areas of Syria. Of course, the ongoing Syrian conflict involves a constellation of contributing factors. However, it is important to understand that GIS technology was being utilized at key points prior to the conflict to analyze antecedents. If decisions had been made to heed the GIS information that was available, perhaps more could have been done to mitigate the fallout of the water shortage. Instead, the Assad regime provided large government subsidies for water-intensive crops, such as wheat and cotton (Gleick 2014), while a more prudent and scientifically supported policy would have steered government subsidies toward the harvesting of less water-intensive crops. Since the full-blown civil war broke out in Syria, the water crisis has deteriorated further as crucial water infrastructures such as dams and supply pipelines have routinely been targeted by forces on all sides of the conflict, including government forces, rebel groups, and ISIS fighters, further destabilizing resources for the civilian population (Pacific Institute 2017). As devastating as these events are to our times, they have a long history. The Pacific Institute's Water Conflict Chronology Timeline (2017) traces water conflict in the Middle East as far back as 700 B.C., leaving little doubt about the crucial role that water shortages have, and continues to play in Middle Eastern conflicts, as well as in conflict zones across the globe.

However, not all water crises stem from a shortage of water. Many are caused by an overabundance. Water-related disasters are most devastating to vulnerable geographical regions, and spatial tools such as GIS have been vital in all stages from risk evaluation to disaster response (Bryan et al. 2001; Zhang 2004; Chen et al. 2011). As such, GIS has proven to be an effective tool for mapping out the extent of flood zones as well as modeling future flood scenarios (Johnson 1995; Cova 1999; Taramelli et al. 2015). Areas of particular concern are those that are coastal, low lying, and/or particularly susceptible to meteorological events. Hurricanes, typhoons, and other coastal storms are among the most destructive and costly natural occurrences as they put large portions of the world's coastal population at risk (Blaikie et al. 2014). Developing countries with fewer resources are typically more vulnerable to such disasters; however, even in these countries, GIS technology has been helpful in influencing responses to extreme weather events (Van Westen 2000; Alcántara-Ayala 2002).

Scientists working in Central Vietnam have advocated for the integration of GIS with local knowledge of the indigenous population in order to maximize the efficacy of disaster management (Tran et al. 2009). Such research delineates the particular vulnerability of poor people living in these disaster-prone areas who are trapped in poverty by a cycle of seasonal destruction and futile attempts to rebuild. This research team also put forth meaningful solutions geared toward the local culture, which involved recommendations regarding where and how new structures should be built, and included an emphasis on community engagement in continuing to collect data for the perpetuation of the common good (Tran et al. 2009). Although it was noted that the collection of up-to-date spatial data and the management of sophisticated GIS in a developing country are difficult, the authors were confident that through a partnership between the local community, the provincial government, and a local university, it would be possible for this community in Central Vietnam to maximize their disaster preparedness using GIS (Tran et al. 2009).

13.4.1 The Philippines and Typhoon Haiyan

In addition to Vietnam, various other places in Southeast Asia are routinely affected by large-scale weather events. Notably, the Philippines is one of the most geographically vulnerable locations on the planet, enduring more typhoons than anywhere else in the world (Primavera et al. 2016). On November 7, 2013, the islands of the Philippines were hit by Super Typhoon Haiyan, which destroyed more than a million homes and caused over 100,000 deaths (Primavera et al. 2016; Chiu 2013). As part of a damage assessment, researchers examined the storm surge effects on the city of Tanauan, relying on GIS, survey data, and satellite imagery instead of precipitation records which had been lost (Yi et al. 2015). Geospatial maps were created using survey point data and firsthand accounts displaying the extent of the flood surge (Yi et al. 2015). Another study implemented a mixed method approach using both crowd-sourced information via open-source mapping (obtaining geospatial and attribute information by a large number of people through the Internet, much like Wikipedia does for articles) and remote sensing satellite image analysis to compare the accuracy of crowd-sourced building damage data and aerial imaging with field-level damage assessments (Westrope et al. 2014). Findings indicated that crowd-sourced data tended to over- or underrepresent certain damaged areas, but overall, the study was able to derive recommendations to improve accuracy for open-source mapping as well as provide better directions for contributors to make more reliable assessments (Westrope et al. 2014). These studies demonstrate the potential for open-source spatial data in future disaster relief efforts.

13.4.2 Post-disaster Recovery

In spite of an increased capacity to react to and withstand natural disasters, citizens of developed countries are far from immune to violent weather phenomena or the many problems they leave in their wake. One of the largest weather events to hit the United States in recent history occurred on October 29, 2012, when Superstorm Sandy hit the New York/New Jersey coastline, costing over $19 billion in damages and causing 43 deaths (Gruebner et al. 2015). Wang et al. (2014) examined the storm surge extent utilizing a sub-grid (i.e., fine-grained) model and incorporating GIS and light detection and ranging (LIDAR) data. Utilizing these tools allowed for the development of a high-resolution inundation model highlighting the areas within NYC that were most heavily affected by the storm (Wang et al. 2014). Apart from the physical damage sustained in wake of Superstorm Sandy, a number of residents were further burdened by emotional trauma (Gruebner et al. 2015; Lowe et al. 2015).

Vulnerability and resiliency appraisals in regard to mental health outcomes of large-scale disasters have become more prominent in mental health research and are known to be highly dependent on both individual- and community-level sociodemographic factors (Lowe et al. 2015). One post-disaster mental health study examining the geographic variability of mental health outcomes after Superstorm Sandy relied upon a spatial epidemiological approach and showed that vulnerability and resilience depended in part on geographic location as identified by GIS (Gruebner et al. 2015).

13.4.3 Understanding Risk and Protective Factors for PTSD

One of the most ubiquitous concerns regarding the mental health of persons affected by natural and man-made disasters is the development of post-traumatic stress disorder (PTSD) symptoms. Traditional models of PTSD exposure have put Euclidian distance from the disaster high on the list of risk factors for people in zones of disaster or conflict. This is intuitive, given the experiential nature of PTSD. However, our group has found a wider and sometimes counterintuitive constellation of factors that influences victims' propensity toward developing PTSD symptomatology. We have found the context of the event to be particularly important. For example, being in the line of sight (LOS) of a disaster may predict outcomes better than a simple measure of proximity, while socioeconomic, cultural, and environmental factors must always be considered. In New York City, deference to these various factors has proven to be vital, given the unique architectural landscape as well as the vast cultural and socioeconomic diversity that exists. Thus, the complex nature of PTSD symptomatology against the backdrop of the New York City skyline has necessitated novel approaches to measurement and factor analysis, especially in the wake of the 9/11 terrorist attacks.

The association with discrete space and time-bound disaster events has tied the epidemiology of anxiety disorders, including separation anxiety, agoraphobia, and PTSD, to geography (Hoven et al. 2005, 2004; Musa et al. In Review-a). Moreover, though several researchers have demonstrated a strong relationship between physical proximity to traumatic events and PTSD risk (Goenjian et al. 2009; Groome and Soureti 2004; Pynoos et al. 1987, 1993), our group has found a more complex relationship between proximity and PTSD symptomatology, especially in children and adolescents. In fact, Hoven et al. (2005) actually found that attending a ground zero area school on 9/11 in Lower Manhattan, NYC, was actually a slightly *protective* factor against PTSD, and no relationships were observed between rates of PTSD and the Euclidian distance between a child's school or residential zip code and ground zero (Musa et al. 2003, 2013).

Instead, individual (female gender, younger age, etc.)- and neighborhood-level environmental factors (living in low socioeconomic status [SES], low-quality, high-crime neighborhoods) and higher levels of personal exposure (direct, indirect, or TV) to 9/11 as well as prior traumatic events were found to be more predictive of probable PTSD symptoms (Musa et al. 2013, In Review-a). In this particular study, levels of direct exposure were defined as endorsing two or more of the following five events: personally witnessing the attack, being hurt in the attack, being in or near the cloud of dust and smoke, having to be evacuated to safety, and being extremely worried about the safety of a loved one (Hoven et al. 2005). Thus, close proximity to the attack is implied in some of the categories, but not required for a person to be considered to have had direct exposure. For example, an individual could have witnessed the planes crashing into the World Trade Center from an outer borough of New York City and experienced extreme worry about the safety of a relative in the area while being miles away in the safety of their home. Another individual in Manhattan, with much closer Euclidian proximity to the World Trade Center, might have not been able to see the events unfolding in real time, due to a view obstructed by the multitude of tall buildings, and also been less personally connected to the events on the ground due to various familial circumstances and therefore have greater proximity but perhaps far less traumatic exposure and lower risk for developing PTSD.

According to the American Psychiatric Association (1994), PTSD involves the experience, witnessing, or being confronted by an event that involves threatened death or serious injury to self or others. Given that individuals with a direct LOS had a clear view of the largest, costliest, and deadliest terror attack in US history, the findings that they had high risk for PTSD are of particular importance, especially when considering the need to mobilize an efficacious mental health response to such a wide geographic area. In order to account for this challenge of determining the line-of-sight (LOS) exposure to 9/11, we used GIS viewshed analysis to combine information from an isotropic landscape model reflecting flat ground elevation and a digital elevation model (DEM) of the underlying ground elevation to reflect a more accurate surface of the NYC landscape (Musa et al. In Review-b). In each of these models, locations at every 10 ft were selected along the roof line of the original towers as observer points. Raster models (grid of cells much like a digital photograph) were calculated using bilinear interpolation to determine the elevation of each observation point (Esri ArcGis 2012) and whether each cell had direct line of sight to the observer feature (Musa et al. In Review-b). As we did not have information as to which floor the participant lived on, the analysis was restricted to the street-level and building rooftops. The number of cells which had direct line of site to the original towers was then aggregated to the postal code to estimate the proportion of the neighborhoods from which the World Trade Center was visible prior to its collapse, thus estimating where real-time visual trauma exposure might have been most salient.

The results of the GIS viewshed analysis (see Fig. 13.2a, b) showed that the outer borough of Brooklyn held the lion's share of rooftop and street-level viewpoints, encompassing 32.7% of pixels, followed by Queens and Staten Island (Musa et al. In Review-b). Manhattan and the Bronx collectively possessed only 15% of the pixels with a rooftop and street-level view of the World Trade Center (see Fig. 13.2b). It is perhaps surprising that Manhattan, the borough in which 9/11 occurred, had

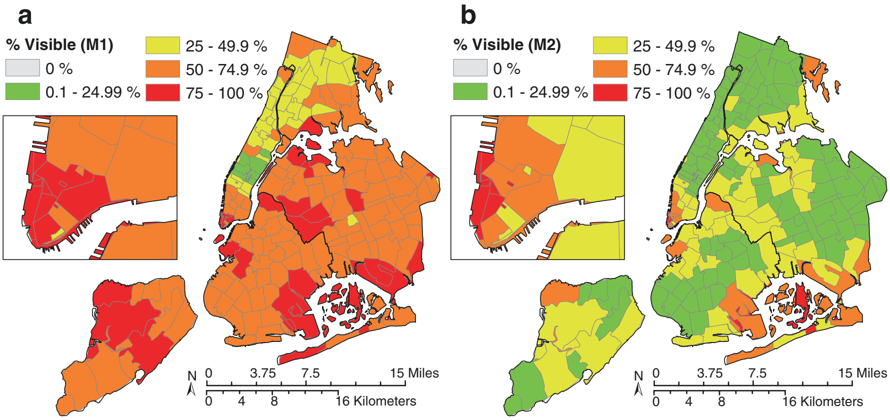

Fig. 13.2 (**a**) Pixels with rooftop view of the WTC. (**b**) Percent of zip code with rooftop view of the WTC. Author: George J. Musa, PhD, Global Psych Epi Group, Columbia University—NYSPI, March 2, 2018, Projection: NY-LI State Plane (NAD83); Sources: NYC Dept. of City Planning, NYC Department of Information Technology and Telecommunications

such a small percentage of the overall visibility. However, this speaks to the complex architectural landscape of New York City and the key role of GIS in the multifaceted analytical approaches necessary to aggregate relevant data and produce a more accurate portrait of the exposed populace.

13.5 GIS Simulations

The ability to critically assess, visualize, and accurately model large-scale natural disasters is an integral component of disaster preparation and of evacuation planning strategies (De Silva and Eglese 2000; Xu et al. 2008). A valuable benefit that GIS and other digital mapping software can offer is the capacity to run simulations of hypothetical disasters (De Silva and Eglese 2000; Takeuchi et al. 2003; Uno and Kashiyama 2008). These disasters might be strictly man-made, due to war or terrorism, attributable to a combination of natural and man-made factors as in the case of the Fukushima Daiichi nuclear disaster, which was catalyzed by the Great East Japan Earthquake/Tsunami, or strictly attributable to environmental factors. Regardless of the cause, there needs to be a shift away from the past orthodoxy that focused on reacting after a disaster toward a preventative approach that uses GIS and other vital technology to simulate potential disaster scenarios in order to better prepare for them. Geospatial technologies like spatial decision support systems, multi-agent modeling, and artificial neural networks have already been proven to effectively model and simulate flooding in flood-prone areas (De Silva and Eglese 2000; Uno and Kashiyama 2008; Kia et al. 2012). Similarly, the Philippines' Nationwide Operational Assessment of Hazards (NOAH) Project makes use of high-resolution topographic maps, water surface elevation data, and GIS technology to model temporal changes in storm surge and coastal flooding based on water inundations and hydrographic information (Lagmay et al. 2017). Initiatives like these are beneficial for reactively assisting with evacuation plans but can and should also preemptively assist in disaster planning for future flooding.

13.6 Remote Sensing and Light Detection and Ranging (LIDAR)

In recent years, remote sensing applications have become increasingly prominent within the realm of disaster response, largely due to improved technologies, more advanced and specialized satellite networks, as well as improved image resolution (Joyce et al. 2009). Satellite imagery is an important constituent of disaster awareness and can be ideal for observing and assessing damage when used in conjunction with GIS and other digital mapping software (Sanyal and Lu 2004; Tralli et al. 2005). Satellite technology is frequently used to determine temporal changes in climate and is a vital instrument in the monitoring and understanding of climatological systems (Yang et al. 2013). With the availability of several satellite sensors, remote sensing has aided in the detection of fault lines for ensuing earthquakes, mudslides, and flooding (Metternicht et al. 2005; Joyce et al. 2009). It is also integral to the detection of man-made disasters such as oil spills (Jha et al. 2008) and terrorism (Huyck et al. 2003). Additionally, remote sensing can help with the paucity of data within developing countries that are, by the nature of their geography, more susceptible to flood disasters (Sanyal and Lu 2004).

13.7 Cost-Effective Data

As previously mentioned, the most vulnerable geographic regions tend to be the least equipped to deal with the aftermath of natural disasters. It is expected that impoverished nations and their agencies generally lack accurate geospatial data, particularly for rural areas in which data is either nonexistent or years or even decades old (Antifaev 2013). Striking a balance between cost and data accuracy is, therefore, an important consideration especially for countries with budgetary constraints. Field survey data is often very time-consuming and expensive to obtain. In light of this, satellite-based synthetic aperture radar (SAR) in conjunction with LIDAR imagery has been used as a cost-effective method to make up this deficiency and has become a prominent feature for initiatives such as the University of the Philippines' Disaster Risk and Exposure Assessment for Mitigation (DREAM) program (Antifaev 2013). Offering high-accuracy and high-resolution spatial data, SAR and LIDAR imaging have been shown to be viable cost-effective methods for disaster management agencies in poorer countries (Mumby et al. 1999; Antifaev 2013).

13.8 Conclusion

Geospatial applications like GIS, including remote sensing, are vital for the effective preparation and mitigation of disasters. As these technologies continue to improve and geospatial data becomes more readily available, new opportunities and effective strategies for disaster prevention and management will continue to develop. These technologies will not only improve upon existing crisis response policies but can also be integral for the preplanning stages of future hypothetical disasters. The growing frequency and unpredictability of large-scale weather phenomena like typhoons and hurricanes continue to be an enormous challenge for government agencies, especially those with diminished resources. In light of this, GIS and satellite imagery can not only serve as viable and cost-effective measures but can also pave the way for new innovations that optimize crisis response and more proactive disaster mitigation strategies. There are also powerful implications of this new technology in the response to man-made disasters.

As it pertains to the crucial topics presented in this book, there are a myriad of applications for further collaborative fieldwork using advanced geographic technology. In the study conducted by El-Khani et al. (2017), mental health questionnaires were disseminated to Syrian families in a necessarily innovative way due to the brutal nature of the ongoing conflict. The study materials were given to participating families alongside bread deliveries by a local humanitarian aid group. El-Khani et al. (2017) and their local partners were able to achieve an astounding response rate of approximately 60% (1783 out of 3000 respondents) from internally displaced persons and permanent residents by utilizing only one bakery and basic lists of families. GIS technology might be used for expansion of this work to target other NGO bakeries that have access to larger numbers of people in need, and to plot the best daily routes to reach them, given the rapidly changing landscape of a war zone. In the wake of their findings, El-Khani and Calam (2019) called for intervention programs that could be delivered by nonspecialists to promote better mental health within zones of conflict. However, in order to train and mobilize nonspecialists while keeping them safe and maximizing the efficacy of their intervention, a logistical plan of action must be put into place. By aggregating what is known about the people in need, their local area, and the hardships they face on a daily basis, researchers, clinicians, and trained nonspecialists might be better prepared to respond when unknown variables inevitably come into play.

Another example from this book is the work of Watanabe et al. (2019), which described indoor community centers constructed in the wake of the Fukushima nuclear disaster to foster socialization, education, and a therapeutic environment for children and their families. These play centers should serve as a model for what can and should be done for children whose communities have been made unsafe by natural or man-made disasters. However, to maximize attendance and increase the efficacy of the interventions, the geographic placement of future centers should take into account the factors that made the communities unsafe in the first place, as well as the proximity to local population centers and public transportation as well as other relevant geographic factors.

Watanabe et al. (2019) were also critical of the lack of sufficient analysis of the radioactive plume in the wake of the Fukushima nuclear disaster and point to this failure as a cause of unnecessary suffering, both physical and mental, in the affected population. A detailed analysis of the trajectory of the plume, with a recognition of the population centers in its path, might have mitigated some of this physical and psychological suffering. Additionally, the stigma and uncertainty regarding the direction in which the airborne nuclear material was traveling and, thus, which people and places were affected would have almost certainly been mitigated by comprehensive analysis and timely dissemination of accurate information.

Finally, as we look toward the future of GIS, spatial analysis, and the ubiquitous age of social media, there are further ways in which the suffering of children and their families might be assuaged. Abdulmalik and colleagues (2019) in this book discussed the challenges facing the inhabitants of northeastern Nigeria. Despite limited access to the Internet in rural areas, Boko Haram continues to utilize social media in an attempt to recruit and radicalize. Some media outlets even speculate that an increased sophistication of Boko Haram's social media package and newfound similarity to the videos and posts put forth by ISIS signal a closer collaboration between the two groups (BBC Monitoring 2015). This increased risk magnifies the necessity for international partnerships to analyze how social media posts affect the local population in global hot beds of terrorist activity. Spatial analysis can assist in this mission, both to pinpoint exact locations of where digital calls to violence are emanating from and to gauge the local reaction. This type of detailed analysis will almost certainly be crucial for understanding how terrorist groups subvert and coerce the local population and for the development of novel ways to counteract this messaging. As discussed broadly in this book, children are disproportionately affected by natural and man-made disasters. Specifically, in the chapter by Abdulmalik et al. (2019), the abduction, recruitment, rape, forced marriage, and murder of children by Boko Haram is discussed in horrifying detail. Given the urgency of need, the brutality toward the most vulnerable members of the population, and failure of local authorities to eradicate this threat, it is imperative that we use the available technological advantage to mitigate the suffering of those affected.

There is some encouraging work being done on the utility of GIS models and modern data processing techniques to analyze the variables involved in previous events and improve responses to future disasters (Xu et al. 2016). These new technologies offer a wealth of information about variables such as risk perception and public opinion and offer more robust data and analysis than ever previously available. However, like the technological systems themselves, more connection and widespread use will yield more comprehensive results. It is essential that these burgeoning technologies be utilized across the globe to model and prepare for likely disaster events before they occur and, when the worst happens, to more effectively intervene. The mental and physical health of future generations hang in the balance.

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