Integrating Public Health, Earth Observation Sciences, and Engineering Information Systems for Critical Disaster Reduction

by

Stacy Young[1], Josephine Malilay[1], Carlos Sanchez[1], Dahna Batts-Osborne[1]

ABSTRACT

Disaster epidemiology uses a variety of methods to identify risk factors that predispose individuals or populations to death, injury, or illness during the pre-impact, impact, and post-impact phases of a disaster. Emerging technologies including earth observation sciences (i.e., remote sensing imagery, satellite observations) and engineering information systems (e.g., geographic information systems, database management systems, computing and processing technologies) can enhance current disaster epidemiology methods by offering an improved understanding of the nature of hazards inherent in natural and technologic disasters. Refining the methods by which information is gathered and analyzed will effectively contribute to the goals of prevention and mitigation. This paper illustrates uses of technology in disaster epidemiology field studies to improve information gathering, information transfer and analysis, and public health post-disaster assessments.

KEYWORDS: geographic information; global positioning systems; natural disasters; remote sensing; satellite imagery

1.0 INTRODUCTION

During the last decade, wind and seismic events have affected an estimated 300,000 people, resulted in 140,000 deaths, and caused billions of dollars in damage (ICRC, 2002). The goal of public health in disasters is to prevent or reduce the number of deaths, illnesses, and injuries caused by natural or technologic disasters. Disaster epidemiology uses a variety of methods to identify risk factors that predispose individuals or populations to these adverse health outcomes during the pre-impact, impact, and post-impact phases of a disaster. Knowledge of these hazards—their causes, changing magnitude and distribution of risks, and prediction—can assist public health scientists in identifying mechanisms of death, injury, and exposure and improve prevention and mitigation strategies for future disasters.

Emerging technologies including earth observation sciences (i.e., remote sensing imagery, satellite observations) and engineering information sciences (e.g., geographic information systems [GIS], database management systems, computing and processing technologies) can advance disaster epidemiology methods. Earth observation sciences and information technologies can be useful tools in evaluating human health in wind and seismic events. For example, remote sensing and GIS can be used to monitor weather and climate changes, generate precision forecasts, classify land use, examine associations between location and adverse outcomes, identify and measure community exposure to public health threats, and improve survey sampling methods. Using these technologies to refine the methods by which information is gathered and analyzed after a disaster will effectively contribute to prevention and mitigation.

Mitigating the impacts of disasters requires a solid foundation of science and technology. These technologies provide innovative approaches to hazard risk reduction by characterizing the nature of hazards in these events and enhancing research and field methods. This paper illustrates uses of technology in

[1] Centers for Disease Control and Prevention (CDC), National Center for Environmental Health, Health Studies Branch, Disaster Epidemiology and Assessment Team, MS F-46, 4770 Buford Hwy NE, Atlanta, GA 30341-3724

disaster epidemiology field studies to advance information gathering, information transfer and analysis, and public health post-disaster assessments.

2.0 TECHNOLOGY FOR INFORMATION GATHERING

2.1 Remote Sensing and Satellite Images

In remote sensing, a sensor gathers observation data about an object or phenomenon, without direct physical contact between that sensor and the object or phenomenon being observed (NASA, 2004). Remote sensing is a key component in predicting upcoming disasters through the tracking of storms and monitoring of volcanic domes or seismic faults (NASA, 2004). For example, radar images that help make precision forecasts have increased the effectiveness of early warning systems (Smith, 2003), and storm tracking capabilities have allowed the National Weather Service to issue longer-range hurricane forecasts—5-day hurricane forecasts, instead of previously used 3-day advisories (Devlin, 2003). Additionally, information about human exposures provided by remote sensing—coupled with GIS and information from environmental health laboratory-based biomarkers indicating human exposure to chemicals—can aid clinicians, toxicologists and public health scientists in conducting studies to determine the scope and magnitude of human health problems. Specific examples of how remote sensing can be applied in this manner are found in epidemiologic investigations of transboundary haze and landslides recently conducted by the Disasters Epidemiology and Assessment Team (DEAT) at the Centers for Disease Control and Prevention (CDC).

2.1.1 Health Assessment of Possible Exposure to Trans-boundary Haze among Malaysian Children and Pregnant Women from Vegetation Fires in Southeast Asia.

In 1997, uncontrolled forest fires in Indonesia resulted in severe smoke pollution. In most exposed areas of Malaysia, haze concentration levels exceeded local ambient air quality standards and guidelines for particulate matter. To determine the full impact of the haze episodes short- and long-term health outcomes from short- and long-term exposures to biomass smoke and haze in children and pregnant women were assessed (THHIT, 2003).

The epidemiologic team collected survey information, hospital records, biologic samples, and environmental samples. Earth observations data will be applied to atmospheric transport models that can then be used in conjunction with the health information collected by the survey team. Combining these sources of information might aid in determining hazardous areas and identifying communities at risk.

For example, remote sensing systems such as the NASA-based Aqua and Terra Moderate Resolution Imaging Spectroradiometer (MODIS) can dramatically improve scientists' ability to monitor the daily cycles of the large-scale burning of plant biomass worldwide. With MODIS scientists can gather real-time data on how fast and in which direction fires are spreading, as well as how severely a given fire may affect air quality in downwind areas. Space-based remote sensing systems such as MODIS can be linked with *in situ* observing systems (e.g., ambient air ground monitors) to produce models that can more comprehensively and accurately define areas exposed to peat- and vegetation-based fires. Once these areas have been identified, maps of the areas can be joined with epidemiologic information (e.g., geographic patterns of pediatric respiratory illnesses) and used to identify potential associations between illness and exposure to haze and to recommend preventive strategies for vulnerable populations during haze events.

2.1.2 Assessment of Deaths from Landslides Related to a Tropical Storm in Chuuk State, Federated States of Micronesia.

On July 2, 2002, the State of Chuuk received 19.74 inches of rain from tropical storm Chata'an The excessive rain was an important factor in the initiation of more than 60 landslides, 12 of which caused 43 deaths, hundreds of injuries, and an estimated 1,000 displaced residents (population 47,000) (Sanchez, 2003).

Conventional analytic methods determined that people who were unaware of the hazards of landslides, those who were inside a structure at the time of a landslide and children were at greatest risk of dying during the slides. Viable risk-reduction strategies were proposed on the basis of these findings. However, greater knowledge of the storm's character and of land topography with respect to slopes and soil integrity might have offered additional insight into deaths and injuries in this event.

For example, 3-D Precipitation Radar maps provided by the Tropical Rainfall Measuring Mission (TRMM) might have provided information on the intensity and distribution of rain on the islands. Vegetation cover and soil moisture content (e.g., observed using the VEGETATION Monitoring Instrument [VGT 1 & 2][2]) might have provided clues as to the cause of the landslides and helped predict areas where future slides were likely. Three-dimensional digital maps of the Earth's surface generated from elevation data obtained by the Shuttle Radar Topography Mission (SRTM) and enhanced with Landsat satellite images also could have been used to create elevation models for use in predicting susceptible locations.

Assessing patterns in mortality from landslides relative to rainfall, vegetation cover, and elevation (e.g., slope) can be used to identify hazards and human vulnerabilities, explain human survivability, and assist in designing warning systems to prevent or reduce mortality in future landslides. For example, these links could aid in identifying shelter locations suitable during both tropical cyclones and cyclone-induced landslides.

2.2 Geographic Information Systems

The U.S. Geological Survey (USGS) has describes a GIS as "a computer system capable of storing, manipulating, and displaying geographically referenced information (i.e., data identified according to their locations) from the real world for a particular set of purposes" (USGS, 2004). In a disaster setting, GIS is an extremely useful tool by which geographic information about infrastructure, population distribution, and climatic conditions can be collected, stored, and analyzed. GIS also provides a tool for linking epidemiologic and earth observations data.

3.0 TECHNOLOGY FOR ANALYZING AND TRANSFERRING INFORMATION

3.1 Geographic Information Systems

Innovations in GIS technology are accepted tools for the presentation of hazard vulnerabilities and risks. Although mapping the location of people and characteristics of their environment, how they change, and their relative proximity to each other will suffice for some applications, disaster epidemiology requires additional analysis capabilities.

Bailey and Gatrell (1995) distinguish between *spatial analysis*, the study of spatial phenomena using the basic GIS operations such as spatial query and join, buffering, and layering, and *spatial* <u>*data*</u> *analysis*, the application of statistical theory and techniques to the description and modeling of spatially referenced data, which is the discipline of spatial statistics. Disaster epidemiology will benefit most greatly from efforts to refine spatial statistics methods (e.g., estimation, prediction, and hypothesis testing). Combining spatial statistics within a GIS will provide more sophisticated methods for spatial modeling and analysis requiring inferential spatial statistics (Krivoruchko and Gotway, 2002).

[2] VGT 1 & 2 are part of the SPOT4 and SPOT5 (Satellite Probatoire d'Observation de la Terre) missions.

3.1.1 GIS Spatial Analysis of Deaths Related to Hurricane Andrew

On August 24, 1992, Hurricane Andrew, a Category 4 storm, struck south Dade County, Florida, with maximum sustained wind speeds of 145 mph (NOAA, 1992). Fourteen hurricane-related deaths were identified by the Dade County Medical Examiner's Office (CDC, 1992). GIS was used to spatially link the 14 deaths directly related to the hurricane with the location of designated evacuation zones and with structural damage assessment data to identify potential risk factors for death and injury (Malilay, 1993). Most deaths occurred in designated storm-surge evacuation zones (71%) or in areas where structural damage caused by wind was rated at "medium" to "completely destroyed" (57%). Almost all deaths occurred in wind-damaged, rather than storm-surge damaged, structures; and 29% of deaths occurred inland from any designated evacuation zone. Spatial analysis using GIS raised an important area of study—whether evacuation zones based solely on a storm surge inundation model adequately protect the public.

3.1.2 GIS Spatial Data Analysis of Disaster-related Deaths

Since 1986, the American Red Cross (ARC) and the Centers for Disease Control and Prevention (CDC) have collaborated to provide timely and comprehensive information about disaster-related deaths. The Health Impact Surveillance System for Disasters (HISSD) collects information about morbidity and mortality resulting from presidentially declared natural disasters and other disasters requiring a national ARC response.

Geocoded locations of the deaths and injuries reported to this system could be used to create relative risk maps (e.g., Kernel density estimation = density of cases/ [density of cases + density of controls]). Identification of locations where case intensity significantly exceeds control intensity (high local relative risk) could be used to identify areas where populations are at risk from disasters. This information may in turn assist development of effective mitigation plans and subsequently decrease disaster-related morbidity and mortality.

3.2 Information Exchange and In-Field Computing and Processing

Information capture and exchange is crucial in conducting epidemiologic field investigations. Software applications and hardware that make technology available in the field can improve the efficiency of current epidemiologic methods. Handheld devices (e.g., PDAs, tablet PCs) could be used for building questionnaires and collecting survey information after a disaster. Interfacing these systems with barcode scanners and global positioning system (GPS) hardware and software would further enhance their utility. For example, bar code number scanners could be used to label and track biologic or environmental samples collected in the field, and GPS could provide instant geographic references for use in mapping and assessment of spatial patterns.

Ideally, these tools also would provide access to a repository of spatial databases including maps, geographic features, population census data, and locations of hospitals and schools that would be geocoded and ready for access. For example, survey teams have used paper copies of census block maps or handmade maps of areas where maps were not available in field assessment. Access to electronic maps or the ability to create them through adding points, lines, and redline markups onto a PDA screen while in the field would increase efficiency in the field. Finally, the addition of wireless communications (wireless Ethernet, Blue tooth, cellular telephone networks) would facilitate rapid transmission of information from the field to a base station for mapping, analysis, and tracking.

4.0 TECHNOLOGY TO ENHANCE PUBLIC HEALTH POST-DISASTER ASSESSMENT METHODS

Disaster epidemiology uses a variety of methods to identify risk factors that predispose individuals or populations to death, injury, or illness during the pre-impact, impact, and post-impact phases of a disaster. Two of the most important post-disaster epidemiologic methods used to conduct field investigations are community-based rapid needs assessments (RNAs) and surveillance.

4.1 Rapid Needs Assessments

RNA refers to a set of tools—epidemiologic, statistical, and anthropologic—designed to provide, quickly and at low cost, accurate and reliable population-based information about an affected community's needs after a disaster in a simple format to decision makers (WHO, 1999). The primary objective is to obtain information about the needs of an affected community as these needs change in the aftermath of a disaster event. This technique has been applied to numerous hurricane and earthquake events. The objectives are to (1) describe the impact of the event on the health status of affected communities; (2) characterize the demographics of affected communities; (3) determine the critical needs (i.e., food, water, shelter, electricity) of affected communities; (4) prevent or reduce adverse effects on health; and (5) evaluate the effectiveness of relief programs.

Information initially collected during RNAs should focus on the geographic areas most severely affected (WHO, 1999). However, to complete an assessment as quickly as possible and relay critical information to decision makers in a timely manner, scientists may have to wait for aerial flyovers or phoned-in reports. Alternatively, the most affected areas may be located using only information immediately available after a disaster. As a result, assessments may be delayed or the areas identified as the most affected for the purposes of the rapid assessment may not in fact be the worst (WHO, 1999). Remote sensing and high-resolution imagery technologies can ameliorate these issues by providing real-time data that can precisely identify affected areas. Some technologies may even be able to predict areas likely to have severe damage.

A RNA was conducted after Hurricane Isabel. On Thursday, September 18, 2003, Hurricane Isabel made landfall near Drum Inlet, between Cape Lookout and Ocracoke Island, North Carolina. The high winds and storm surges, combined with the broad scope of the storm, caused at least 40 deaths; resulted in over a billion dollars damage; and led to a presidential disaster declaration covering 36 North Carolina counties (FEMA, 2003). Immediately after the hurricane made landfall, meteorologic maps were reviewed to examine the path of the hurricane and landfall characteristics to project an area of likely heavy impact. A three-county area in the direct path of the eye was chosen as the assessment site. However, 48 hours after landfall, damage assessments from local health directors, field evaluations, and power company reports identified a 14-county area north of the initial assessment area as the most heavily damaged region. As a result, a second assessment was conducted in this 14-county area.

Information like that provided by the H*Wind Project might have might have estimated the extent and strength of the wind field and helped to more accurately predict areas likely to receive heavy wind damage. The H*Wind Project was developed by the Hurricane Research Division at National Oceanic and Atmospheric Administration (NOAA) to integrate hurricane wind data from a variety of platforms (AOML, 2004). Early notification by this system would have allowed survey teams to deploy to the field more rapidly. As a result, information would have been collected and relayed to decision makers more rapidly and effective responses implemented more quickly.

4.2 Surveillance

Surveillance is the systematic collection, analysis, and interpretation of deaths, injuries, and illnesses to provide information about adverse health effects related to a disaster event in a community (Tsui, 2003).

Technology aided surveillance efforts after the Northridge Earthquake in 1994 when an outbreak of coccidioidomycosis was identified in Ventura County, California (Schneider, 1997). Coccidioidomycosis is an infection caused by inhalation of fungus spores that grow in the topsoil in limited semiarid areas of the Western Hemisphere. Earthquakes or landslides can dislodge soil and create dust clouds that contain airborne spores.

Public health officials attempted to determine the extent of coccidioidomycosis infections in the months after the quake. Active surveillance methods (e.g., obtaining physician reports to the health departments, searching hospital infection control and medical records, collecting serologic test results from laboratories that routinely receive specimens from Ventura County) were used to identify cases. USGS personnel used high-altitude photography to aid these efforts. Their determination of the exact locations and intensities of main shock and larger aftershocks, as well as the location and size of an estimated 11,000 landslides focused surveillance efforts on specific geographic locations that were likely to be exposed to airborne spores.

5.0 CONCLUSION

Effective public health action within the context of disaster epidemiology relies upon collection of accurate and timely data, precise analysis and interpretation of these data, and effective dissemination to decision makers. Earth observations data and engineering information systems such as those described here can enhance each step in this process. Thus they should be included in any long-term strategy to improve response to wind and seismic disasters.

A further discussion of the technology will be necessary to determine their utility relative to their limitations (e.g., impact of cloud cover, repeat frequency for imaging the same area on the ground, field readiness and durability, and image resolution [the amount of detail in an image]).

6.0 INTERNET ADDRESSES FOR DESCRIBED EARTH OBSERVATION SOURCES

Aqua and Terra MODIS (Moderate Resolution Imaging Spectroradiometer):
http://modis.gsfc.nasa.gov

H*Wind Project
http://www.aoml.noaa.gov/hrd/Storm_pages/background.html

Landsat
http://landsat.gsfc.nasa.gov

SPOT (Satellite Probatoire d'Observation de la Terre) VGT 1 & 2 (VEGETATION Monitoring Instrument):
http://www.spotimage.com
SRTM (Shuttle Radar Topography Mission):
http://www2.jpl.nasa.gov/srtm

TRMM (Tropical Rainfall Measuring Mission):
http://trmm.gsfc.nasa.gov

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