The Application of Geographic Information Systems and Global Positioning Systems in Humanitarian Emergencies: Lessons Learned, Programme Implications and Future Research

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Geographic information systems (GIS), global positioning systems and remote sensing have been increasingly used in public health settings since the 1990s, but application of these methods in humanitarian emergencies has been less documented. Recent areas of application of GIS methods in humanitarian emergencies include hazard, vulnerability, and risk assessments; rapid assessment and survey methods; disease distribution and outbreak investigations; planning and implementation of health information systems; data and programme integration; and programme monitoring and evaluation. The main use of GIS in these areas is to provide maps for decision-making and advocacy, which allow overlaying types of information that may not normally be linked. GIS is also used to improve data collection in the field (for example, for rapid health assessments or mortality surveys). Development of GIS methods requires further research. Although GIS methods may save resources and reduce error, initial investment in equipment and capacity building may be substantial. Especially in humanitarian emergencies, equipment and methodologies must be practical and appropriate for field use. Add-on software to process GIS data needs to be developed and modified. As equipment becomes more user-friendly and costs decrease, GIS will become more of a routine tool for humanitarian aid organisations in humanitarian emergencies, and new and innovative uses will evolve.

Keywords: geographic information, global positioning systems, remote sensing, satellite imagery, humanitarian emergencies.

Introduction

The last decades have seen the introduction of geographic information systems (GIS) in diverse public health settings. GIS methods include global positioning systems (GPS) and remote sensing. Long used as planning and data collection tools by military and civilian institutions, these technologies are now widely applied to epidemiology and public health in developed countries and, to a lesser extent, in underdeveloped countries. Most international health applications of GIS methods have been in
outbreak investigations and epidemiologic studies of infectious diseases. These uses have been well documented in the literature and are gaining acceptance as valuable epidemiologic tools (Vine et al., 1997; Moore and Carpenter, 1999; Robinson, 2000).

Applications of GIS methods in humanitarian emergencies (HE) are less well documented. Use of GIS methods for resource allocation, planning and logistics has become a standard component in major HE (in Kosovo, Sierra Leone and Afghanistan). Recent work by the International Emergency and Refugee Health Branch (IERHB) at the Division of Emergency and Environmental Health Services, Centers for Disease Control and Prevention (CDC), and by other organisations have used GIS methods in diverse ways to complement and enhance epidemiologic methods in HE, such as conducting rapid health assessments or estimating mortality.

In this report, we document current uses of GIS methods in HE, and discuss lessons learned, programme implications and future research needs.

Background

The most famous example linking the science of epidemiology with the use of geographic information occurred almost 150 years ago, when John Snow investigated London’s cholera outbreak in 1854 (Snow, 1855). Today, GIS and satellite data are used to examine the relation between cholera epidemics and the changing patterns of warm-water ocean currents (Colwell, 1996). A Medline search in January 2003 showed the first public health article using GIS published in 1986, coinciding with the time GIS became available on personal computers; 94 per cent of the 255 articles in the search were published in 1995 and later.

GIS and GPS are powerful computerised tools to examine the spatial location component of epidemiology and link it with person and time information. GIS has been defined as a computer system that stores and links non-geographic attributes or geographically referenced data with graphic map features to allow for a wide range of information processing and display operations, as well as map production, analysis and modelling (Tim, 1995). GPS is a constellation of earth-orbiting US-government satellites that transmit information to hand-held or built-in receivers that can calculate a location with a potential precision of one square metre (longitude, latitude and elevation) (CDC, 1993). Remote sensing or satellite imagery refers to the data obtained by sensors on earth-orbiting satellites. Remote sensing data can be used in GIS to show animal and vector habitats; surface areas of water, deserts and forests; and human activity (settlements, roads, land usage) (CDC, 1993).

These technologies are now widely used in the developed world for epidemiology and public health (Vine et al., 1997; Moore and Carpenter, 1999; Robinson, 2000). Functions of GIS encompass mapping of the location and distribution of disease in either endemic settings or outbreak investigations (Wartenberg, 2001). GIS has added new ways of presenting information collected with traditional epidemiologic methods. Simple thematic maps can be used for decision-making and advocacy. GIS allows overlaying of maps to link information from various diseases or health sectors that may not usually be linked and can help with interpretation of data. A potential example is overlaying of information on food distribution, acute malnutrition, micronutrient deficiencies and a measles outbreak. GIS maps and satellite imagery have advantages over conventional maps because more information can be updated frequently and distributed rapidly through electronic
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devices including the Internet (Foresman, 1999). Data collection (for example, during rapid assessments or surveys) can be faster, more accurate and may require fewer resources once equipment has been purchased (Melnick and Fleming, 1999). GIS methods may increase accuracy (through improving random sample selection) and precision (time-saving methods may allow increasing sample size) (Roper and Mays, 1999). Other applications of GIS may not only improve data presentation, but enhance epidemiologic methods; those include time series modelling (diffusion of disease, changes in vector habitat, seasonality of cyclical patterns in incidence) and spatial correlation to examine risk factors for disease, accessibility modelling for health service planning (O’Dwyer and Burton, 1998).

GIS methods in international health have been used in the research, outbreak investigation and control of vector-borne diseases (Kitron, 1994; Dale et al., 1997) with the main focus on malaria (Hay et al., 2000), as well as tuberculosis (Porter, 1999; Tanser and Wilkinson, 1999), helminthic infections, including schistosomiasis (Brooker and Michael, 2000; Brooker et al., 2000), leptospirosis (Barcellos and Sabroza, 2001), gonorrhrea (Becker et al., 1998) and hepatitis C (Mujeeb et al., 2000). Other applications in international settings included prevention of diarrhoeal disease (Njemanze et al., 1999), access to primary health-care (Perry and Gesler, 2000), mapping of population movements for public health management (Stern, 1998) and health inequalities research (Szwarzwald et al., 2000; Mitchell et al., 2002). GIS mapping and remotely sensed data also are being used to assess and model catastrophic events such as earthquakes, toxic runoff, and toxic plumes (Croner et al., 1996). For example, GIS mapping of earthquake-related deaths and hospital admissions from the 1994 earthquake in Northridge, California, showed that factors such as age and activity of people during the earthquake may be as important as seismic features in predicting injury from earthquakes (Peek-Asa et al., 2000).

Spatial statistics for public health application is now a rapidly evolving field. Methods include calculation of crude, adjusted and smoothed rates; tests for spatial randomness; and regression analysis to examine associations between geographic distribution of exposure and disease (Kulldorff, 1999). Statistical models may include distance-oriented measures (for example, distance to the nearest clinic or water source) or geospatial smoothing techniques similar to those used in time-series modelling. An example is inverse density-weighted smoothing, where more weight is given to closer samples and less to those that are farther away, resulting in reduced variability of estimates (Isaaks and Srivastava, 1989). Statistical techniques also are available to analyse spatio-temporal data (Kulldorff, 1999) (for example, to examine distribution of vector habitats and malaria over time (Dale et al., 1997)).

Uses of GIS in humanitarian emergencies

We define a humanitarian emergency as a situation affecting large civilian populations and usually involving a combination of conflict, food insecurities and population displacement resulting in significant excess mortality or morbidity. We have identified different uses of GIS that support and enhance epidemiologic methods in humanitarian emergencies. Hazard, vulnerability and risk assessments are used as early warning systems to prevent or mitigate emergencies resulting from famine. GIS can be a component of rapid assessments to identify the magnitude of and resources needed for an emergency. GIS methods can also be used in site planning and to enhance survey
methods, investigate disease outbreaks, establish health information systems, integrate data and programmes and monitor and evaluate programmes. Both rapid assessment and survey methods may use households as sampling units and be similar in outcomes studied as well as GIS methods used.

The initial equipment and capacity building to use GPS/GIS technology in emergency humanitarian activities can range from using the available computer and printer, obtaining shareware from the internet and reallocating personnel to collect data as the need arises, to acquiring state-of-the-art computers, printers and GIS instruments, purchasing the most recent versions of sophisticated GIS software, obtaining training to use these resources and having dedicated personnel to run the system and collect data. Equipment, capacity building and personnel (assuming one full salary) may currently cost up to US$100,000. At the low end, a user with some knowledge of surveying and navigation could use a basic computer, a GIS instrument that obtains latitude and longitude of features and GIS shareware software for less than $2,000. Through our experience in working in HE, most organisations have a computer with sufficient power to run GIS software that allows entry of latitude and longitude of features and draws and prints maps, but may not have a GPS unit. However, GIS/GPS have become more common over the years and the hardware and software prices have dropped. It is hoped that more organisations will purchase and use this equipment and software. We are currently developing shareware software that will enable people to use GIS/GPS to enumerate the HE-affected population and, at a later stage of software development, conduct rapid assessments of vaccine coverage, malnutrition, health conditions and sanitation.

Use of GIS in HE encompasses work under extreme field conditions. Our experience with several different types of GPS instruments is that they worked with minimal performance loss under high temperatures (above 40°C for several hours), through sandstorms and torrential rain, and after being dropped or bounced around in cars and in backpacks. Data were not lost during these conditions or even when the batteries expired.

GIS has now become essential to the planning for, response to, and monitoring of HE for many organisations active in HE. Many United Nations (UN) organisations have specific GIS units: the WHO Health Map unit (WHO, 2002), the UN High Commissioner for Refugees’ (UNHCR) geographic information and mapping unit (UNHCR, 2002) and the World Food Program’s vulnerability assessment mapping unit (WFP, 2002). The UN Office for the Coordination of Humanitarian Affairs (OCHA) also provides mapping services in conflict areas (OCHA, 2002a). Recent information systems in emergencies have been designed as inter-agency projects using GIS such as the Sierra Leone Information System (UNHCR/OCHA, 2002), the Afghanistan Information Management Service (AIMS) (UNAMA, 2002) and the Humanitarian Information Centers (HIC) established by OCHA in several countries surrounding Iraq (OCHA, 2003). Donor organisations are increasingly adding GIS capacity to their programmes. In the US, both the State Department and the US Agency for International Development (USAID) have added GIS capacity to their HE programmes (one example is in Guinea (USAID, 2003)) and are increasingly providing funds to build such capacity in NGOs and other implementing partners. Similar initiatives are taking place in Europe (for example, European Commission Humanitarian Aid Office (ECHO, 2003), UK Department for International Development (DFID, 2003), Swedish International Development Cooperation Agency (SIDA, 2003)) and other donor organisations active in HE. As the importance of GIS increasingly becomes
recognised, the way it is used in HE will quickly evolve. Below are documented the
following current uses of GIS in HE.

**Hazard, vulnerability and risk assessments**

Hazard assessment has been used on a continental scale in Africa to identify and
predict drought through the analysis of long-term trend in vegetation patterns and its
relation with the El Niño/Southern Oscillation (ENSO) weather pattern (Eastman et al.,
1997). GIS has also been a component of vulnerability assessments in many different
African countries such as the recent severe famine in southern Africa. Food security
mapping examines the degree to which a population or region is susceptible to a range
of hazards that threaten food supplies or for which food assistance is required. For
example, major parts of Africa are affected by a severe food crisis that was estimated in
December 2002 to affect 38 million people (WFP, 2002). The crisis is aggravated by
the HIV/AIDS epidemic that has a direct impact on food security and nutrition for
individuals, households and communities (OCHA, 2002b). Vulnerability mapping and
GIS risk assessment methods have been used to design and develop an integrated
computer system for famine early warning (Marsh et al., 1994). USAID is funding a
famine early warning system that is based mainly on two types of satellite imagery:
normalised difference vegetation index and meteorological satellite rainfall estimation
(FEWS, 2003). The normalised difference vegetation index provides an indication of
changes in vegetation in response to biophysical conditions, including plant type,
weather and soil, whose main use is to compare the current state of vegetation with
previous time periods to detect anomalous conditions (for example, the same time in an
average year or a reference year). Meteorological satellite rainfall estimation imagery
uses satellite data; global telecommunication systems (GTS) gauge rain reports; model
analyses of wind, topography and relative humidity; and an algorithm that takes into
account geography and seasonality. The result is a spatial estimate of rainfall. The
main use of these images is to compare the current state of rainfall with previous time
periods to detect anomalous conditions (FEWS, 2003). These tools assist decision-
makers to determine food security and predict how many people will need food aid to
prevent or mitigate famine emergencies.

Risk assessment makes predictions on the morbidity or mortality by
examining the interaction between a hazard and the vulnerability of a population. For
example, the number of people at risk for malnutrition and malnutrition-related death
expected from the estimated distribution of drought severity factors and individual
factors of vulnerability (for example, socio-economic factors, loss of food access) was
mapped during the Ethiopian famine in 1984 (Eastman et al., 1997). This project could
have benefited from GIS-based mapping techniques (for an example of GIS use in the
current context of Ethiopian drought and food insecurity see also section on ‘Data and
programme integration’).

**Rapid assessments**

In the acute phase of HE, rapid assessments help to determine the magnitude and
severity of the situation, the amount of resources needed, as well as the need and
feasibility of an intervention (MSF, 1997). GIS methods can be used to map an area
for site planning, including information about environmental conditions; transport
routes; habitable land; and availability of water, food and fuel. Additional information, such as distance from the household to nearest health clinic, food distribution site, drinking-water source or latrines, can be used to assess access of the population to essential services. Decision-makers can use this information for planning and resource allocation (such as water and food distribution sites and latrines) as well as for determining whether certain minimum standards and indicators are being met. Remote sensing maps can also be used to help identify water and fuel sources.

In the acute phase of HE, population size estimates are necessary to determine the scope of the emergency and the resources needed and to provide reasonably accurate population denominators for health indicators. In this early stage, systematic random sampling of housing units is usually not feasible. A method called the quadrant has been used in several refugee camps (Henderson and Spiegel, 1999; Brown et al., 2001). It consists of mapping the boundary of the camp, laying a grid of square blocks or quadrants over the camp, randomly selecting square blocks, counting the population in all households (Brown et al., 2001) or a random subsample of households in each randomly selected block (Henderson and Spiegel, 1999). The number of people estimated per square block can then be extrapolated to the total population. GIS and GPS can be used for mapping the area, creating the grid, and locating the selected square blocks. Modern GIS software allows obtaining accurate geographic coordinates of key roads, trails, landmarks, plots and non-residential areas to create a map that includes inhabited space with precise outer limits of the area. However, population estimation methods have not been standardised, and only a few examples have been validated using camp registration data (Henderson and Spiegel, 1999; Brown et al., 2001). Future research questions include the optimal number and size of square blocks, addressing heterogeneity in population density between the square blocks, and methods to deal with partial square blocks at the limits of the camp area. An alternative approach to estimate population size may be distance-based methods such as the T-square method (Espie, 2000), which has not yet been used, in HE. During population estimations, a simple questionnaire can be added for a rapid assessment of the health status of the population (for example, morbidity, mortality, nutrition or vaccination status).

Mapping population movements is becoming a standard application of GIS in the acute phase of HE as well as during repatriation and resettlement. Spontaneous population movements may require reassessment of the situation in any phase of an HE. Before population transfers are planned, GIS mapping can help ensure that a secure location is chosen, sufficient water and sanitation facilities exist or can be developed and adequate human and material resources and programmes are in place. For example, in Guinea 2001 an increase in death rates among Sierra Leonean and Liberian refugees was documented after most of them were relocated to new camps, possibly because some refugees were not relocated to individual family shelters as quickly as planned, causing overcrowding of temporary shelters and overburdening of existing facilities (CDC, 2001; UNHCR, 2001).

Remote sensing maps and aerial views can also provide rapid information to estimate population sizes and movements in HE. This may be particularly relevant in areas that are not covered by humanitarian agencies — for example, because insecurity does not allow access. In 1994 in Goma, Democratic Republic of Congo, the population size was underestimated when aerial views alone were used, most likely because displaced people without shelter were not included (NAS, 1997). Modern high-resolution remote sensing using thermal imaging can provide additional information that may improve population estimation (for example, fires for cooking
and heating). Geographic and environmental conditions such as dense tree cover, smoke plumes and topographic features in the area may limit the use of GPS and satellite imagery. Figures 1 and 2 show a satellite image and the corresponding map of the refugee camps and environmental conditions in the Goma area in 1994.

**Survey methods**

Two sampling methods have applied GIS and GPS to survey mortality in the Democratic Republic of Congo (IRC, 2000). The first method, a modification of the Expanded Programme on Immunisations (EPI) methodology (Henderson and

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**Figure 1** Spot satellite image and corresponding map (see Figure 2) of the refugee camps and environmental conditions in the Goma area bordering Virunga National Park, Democratic Republic of Congo, 1995

Figure 2 The corresponding map (see Figure 1) of the refugee camps and environmental conditions in the Goma area

Sundaresan, 1982) requires that the approximate population size and location of sub-areas (villages or clinic referral areas) or clusters are known. In the first stage, clusters are selected proportional to population size. In the second stage, boundaries of clusters are mapped and a grid of square blocks is laid over the map, random numbers are assigned to square blocks, and a square block is randomly selected as the location where all selected or a sample of households are surveyed. GIS and GPS are used for mapping and to locate the randomly selected square blocks (IRC, 2000). Main questions for future research are the number of clusters (a minimum of 30 clusters has been recommended (Binkin et al., 1995)), the size of the grids and heterogeneity in the outcome of interest between clusters. Design effect and intraclass correlation indicate heterogeneity that can be anticipated on the basis of the nature of the outcome (for example, conflict-related mortality may vary considerably between villages because of the intensity of military activities and destruction) and experiences from previous surveys (Katz and Zeger, 1994). Studies are needed comparing this method with the standard EPI method in terms of quality of the outcome estimate, cost and degree of difficulty.

The second method is applied when the overall population can be estimated but population sizes of sub-areas are not known. A random starting location is chosen for sampling along a north-south road. Additional sampling locations are selected at predefined increments to the east and the west, called east-west transects. The process of sampling along east-west transects is repeated at predefined intervals to the north
and south until the whole survey area is covered. This method oversamples rural areas and undersamples areas with high population density. The radius of each sampling point, defined as the distance between the first and the farthest household of the sampling location, can be used as a weight to adjust for this sampling bias (Roberts and Despines, 1999). GPS are used to locate sampling locations and to measure the radius of the sampling point. Main questions for future research are the number of sampling locations (which also can be called systematic random clusters), and addressing heterogeneity in population density between sampling locations. The distance between sampling locations depends on the size of the survey area and the number of sampling locations. The number of households per sampling location depends on the sample size, the number of sampling locations and the average number of household members eligible for the survey. Validation of this methodology is warranted using standard methods.

GIS and palm-pilot-like devices with a GPS unit allow questionnaires to be read and answers recorded electronically, reducing the use of paper. Data can be transferred directly to a computer for analysis. This represents significant time savings and reduces one potential source of error when data are transferred from paper to computer (Roper and Mays, 1999; Selanikio et al., 2002). Furthermore, while doing the survey, key landmarks, such as latrines, water points and health clinics, can be recorded, mapped and used in conjunction with data recorded from households to aid in interpretation.

**Disease distribution/outbreak investigation**

GIS improves our ability to investigate infectious disease outbreaks in HE. Clustering can give first hints toward causality within neighbourhoods or according to geographic features. On a larger scale, case distribution maps can help to direct vaccination campaigns.

**Health Information Systems**

After a multinational UN force had restored peace in East Timor in 1999, UNHCR asked CDC to implement a health information system in camps for East Timorese refugees in West Timor. Fourteen sentinel sites in four districts were selected for mortality surveillance by size, location and accessibility. The selected sites represented approximately 50,000 (36 per cent) of the 140,000 refugees. The UNHCR geographic information and mapping unit provided maps of the refugee camps in West Timor for the selection process. These maps can be further used to show local or regional trends in mortality over time and relate them to environmental conditions or disease outbreaks (Friedman and Spiegel, 2000).

**Data and programme integration**

CDC collected information about nutrition surveys among children under five years of age conducted by various NGOs from September 1999 through June 2000 during the Ethiopian famine. The surveys provided overlaying maps showing where nutrition and health organisations had operated, food had been distributed and acute malnutrition
surveys had been conducted. The maps allowed decision-makers to modify programmes and resource allocation by directing organisations and food delivery to areas of greatest need, and conducting additional surveys where information was lacking (Spiegel et al., 2000).

Monitoring and evaluation

GIS maps can be used to monitor and evaluate aid programmes in HE. Maps of refugee populations in a camp, water distribution sites and latrines indicate whether or not minimum standards in water supply and sanitation have been achieved (Sphere, 2000). Trends in malnutrition rates and locations of surveys, aid activities and food distributions can show whether resources are adequately allocated or programmes need adjustment according to changing needs of emergency-affected populations.

Lessons learned and future research

The documented uses of GIS in HE have a variety of programme implications. Many of the documented applications need further methods development. To use GIS methods effectively in HE, potential disadvantages and unanswered questions also have to be addressed in future research. First, GIS/GPS equipment and software can be expensive and require specific skills and training (Melnick and Fleming, 1999). Limitations for developing countries or small organisations may be the costly nature of resources required to generate useful GIS data. Hiring a GIS consultant may allow for the costs associated with purchasing software and training an individual to perform GIS work to be bypassed. Cost-effectiveness and time-saving studies are needed to evaluate the use of GIS methods in HE. GIS users need to be trained in epidemiology to understand that GIS is an enhancement rather than an alternative to traditional epidemiologic methods (Vine et al., 1997). Users should be aware that data in HE may be insufficient or inadequate. One of the main potential limitations of GIS is that of ‘masking’ the underlying problems of data with a cosmetic technology: everything looks neat and tidy, while it is often not. In contrast to tables and graphs, maps do not allow for cross-checking. Therefore, training must include appropriate presentation and interpretation of data to make them comprehensible by decision-makers (Melnick and Fleming, 1999) and to prevent over-emphasising or obscuring evidence (Scholten and de Lepper, 1991). To examine causal relations between exposure and disease, multivariate models are required that control for potential confounders and effect modifiers (Melnick and Fleming, 1999). Maps based on those models can show the predicted geographic variation of disease risk (Clarke et al., 1996). Second, equipment and methodologies have to be practical, durable and appropriate for field use. GIS methods for rapid assessments and surveys need further study, and add-on software needs to be developed and modified to make this method easier to implement. Finally, although geo-coded datasets and satellite imagery become increasingly available in the public domain or commercially (Clarke et al., 1996), most GIS data in HE will still require persons in the field to collect data and interpret it according to the circumstances on the ground.
**Conclusions**

GIS methods provide improved ways of presenting traditional epidemiologic data as well as new spatio-temporal information that has a variety of implications for programmatic decision-making, monitoring and evaluation in HE. Main limitations and future research needs are related to equipment and training development including the appropriate presentation and interpretation of information. Future use of GIS in HE will increase and become essential. As equipment becomes more user-friendly and costs decrease, more and more humanitarian aid organisations will incorporate it into their basic tools for programming, as well as monitoring and evaluation. New and innovative uses for GIS in HE will also evolve.

**Acknowledgements**

We thank Dabo Brantly, Renata Caldwell, Carol Crawford, Thomas Handzel, Allan Hightower, Mary Kay Larson and Sam Posner, all from CDC, for fruitful discussions and inspirations that helped us in writing the paper. We also thank the WHO health map unit and the UNHCR geographic information and mapping unit for providing GIS maps. We also thank the UNHCR geographic information and mapping unit for providing the satellite image and GIS map.

**References**


—— (2003) UN Office for the Coordination of Humanitarian Affairs. Available at: http://www.reliefweb.int/ocha.ol/


SIDA (2003) Available at http://www.sida.se


—— (2002) Geographic Information and Mapping Unit (GIMU). Available at: http://www.unhcr.ch/cgi-


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