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FOCUS on Field Epidemiology

Mapping for Surveillance and Outbreak Investigation

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The epidemiology toolbox is diverse and wonderful. The statistical methods alone are mind-boggling: you can get numbers to quantify associations from here to kingdom come. After all, who doesn't love to sit down at a tidy desk with a stack of analytic output to decipher? But what if a picture could tell you the same information as those lines and lines of numbers?

For those of us who are more visually oriented, maps are commonly used in epidemiology to present complicated information succinctly and clearly. Sometimes a picture can truly be worth a thousand words!

This issue of FOCUS discusses how maps can be used in field epidemiology practice, particularly in surveillance activities and outbreak investigations. We also discuss commonly used computer software programs that can capture and analyze data and integrate them into a spatial display.

Maps

The earliest documented epidemiologic study relied on mapping. In his investigation of a cholera outbreak in London in 1854, Dr. John Snow used both maps (Figure 1) and statistical data to trace the source of the outbreak to a public water pump on Broad Street and show that the well had been contaminated by sewage from a nearby cesspit.

Figure 1. John Snow's now-famous map of clusters of cholera cases in London, England, in 1854

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Infectious disease surveillance and outbreak investigation using GIS (2004)
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Perhaps the most noted example of the use of maps to convey complicated statistical information comes from outside the field of public health. In documenting Napoleon's attempt to conquer Russia in 1812 and 1813, French civil engineer Charles Joseph Minard created a map in 1869 (Figure 2) that elegantly conveys the devastating effects of winter weather on the French army as it retreated across Europe. (1)

The map displays multivariate data (army size, direction, geographic location, temperature, and time). The line widths show the size of the French army on its advance to Moscow (tan) and its retreat (black), while the chart below the lines plots temperature.

A more recent example (Figure 3) shows a map created during participatory disease surveillance and response activities around avian influenza in rural Indonesia in

Figure 2. Losses of the French Army in the Russian Campaign 1812-1813 by Charles Joseph Minard, 1869 (1)

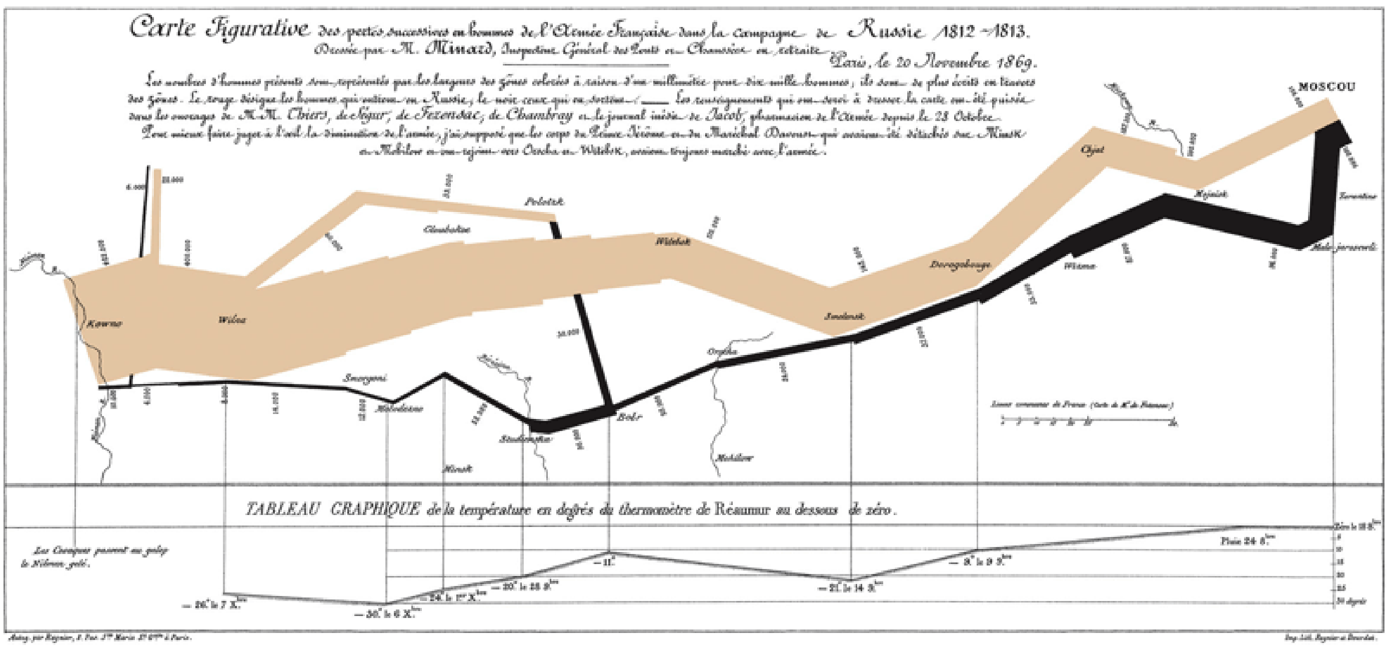


Figure 3. Map documenting investigation of an avian influenza outbreak in poultry in a rural village in Indonesia, 2005 (2)

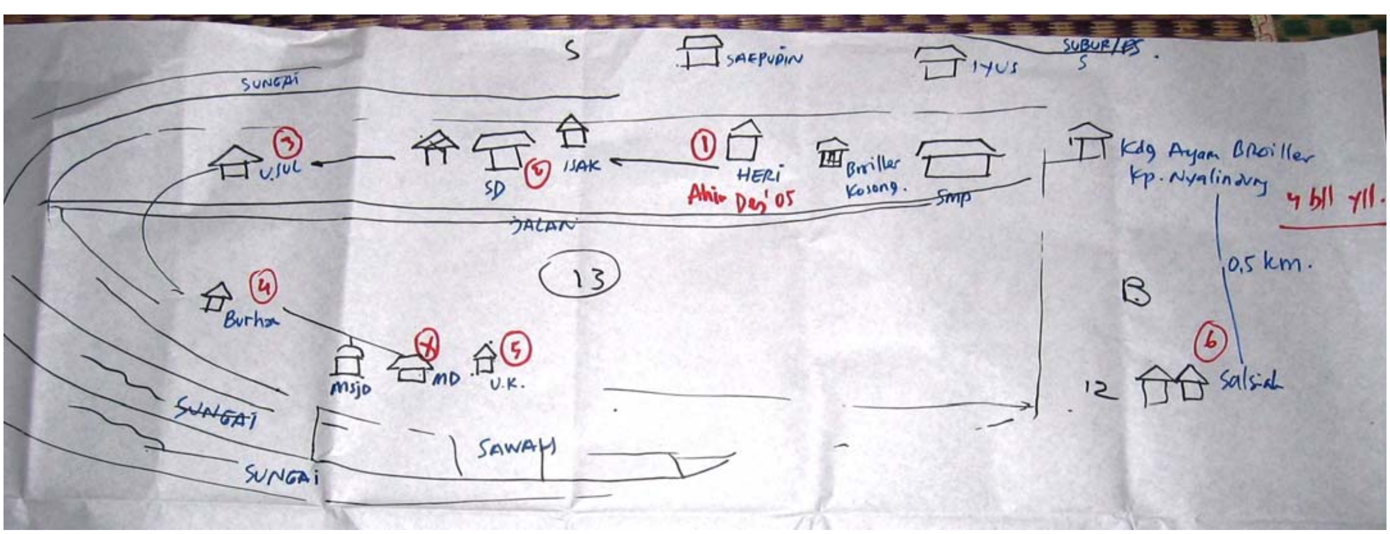


Photo credit: Dr Gavin Macgregor-Skinner/USAID

2005. The map was created using a technique called participatory mapping and shows the sequence of events during an outbreak of highly pathogenic H5N1 avian influenza in poultry in a small village.

The disease initially spread through the village from House 1 to House 5; it also appeared in a second village of 12 households located nearby (designated as 6 on the map) and at a local commercial broiler farm (top right corner). Subsequent investigation revealed that residents of House 1 and households in the second village worked at the broiler farm and had probably introduced the H5N1 virus into their communities by carrying it home on their shoes and clothing. (2)

Geographic Information Systems

In addition to hand-drawn maps, epidemiologists can also take advantage of sophisticated computer software programs to display and analyze spatial data. A geographic information system (GIS) is a computer program designed to store, manipulate, analyze, and display data in a geographic context. GIS capabilities are ideal for use in infectious disease surveillance and control, and in outbreak investigation and response.

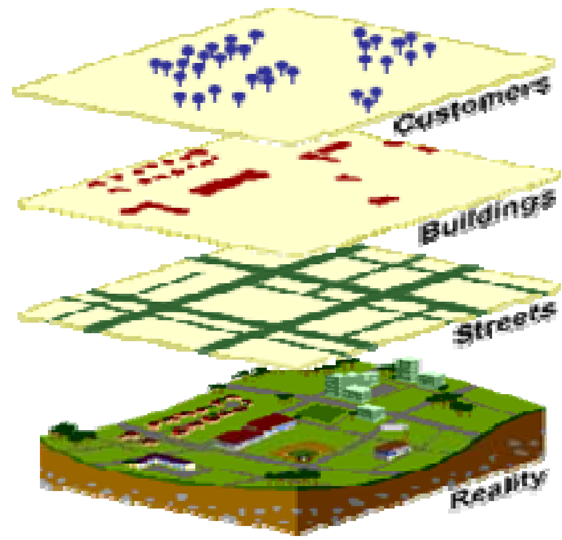
GIS can help:

- optimize data collection and management;
- strengthen data analysis;
- strengthen outbreak infrastructure and support;
- map epidemic dynamics in near real-time;
- quickly plan and target response;
- rapidly communicate information;
- monitor changes in disease over time;
- plan and monitor intervention and eradication programs; and
- aid emergency preparedness by mapping surveillance data in near-real time for early outbreak detection.

Typically GIS displays different types of information in different map "layers." Let's take a closer look at these GIS map layers using the example of an investigation of West Nile virus (WNV), which is primarily spread to people through mosquitoes that have fed on infected birds.

One map layer would contain the street network that could be used to geocode (apply longitude and latitude values to) infected case-patients. A second map layer would show the location of different types of buildings, including enclosures for sentinel species (such as chicken coops and horse stalls) as well as office buildings and dwellings. A third map layer would show the population at risk. Other useful layers would include a land cover layer, a digital elevation map, a precipitation map, a temperature map, a map of water features, and a map showing the location of veterinarians and physicians who could provide health care in the event of an outbreak (Figure 4).

Figure 4. Example of possible GIS map layers



You can do a lot with data after it is entered into a GIS tool (either a desktop or a handheld computer). In our WNV example, as the disease spreads, you can easily maintain surveillance of case-patient locations and the progression of the disease for early outbreak detection. You can identify areas with environmental conditions ideal for mosquito breeding using the land cover, elevation, precipitation, and temperature layers, and apply preventive measures in those areas. Similarly, you can predict which populations are vulnerable to infection based on their proximity to mosquito breeding grounds. You can plan ahead by simulating how an epidemic could evolve given the introduction of infected mosquitoes and birds at various locations, and determine where to target interventions and/or strengthen healthcare resources.

Infectious Disease Surveillance and GIS

Some actual surveillance programs using GIS are described below.

WHO Public Health Mapping Programme

In 1993, the World Health Organization (WHO) and UNICEF developed the Public Health Mapping Programme to boost efforts to eradicate Guinea worm disease, which affects the isolated rural poor. GIS was used to visualize disease foci, monitor newly infected or re-infected villages, identify populations at risk, target cost-effective interventions, and monitor eradication efforts. The Public Health Mapping Programme is a good example of how technologies developed to accelerate the control of one disease can enhance the control of others. Since the Guinea worm project, GIS and mapping have been greatly expanded to meet data needs for several disease control initiatives, including programs for the elimination of onchocerciasis (river blindness), blinding trachoma, African trypanosomiasis (sleeping sickness) and lymphatic filariasis (elephantiasis), as well as global initiatives to eradicate poliomyelitis and reduce malaria.

HealthMapper

The elimination of lymphatic filariasis as a global public health threat has been made possible by greatly improved diagnostic techniques and advances in treatment methods. The elimination strategies include mass drug administration to those at risk and promotion of the benefits of intensive hygiene on affected body parts. However, until recently, the populations at risk and their size and location had not been identified. The WHO and its partners adopted the HealthMapper software application for mapping and surveillance to plan and manage the elimination program. HealthMapper has enabled countries to estimate the prevalence of the disease at the district level and to identify the precise areas that should be targeted for mass drug administration. The GIS also serves as a tool for standardizing program surveillance and monitoring indicators in different countries and regions. (3)

Roll Back Malaria Partnership

Roll Back Malaria is a global partnership established to enable countries and communities to take effective, sustainable action against malaria. The WHO strategy to reduce malaria includes prompt treatment with effective drugs, use of insecticide-treated materials and other vector-control methods, intermittent preventive treatment in pregnancy, and emergency and epidemic preparedness and response.

To monitor the Roll Back Malaria partnership, the WHO developed a GIS that could:

- strengthen surveillance at the local level for early detection and response to epidemics;
- complement existing national and international health monitoring systems;
- integrate information on community interventions, control interventions, private and public health providers, partner intervention areas, and resources; and
- be accessible at different levels.

US West Nile Virus Surveillance

In the US, the Centers for Disease Control and Prevention (CDC) developed a national surveillance plan for West Nile virus (WNV) to monitor the geographic and temporal spread of infection, provide current national and regional information on the virus, and identify regional distribution and incidence of other arbovirus diseases.

GIS has been used extensively to enhance the federal surveillance system and communicate results to the public. The CDC combined forces with the US Geological Survey to map the progression of WNV through mosquito, wild bird, horse, and human populations (Figure 5) and track the disease in sentinel species (chickens).

At a more local level, the state of Pennsylvania has developed a comprehensive network to combat the spread of West Nile virus. This network covers all 67 counties and includes trapping mosquitoes, collecting dead birds, and monitoring horses, people, and sentinel chickens. The program includes the WNV Tracking System, a spatially-driven surveillance program for following and responding to the spread of West Nile virus in the state.

The tracking system collects information on the presence of the virus in any vector, identifies mosquito-breeding

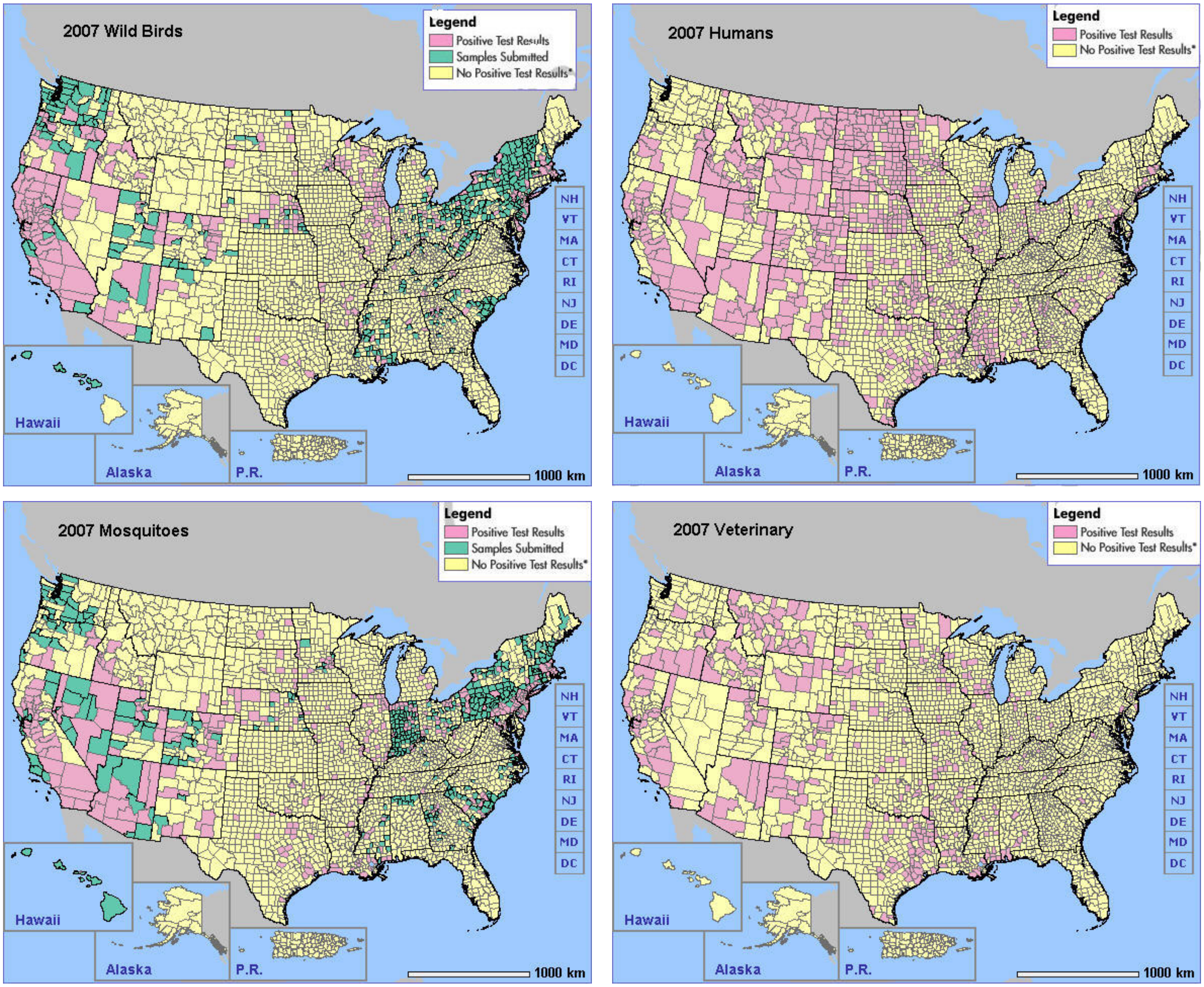
Additional Resources for GIS Mapping

World Health Organization Public Health Mapping Programme
http://www.who.int/health_mapping/en/

WHO HealthMapper
http://www.who.int/health_mapping/tools/healthmapper/en/

Roll Back Malaria Partnership
http://www.rbm.who.int/

Figure 5. 2007 U.S. Geologic Survey 2007 West Nile virus surveillance maps



areas, and helps target control efforts. An internal Web server automatically retrieves any new data and alerts decision makers via e-mail. Detailed maps are generated and posted on a secure Web site. Data approved for public release, such as the summary statistics by county, are published on Pennsylvania's West Nile Virus Surveillance Program Web site (www.westnile.state.pa.us/).

Outbreak Investigation and GIS

In addition to its use in surveillance, GIS has enhanced outbreak investigation and response at local, national, and global levels. It has been used to strengthen data collection, management, and analysis, develop early warning systems, plan and monitor response programs, and communicate large volumes of complex information in a simple and effective way to decision makers and the public.

Shigellosis

For example, GIS was used during investigation of an outbreak of shigellosis at Fort Bragg, North Carolina during the summer of 1997. A total of 59 cases of *Shigella sonnei* were reported among military health beneficiaries who used the healthcare services of the local military hospital and its affiliated clinics. A significant number of the cases were children, but the preliminary investigation did not reveal any clear associations with a particular daycare center or common location. The outbreak persisted despite educational campaigns about hand washing and hygiene. (4)

Investigators imported the residential addresses of all of the confirmed shigellosis cases into a GIS and mapped them onto digitized maps of the Fort Bragg housing areas. Mapping revealed a cluster of infections on several streets in one particular neighborhood (Figure 6). Interviews with case families and neighbors revealed the presence of small communal wading pools in several yards that were frequented by affected children. Once the pools were removed and home-based information campaigns were initiated, the spread of the illness was halted. (4)

Sexually Transmitted Infections

GIS has also been used to map sexually transmitted infections. For example, GIS was used in Baltimore to map distribution of syphilis before, during, and after an outbreak, providing data suggesting that the disease spread outward from 2 central cores of infection. (5) Also, researchers at

Figure 6. GIS display of a cluster of shigellosis cases in close proximity in a Fort Bragg neighborhood (4)

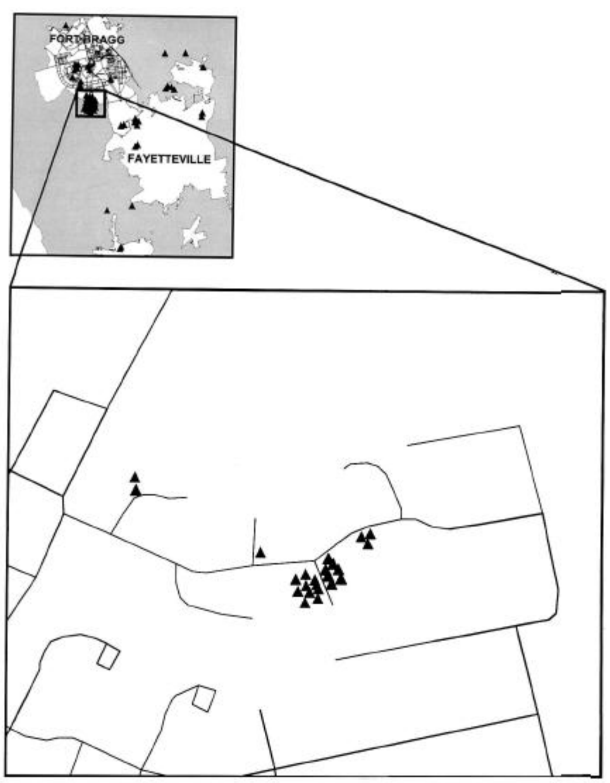
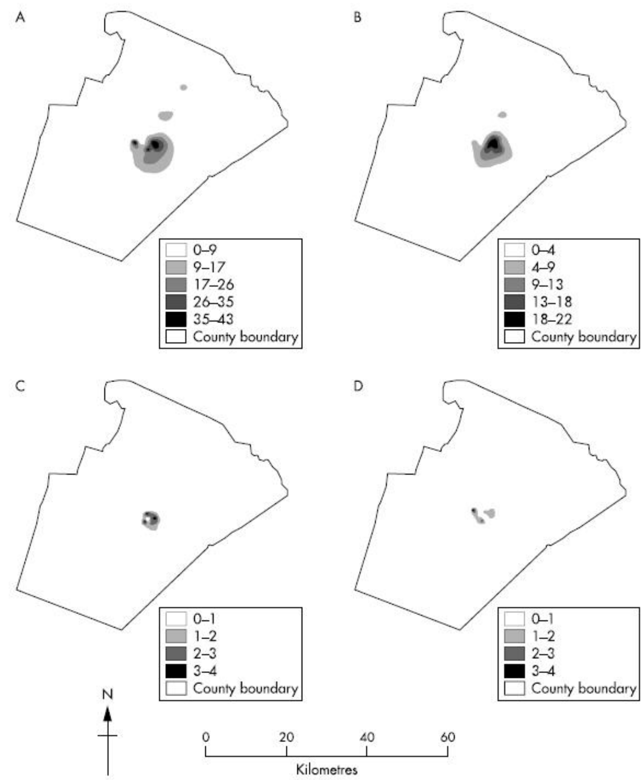


Figure 7. Spatial heterogeneity of Wake County, NC, STD rates in 2000 (A—chlamydia, B—gonorrhea, C—syphilis and D—HIV) (6)



the University of North Carolina at Chapel Hill used GIS to map the distribution of 4 reportable sexually transmitted infections (chlamydia, gonorrhea, syphilis, and HIV infection) in Wake County, North Carolina, and found clearly defined spatially heterogeneous areas of infection for the different diseases (Figure 7). (6)

Global Positioning Systems

Global positioning systems (GPS) add additional functionalities to GIS and increase capabilities during an outbreak investigation. GPS are a critical tool in epidemiology research in which precise identification of research subjects, their locations, and distances to related geographic features is essential. GPS units allow users to locate their positions on an electronic map at any given moment using satellite technology.

Atrazine Exposure

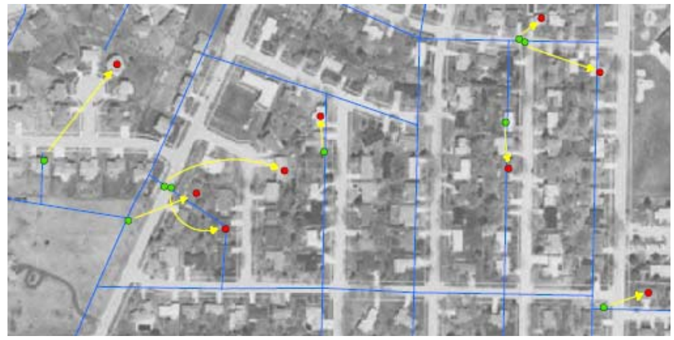
RTI International employed GPS-enabled handheld technology in a National Cancer Institute study designed to determine whether there was a relationship between exposure to the herbicide atrazine and distance from fields where atrazine was used. The project required field trips to verify the locations of households in the study area near selected corn fields in Illinois. To assist research field staff in navigating to the households selected for participation, RTI used an HP iPAQ Pocket PC with a GPS receiver and ESRI's ArcPad® software (a type of GIS software for mapping applications that allows the capture, display, and analysis of geographic information on handheld devices). (7)

The candidate household addresses were geocoded to a street database and loaded onto ArcPad along with aerial photographs and a street centerline database (Figure 8). The field staff used GPS and street name navigation techniques to find the approximate location of the candidate households. When necessary, staff modified the less accurate original address-matched location of each household (green dots) to the actual location (red dots) based on GPS and the ability to see household rooftops on an aerial map. If households could not be seen on the map, a GPS coordinate on the street in front of the household was captured.

Once the candidate households were accurately positioned using GPS, it was possible to measure each household's distance from a corn field where atrazine was used. Then, the concentrations of atrazine found in each household and in biological samples collected from the occupants were correlated with distance from the atrazine source.

The ability to use ArcPad/GPS capabilities instead of paper maps allowed the process of navigating from household to household go quickly and made the repositioning of household locations much more accurate. It would have been almost impossible to do the field work under the study's time constraints without this technology. The precisely measured household locations and the precise distances from households to corn fields provided a higher degree of precision during the data analysis portion of the research.

Figure 8. ArcPad image of selected household locations with street centerlines and aerial photographs



The approach used by this study could easily be applied to infectious disease surveillance and outbreak investigation and response. In an infectious disease outbreak investigation, for example, the technology might be used to measure distance to an exposure such as a water source with cryptosporidium or a farm with hoof and mouth disease.

Outbreak investigation and response are time-limited activities: they must be done quickly to have the greatest effect. Use of GIS and GPS technology can greatly speed field work, allowing investigations to proceed much faster than without these tools.

Summary

The spread of disease — especially infectious disease — is unavoidably spatial. (8) Infection moves from individual to individual following a network of contacts within a population through local or even global transmission. As public health agencies are increasingly discovering, GIS capacity to capture geospatial information is ideally suited for infectious disease surveillance and control. GIS is also highly relevant to meet the demands of outbreak investigation and response.

The next issue of FOCUS will show how GIS can also be used as part of public health disaster planning and response activities to conduct rapid needs assessments.

Further Readings

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