4.8 Geographic Information Systems

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4.8.1 Learning objectives

To understand the following about geographic information systems (GIS):

1. The basics of GIS.
2. The role of geospatial analysis in disaster health.
3. The use and challenges of GIS in Health EDRM.

4.8.2 Introduction

"Location, location, location" is the real estate agents' mantra, emphasizing the overwhelming importance of location on home values. This also provides a framework for the first three questions that should be asked when any disaster occurs, no matter whether it is an earthquake, typhoon, flood or something else. The first question, usually asked by everyone, is *Where has it happened?* The second question, asked mostly by those affected, is *Where are the shelters?* The third question, which is often asked by government emergency management officials, is *Where are the resources?*

The idea that place and location can influence health and safety is old and familiar in many countries and across different cultures. For example, since ancient China, Feng Shui wisdom has offered the understanding that there are a wide variety of energies in different environments, and a variety of Feng Shui methods have been developed for finding places to protect humans and their dwellings from low and attacking energies. In western history, as far back as the time of Hippocrates in the 3rd century BC, physicians have observed that certain diseases seem to occur in some places and not others. More importantly, the spatial nature of epidemiological data has long been understood and used as scientific evidence to support the development of policies to protect and improve human and animal health. In 1854, a cholera outbreak in the Soho district of London, United Kingdom, killed nearly 600 people in just ten days. John Snow, a London physician, identified a contaminated water pump by mapping the locations of water pumps and the homes of people who died of cholera (Figure 4.8.1). After instructing the authorities to remove the handle to the pump, the number of new cholera cases dropped dramatically.

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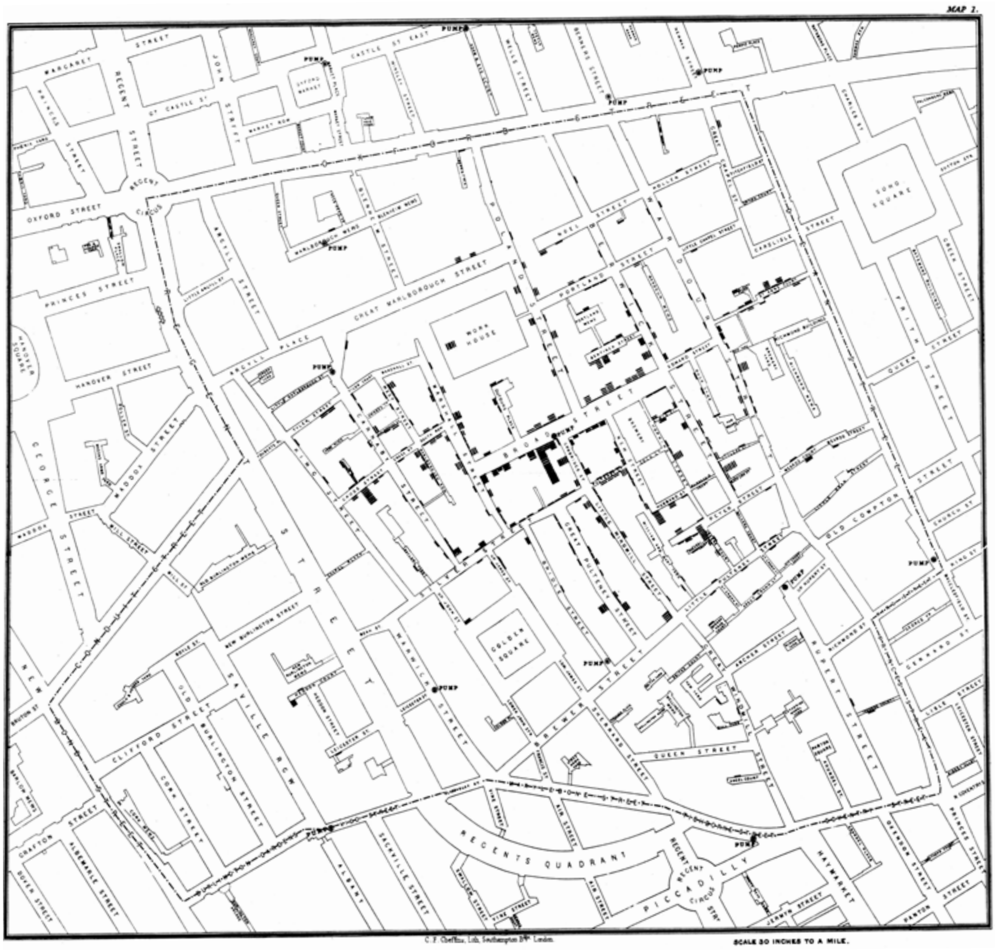
In the modern digital era, people encounter features of geographic locations (such as parks, bus stops, schools, hospitals, police stations and so on) every day. This is also important for Health EDRM, where emergency preparedness and health risk reduction are essentially spatial problems. With the help of new information technology including remote sensing, computers and the internet, all location-based information can be now visualized. Moreover, based on analysis and interpretation of this information, people can better understand relationships, patterns and trends of various components in social-ecological system. This chapter introduces the general concept of GIS, outlines areas of current application in disaster health and discusses future developments.

Figure 4.8.1 John Snow's cholera map



A contaminated water pump in Broad Street proved to be the source for the spread of cholera.

Map drawn by Dr John Snow in approximately 1854; shown in Stamp, LD. 1964. A Geography of Life and Death. This redrafting leaves out some interesting bits of evidence that appeared on the original map, and in Tufte's version. For instance, there was a building across the street from the pump that had no deaths at all.

4.8.3 What is GIS?

There are many working definitions for GIS. In this chapter, GIS is defined as “a computer system that incorporates hardware, software, and infrastructure for capturing, manipulating, integrating, interrogating, modelling, analysing, and visualizing all forms of geographically referenced information.”

GIS have developed rapidly in recent years, providing powerful tools for policy support in a wide range of areas on almost all geographic and administrative levels. For different users, the effectiveness and success of GIS-based applications depends on the hardware, software, technicalities of its implementation and data quality. The design and upgrading of GIS have a close and two-way relationship with the host organization.

4.8.4 GIS hardware

In general, a complete GIS system comprises individual computers, computer configuration and networks, input devices, storage systems, output devices (such as 3D printers) and virtual reality display systems. It should be emphasized that computers for GIS usage can be mobile telephones and personal computers at the low end, or supercomputers and X-Terminals at the high end. Hardware requirements vary considerably depending on the tasks undertaken.

4.8.5 Software

The choice of software depends on the needs of the organization, the functionality desired and the money available, as well as the period during which the system is planned. There are many high quality and widely used proprietary software applications on the market, which should be compared for their costs and benefits before a particular system is chosen. To date, there are five generations of software have been developed: desktop GIS, Web GIS, GIService, Cloud GIS and Smart GIS.

The development of desktop GIS extends the GIS applications to geographic data management, analysis and visualization. Web GIS is the most used by the general public, and includes products such as Google Earth and Google Map. It allows global access to geospatial data with low barriers for using GIS software in many disciplines, thus delivering real-time data and enabling collaborative data collection and mapping across platform. GIService combines functions of GIS and Web Service. Cloud GIS helps users make better use of the power of cloud computing to provide powerful capability in storage, computation and network. Smart GIS will not only make GIS available everywhere, all the time, and for everything but will also make everything as service.

A summary of different open-source and ESRI GIS programs, showing their capabilities and functionalities is available online *(1)*.

4.8.6 GIS Database

The database is the heart of any GIS application project. The development of a GIS-based database is the first step of the project, which involves a process of data acquisition, data digitization, data modelling, and data quality assurance and quality control (QA/QC).

Data acquisition is the GIS-related information acquired in the research project area, usually including data on the ecosystem, climatology, geology, hydrology, land form, soil, and social-economy, as well as other specific information. The data are usually comprised of satellite images, hard copy maps, ground observations and data obtained from the literature.

Data digitization is the process of transforming acquired data from a variety of data formats (such as images or drawings) to a relatively standard data format such as vector and raster:

- Vector consists of features such as point, line and polygon, and is usually stored as a shape file.
- Raster consists of grid cells and pixels which can be stored as images and TIN. After this process, new data will have the same coordinates system, projection, and datum, which can be readily used by GIS software for data analysis.

Data modelling is the process of using the available data to derive additional types of data. For example, the Digital Elevation Model (DEM) and river shape files are used to derive slope, aspect and watershed.

Data QA/QC is the process of validating the GIS data transformed from different sources. Transformed data is validated by comparing the geographic coordinates of pre-determined locations to the field survey results.

Case Study 4.8.1
Map of health vulnerability and disaster risk *(2)*

To measure the health vulnerability of each country, three factors were captured from nine health indicators for the 147 countries along the Belt and Road region *(2)*: population status, disease prevention and coping capacity. Population status is related to proportion of the population aged under 15 or over 65 years of age, the mortality ratio for children under 5 years and the maternal mortality ratio. The most vulnerable countries were Sierra Leone, the Republic of Chad and the Central African Republic. Ukraine was shown to be the least vulnerable among all of the studied countries. For the second factor, disease prevention, which is related to coverage of the measles-containing-vaccine first-dose (MCV1) and diphtheria tetanus toxoid and pertussis (DTP3) vaccines, the Republic of Equatorial Guinea and Ukraine are prominent, because they had low MCV1 and DTP3 immunization coverage. For the third factor, coping capacity, which is related to physician ratio and hospital bed ratio, Thailand, the Solomon Islands and Indonesia were at the top of the scale. After combining the three factors into a health vulnerability index, Greece, the Republic of Korea and the Republic of Belarus were the three least vulnerable countries, whereas countries in Africa, including the Federal Republic of Somalia, the Central African Republic and Chad were the most vulnerable.

As disaster risk is a function of exposure, hazard and vulnerability, the top five areas with the highest disaster risk identified in this study were in locations near the Philippines, the Islamic Republic of Afghanistan, Bangladesh, Somalia and Indonesia. Northwest China, North Africa, eastern Europe and Australia were found to have relatively lower risks.

The most common usage of the GIS-based database is to quantify research objects' spatial distributions as shown in Case Study 4.8.1. The distribution of any phenomenon or indicators on the earth's surface (geographically) is called spatial distribution. As shown in this case study, mapping various selected factors, allows the health vulnerability of the country to be shown visually to answer the question "what is where?".

As stated in Tobler's First Law of Geography, "Everything is related to everything else. But near things are more related than distant things". Understanding the spatial correlations of various factors in a research region is another important application of the GIS-based database. Exploration of spatial data involves the use of statistical methods to determine whether observed patterns are random. Visualization is the most commonly used spatial analysis method, resulting in maps that describe spatial patterns as shown in Case Study 4.8.2. Models might also be used to study cause-effect relationships, to explain or predict spatial patterns.

Case study 4.8.2
Chikungunya in Latin America

Transmission of Chikungunya virus became rapidly established during 2014 in Latin America in places where dengue and its main vector, Aedes aegypti, were present. This 2014 outbreak was the start of a new endemic disease, meaning that in the countries which faced this new arboviral disease, some areas saw stabilization of its transmission with decreased incidence, while others observed a significant increase during 2015. This was the case of the Coffee-Triangle region in Colombia.

In this setting, travellers to endemic areas in Latin American countries should be aware of the risk of infective biting exposure. In order to provide advice to travellers, epidemiological maps for Chikungunya virus were developed using GIS for the Coffee-Triangle region, which is a tourist area with three departments (Caldas, Quindı́o and Risaralda) and 53 municipalities.

Use of GIS-based epidemiological maps allows the integration of preventive and control strategies, as well public health policies for control of this vector-borne disease. For example, preparedness on Chikungunya virus for healthcare workers and students in the region have increased through intense continuing education activities, including community participation on vector control for the purpose of controlling and mitigating the effects of Aedes transmission on Chikungunya virus. Because travellers might also spread the virus, GIS maps also provide relevant information to assess the risk of travellers going to specific destinations with high transmission rates. This allows prevention advice to be made available for both government officials and the general public.

4.8.7 GIS Application in disaster health

Any disaster event creates a significant short-term spike in the demand for emergency services, which will require extraordinary measures. As reported by UNDRR *(3)*, the number of natural, accidental, and intentional disasters is growing globally and is an increasing concern for governments, healthcare organizations and the public. Many research studies, in a variety of countries and regions, have shown how the appropriate use of GIS can enhance the effectiveness of the disaster risk management system, thereby safeguarding the population and the community infrastructure. Much of the responsibility for emergency medical response to emergencies and disasters rests on the healthcare sector, but other sectors need to be involved as well and one of the distinctions of disaster health is its multidisciplinary nature.

In high-income countries, many hospitals and other health care facilities are equipped with new information technologies (IT) such as wireless local area networks (LANs) with disaster medical response capabilities including personal digital assistants, tablets and handheld personal computers. Unfortunately, many disaster events overwhelm or destroy the medical infrastructure by damaging hospitals, limiting emergency supplies and closing medical clinics. Taking advantage of recent advances in IT, hospitals and disaster relief agencies could work together using GIS to develop better plan for disasters.

Studies show that when disasters strike, a comprehensive disaster medical response plan with state-of-the-art IT is essential. This needs to ensure that adequate personnel, supplies, equipment and protocols are established to meet potential threats and are at the correct scale to meet the level of the disaster.

During pre-disaster stages, Health EDRM needs accurate public health data on air, water, sanitation, utilities and community healthcare facilities. Moreover, geo-referenced baseline demographic data and health area boundaries are also important. During a disaster, healthcare organizations need to have an acceptable surge capacity, so that they are able to expand beyond normal service levels to meet an increased demand for medical care. One example of building surge capacity is the development of a national real-time, hospital-bed tracking system named the National Hospital Available Beds for Emergencies and Disasters (HAvBED) system in the USA. The system includes a GIS, established communications protocols, a database and standardized hospital bed definitions.

It is also critical to track patients and essential medical supplies in both pre-disaster and post-disaster phases, as well as during a disaster. A related planning tool is the Emergency Preparedness Resource Inventory, which is a web-based tool that can assess the regional supply of critical resources, prepare for incident management, identify deficiencies in services, and support resource acquisition decisions. The Emergency Preparedness Resource Inventory also includes an inventory checklist to record where emergency equipment and medicines are located, the amount on hand, and how to obtain additional supplies.

GIS can also provide real-time tracking of people both patients and healthcare personnel. Tracking patients during a disaster helps with improved care, family notification and the allocation of emergency services.

This type of technology can help first responders to locate patients during emergency response and transfer patients when hospitals are full, then assist in coordinating patient care as individuals are moved during the emergency care process; as illustrated in Case Study 4.8.3.

Case Study 4.8.3
Health risk distribution of people with high temperature disasters *(4)*

Global climate change is increasing the frequency of extreme weather events, which have substantial impact on human health and social economy *(5)*. As an important type of extreme weather event, extreme summer temperatures have been widespread throughout the world and will continue to increase in frequency, extent and duration *(6)*. High-temperature disasters caused by high summer temperatures directly affect human health. In 1995, the heatwave in Chicago in the USA and the heatwave in Europe in 2003 caused a large number of deaths *(7–8)*. Excessive summer temperatures will increase the incidence of cardiovascular, respiratory, digestive tract and other diseases. High temperature weather will also lead to environmental pollution caused by the accumulation of harmful gases and smoke, further threatening human health *(9)*. However, targeted space control measures such as high-temperature warnings and resource allocation can minimize expected risks. People with different characteristics have different resistance to high temperatures. Therefore, the identification of vulnerable populations and health risk assessment of high-temperature disaster populations are important for targeted disaster prevention and mitigation and resource allocation *(10)*.

Based on the disaster risk assessment framework proposed in the fifth research report of IPCC *(6)* , a conceptual model of “high temperature stress-social vulnerability-population exposure” for population health risk assessment based on high temperature disasters; combined with meteorological data, remote sensing data, and socio-economic statistical data, the GIS and RS platforms have been used to complete the high-temperature disaster risk assessment at the country level. The results show that the hot spots of high temperature disaster vulnerability are mainly distributed in underdeveloped areas, with high temperature stress or poor social economy.

4.8.8 Challenges

Many studies show that healthcare organizations that invest appropriately in IT, including GIS, can improve the quality and efficiency of their healthcare services. In particular, when these investments are incorporated into disaster plans, it leads to benefits for emergency medical response and to other aspects of Health EDRM. However, there are concerns about the safety of the data which GIS collects, stores, analyses and displays; as noted in Case Study 4.8.4.

Case Study 4.8.4
GIS for population-wide health monitoring in the Federal Republic of Germany

In recent years, GIS have become an integral part of public health research. They offer a broad range of analysis tools, which enable innovative solutions for health-related research questions. An analysis of nationwide studies in Germany that applied GIS underlines the potential of GIS for health monitoring in Germany. GIS provide up-to-date mapping and visualization options to be used for national health monitoring at the Robert Koch Institute (RKI). Objective information on the residential environment as an influencing factor on population health and health behaviour can also be gathered and linked to RKI survey data at different geographic scales. Besides using physical information, such as climate, vegetation or land use, as well as information on the built environment, the instrument can link socioeconomic and sociodemographic data to information on health care and environmental stress with the survey data. This allows integration of the data into concepts for analyses. In this way, GIS expands the potential of the RKI to present nationwide, representative and meaningful health-monitoring results. However, in doing so, data protection regulations must always be followed. This balance of the safety of the data with the development of a national spatial data infrastructure and the identification of important data sources that can improve access to high quality data sets relevant for the health monitoring, is an important element in the development of this GIS.

Another challenge associated with implementing GIS in a robust medical disaster response plan is the cost associated with many of the necessary tools. In order to better serve their patients, continuous financial support for accurate, update and sufficient information is needed by healthcare organizations. This is particularly significant in rural US and in low-income countries. The level of regional, national and international efforts to manage disasters also urgently requires a coordinated GIS-based approach that connects local, state, and national emergency programs.

The third challenge to disaster medical response is the effective use of multiple data sources to develop a coordinated management approach *(11)*. The use of wireless LANs, GIS technology, patient-tracking systems and online medical resource databases will improve disaster medical response including early disaster event detection, outbreak management, connecting laboratory systems, response administration, communications and public health alerts; but will need good coordination. These technologies will improve patient care and safety, as well as provide for better command and control, leading to more efficient resource utilization. However, GIS will only make a powerful contribution if they include reliable and representative underlying baseline and situational data. The quality of these data needs to be carefully considered while interpreting the results. To help users better understand the complex situation, the choice of the GIS visualization method (for example, colour or grouping of the variables in a map) can also affect the overall interpretation of the situation.

4.8.9 Conclusions

GIS technology is expanding its application into Health EDRM, covering and going beyond disaster health risk detection, modelling, assessment, response planning and public health policy development. The development and maintenance of disaster health management systems based on GIS, however, not only depend on technology but also involve many components in a complex social-ecological system. Multi- and trans-disciplinary trained professionals equipped with relevant information technologies are crucial to meet the current and future challenges of using GIS in disaster health science.

4.8.10 Key messages

- **A main strength of GIS lies in its powerful ability to combine, analyse and display spatial and attribute data.**
- **This will help to satisfy the need for large-scale data analysis and processing in disaster response planning and improve Health EDRM.**

4.8.11 Further reading

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