GIS in Human Health Studies

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28.1 Introduction to Databases and Geographic Information Systems

Databases used in the field of medical geology are generally comprised of geospatial and/or temporal elements. Although these are not requirements for all medical geology research projects, much of the discussion in this chapter will be focused on databases incorporated into geographic information systems (GIS). GIS are computer-based (or manual) methods that allow a user to input, store, retrieve, manipulate, analyze, and output spatial data (Aronoff 1989). There are four major systems of GIS: engineering mapping systems (computer-aided design/computer-assisted mapping; CAD/CAM), geographic base file systems, image processing systems, and generalized thematic mapping systems. Various software packages are available that perform one or more of these systems, and the relative ability to move data back and forth between them can be critical to the needs and success of a particular GIS. Relational databases are the most commonly used types of databases in GIS (Cromley and McLafferty 2002). Relational database management models are convenient for linking formerly disparate databases together in a GIS. The databases to be joined must share one common attribute, usually an identifier such as coded patient number, sample site, or latitude/longitude. Other database management structures, such as hierarchical and network systems, are not as well suited to health GIS applications, although they may be useful for extremely large databases.

The capability to quickly and easily link large medical or public health databases with equally large geospatial databases represents an important technological breakthrough. Due to advances in computational power and speed, studies may be conducted today that could not have been done in reasonable time frames even just a few years ago. By linking disparate databases in a visually accessible manner (i.e., with maps), researchers are able to recognize

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relationships or discern patterns of disease that can lead to an understanding of causality that was previously not apparent. The value in mapping disease occurrence is appreciated when doing so can illuminate the underlying cause of an outbreak, which may then enable mitigation measures to be taken to prevent further spread of a disease.

The earliest example of using such a spatioanalytical approach to solving an epidemiological riddle is generally credited to a physician named John Snow and the Broad Street Pump of London in 1854 (Cameron and Jones 1983). Dr. Snow mapped a major outbreak of cholera, in a time before the germ theory was well accepted, and hypothesized that there was a causal association between the putative source of the contagion and locations of cases. He convinced city officials to remove the handle of the pump dispensing contaminated water—an intervention that promptly quelled the outbreak. Although modern tools are much more sophisticated than those at Dr. Snow's disposal, our goal remains the same in applying GIS to public health issues.

Currently, databases used in GIS applications are often developed by the user or are available on the Internet or from other sources. In the first edition of this book, databases were typically stored in electronic media formats such as a hard drive, floppy disk, and compact disc-read only memory (CD-ROM). These media have since been replaced by hard drives that are measured in terabytes, external drives, web servers and the cloud (See Sect. 28.3).

GIS databases contain fields in columns and records in rows. A field, or item, is an element of a database record in which one piece of information is stored and represented as a column in a geodatabase table or spreadsheet (Kennedy 2001). *Records* represent different entities with different values for the attributes represented by the fields (Kennedy 2001). *Attributes* are information about geographic features, and they are contained within GIS data layers, or themes (Fig. 28.1). For example, a climate data layer (the feature) may contain the attributes of temperature, rainfall, and relative humidity for a specific geographic point location or region. Attribute data and spatial data comprise the two critical types of data in a GIS. A more in-depth look at how to assemble databases into a project is presented in Other Sources, part C.

Along with the individual databases, *metadata* are also included. Metadata, also called data dictionaries, are simply data about data. Metadata contain information such as the time/place the database was created, field and record identifier information (attributes), data development process (lineage), and individual(s) to contact regarding the data. If the data are displayed in a geographic environment, the metadata must also include additional information such as map scale and projection. Guidelines for what should be included in metadata are provided by the National Spatial Data Infrastructure, which is maintained by the Federal Geographic Data Committee (FGDC) (see Other Sources, part A). An interagency U.S. government organization, the FGDC sets guidelines for all aspects of spatial data, and works with offshore/international partners to develop the global spatial data infrastructure.

28.2 Types of Databases and Their Features

There are enormous numbers of databases available in digital format, but the types of data likely to be used by medical geologists fall into two broad categories: Earth science/ geospatial databases and biomedical/health databases (see Other Sources, part A). What makes the field of medical geology innovative and unique is that it, by definition, brings together in a coherent manner databases from these two general areas in specific applications. This approach leads to fresh perspectives enabling recognition of connections between environmental factors and human health outcomes that may have previously gone unnoticed. Medical geological research can identify mechanistic connections that in turn can lead to new practices or policies. This may result in novel solutions to public health problems, which ultimately benefit large numbers of people. Two case studies are presented in Sects. 28.4 and 28.5 that illustrate the utility of such an approach.

Spatial data are represented in two models, vector and raster. In the vector models attribute data are attached or linked to one of three features: point, line, or polygon. Simply defined, a point is an x, y coordinate such as a mountain peak or soil sample location. The point feature does not have any length or area. A line is defined by the connection of two or more vertices (x, y coordinate pairs). A polyline is made up of numerous lines that represent the same feature, such as a road or river. The line or polyline feature has a length associated that is considered too narrow at the given scale to have an area. The polygon feature is defined by a series of lines that start and end at the same place, such as a state or country. Perimeter and area can be calculated for these features. In summary a line is a set of connected points whereas a polygon is a set of connected lines that have the same beginning and end points.

Features in a vector-based GIS can be linked or joined with attribute data from one or more databases provided a common identifier exists. The National Climatic Data Center (NCDC) generates climate data from ground-based observations. They supply a table of weather stations along with the stations' identifiers and x, y coordinates. This table can be imported into a GIS and point features can easily be made which correspond with weather station locations. Once these features exist in a GIS, they can be linked to other NCDC tables that contain station identifiers and Fig. 28.1 GIS conceptual diagram. Note that different data layers (covers or themes) are overlaid such that queries about individual point locations reveal numerous attributes from a variety of source databases (Figure courtesy of Eric Morrissey, U.S. Geological Survey, Reston, VA)



hourly, daily, weekly, monthly, and/or annual climate data. Climatic conditions can be analyzed from the temporal frame of a single point in time or a complete historical compilation.

A key function of a vector-based GIS is topology. Topology is the spatial linkage between vector features. It stores the spatial relationship of the features with respect to each other. Topology enables the user to determine where a feature is in relation to other features, which parts of different features are shared, and how features are connected. Functions such as which sample points are located within a specific watershed or which counties does a river intersect can be performed (see Fig. 28.1). Topology also reduces the amount of information that must be stored. If two polygons are adjacent, that is they share a common line as a border, the common line needs to be stored only once. It will be saved as the right side of one polygon and as the left side of the other.

Raster systems present data in a regular grid of squares or cells. These cells are often called "pixels," which is an abbreviation of the words picture elements. Each pixel is defined by a row and column number and in GIS these can be converted to x, y coordinates. Pixels contain a single attribute value relating to the feature they represent. In an image that represents soil, a unique value would be given for each type of soil.

The differences in the manner in which vector and raster systems present and store geospatial data often lead people to contrast the two in order to determine which is better. Each model has its advantages and disadvantages. Vector systems, with points, lines, and polygons produce maps that are more like those drawn by hand and therefore are more aesthetically pleasing. Raster systems tend to represent continuous surfaces such as elevation or vegetation well. At the same time they demand large storage capacity because they require a value for every pixel in the image. The answer to the question of which system is better is dependent upon the application. Both systems are effective, but the nature of the application or task generally determines which one should be utilized.

28.3 Software, Computational Technology, and Technical Issues

Developments in software are facilitating the integration of these two forms of data. Vector-based systems now incorporate basic raster-based system functionality and vice versa. The crossover of functionality has helped the user immensely. No longer do entire layers of data need to be converted from one data structure to the other. The integration of the two forms has made data management faster and less expensive while providing better quality of data generated. While this integration has improved greatly over the last several years, there are limitations and certain functions need to be performed in a specific software processing environment (vector or raster) based upon the data model.

Improved computer power with regard to processing speed and storage capabilities has led to increasingly larger and/or higher resolution datasets being processed. Laptops now are more powerful than the high-end systems of just a few years ago. We have experienced the growth of web mapping servers to distribute geospatial data and now cloud computing. Cloud computing takes the storage and processing off site to a set of servers and data centers. One of the main advantages of the cloud is its scalable and elastic nature where it is able to scale up or down to meet the consumers' needs.

Getting data to be used in GIS can sometimes be challenging. Manual efforts such as digitizing (using a flat digitizing table to draw or copy a map into an electronic format), geocoding (using an electronic basemap to match an address to), or scanning (using a scanner to convert a paper map to electronic format) are time intensive.

Using existing digital sources is often preferable, but these sources can also have their share of issues pertaining to quality. These are outlined below.

Scale specifies the level at which real-world features have been reduced to be represented. It is usually stated as a ratio or fraction such as 1:1,000 or 1/1,000, where 1 unit on the map represents 1,000 units in the area represented. An often confusing term for maps is small- or large-scale. Small-scale maps actually represent large areas but the ratio or fraction is a small number. Conversely, large-scale maps represent small areas. The map of a neighborhood would be considered large-scale whereas a map of Asia would be small-scale.

Resolution refers to the amount of detail in the features of the map. The scale of the map determines its resolution. It is the level at which features can be distinguished. On a smallscale map local features, such as ponds and small lakes, will not be represented. The terms fine (high) resolution and large-scale are synonymous; they contrast with coarse (low) resolution, and small-scale.

In GIS, issues of scale and resolution can determine which functions are appropriate as well as the level at which results can be stated (see Fig. 28.2). Ecological fallacy occurs when statements or predictions are made at one level based upon observations made at another. A soil survey conducted in 1 of the 24 counties of Maryland would be insufficient to predict soil characteristics throughout the state. Likewise, a small-scale digital elevation model would be inappropriate to use as part of a local water drainage study.

Accuracy is an important concept when working with GIS. Spatial accuracy, or how well the mapped features are located, must be stated and understood. If the map you are using states a spatial accuracy of $\pm 1,000$ ft, this will not be accurate enough to select a point to dig a well. Likewise, temporal accuracy must be stated. Population data from 1980 will not be accurate enough for current demographic

studies. These are just a couple of ways error can be introduced in GIS.

Projections were developed to represent the curved surface of the Earth on a flat map. Projections are utilized to preserve local angles and shapes or relative size of areas. Every projection distorts the map in some manner and should be carefully chosen with respect to the study. Most GIS can convert data from one projection to another, which enables data layers from different sources to be compiled.

Metadata are information about data. All data sets utilized in GIS should have metadata accompanying them. This information should include the origin and characteristics of the data set, the purpose of the data set, and any problems the data set may have. This information is critical for the proper utilization of GIS data. The increase in the use and sharing of geospatial data has necessitated quality metadata. In 2007, the Federal Geographic Data Committee (FGDC) developed and released the EPA (US Environmental Protection Agency) Metadata Editor (EME). This free software simplifies the creation of metadata with the use of defaults and drop-down menus while meeting FGDC standards.

Remote sensing technology provides satellite imagery and high-resolution, high-altitude aerial photography. Such image data are also becoming more common in the context of GIS. NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) provides free multispectral imagery of the globe every 1–2 days at 250, 500, and 1,000 m resolution. The Landsat program provides free multispectral imagery of the earth's surface every 16 days with a resolution of 15–60 m. There are numerous other low to medium



Fig. 28.2 Example of the effect of using databases of different scale. *Both panels* represent soil types displayed from digital databases for the exact same field sites (locations of individual transects are indicated with *black circles*, and latitudes and longitudes have been determined with a hand-held global positioning system [GPS] device). *Left panel* shows level of resolution available with STATSGO data (from the U.S.

Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE), 1:250,000. *Right panel* reveals much greater detail available with SSURGO data (from the U. S. Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE), 1:24,000 (Data from Bunnell et al. 2003)

resolution imagery products available as well as a growing number of high resolution imagery. If purchasing or processing this imagery is impractical for consumers, GoogleEarth provides free visual access to an incredible amount of this imagery.

Raster data can exist either simply or with multiple values, for example, representing spectral bands. Geodatabase features with the same type of geometry make up simple or topological feature classes (Zeiler 1999). Object classes retain descriptive information related to geographic features, but they are not elements found on a map (Zeiler 1999). Depths of wells could make up an object class, for example, in a medical geology GIS examining proximity of drinking water wells to sources of arsenic in Bangladesh (see also Chaps. 12 and 29, this volume). Due to advances in computer technology, large raster data sets can now be manipulated and spatial data rigorously analyzed statistically with relative ease, thus making incorporation into epidemiological frameworks feasible (Robinson 2000).

New sources of geospatial data have developed as well. Historically these data would reside on a hard drive on a desktop computer to be utilized by trained GIS personnel. This platform has evolved into the laptop and PDA's (personal digital assistant) and smartphones with internet linkups. These offer additional capabilities in processing or viewing data. In addition these devices often can serve as a global positioning system (GPS) which determines coordinates which serve as input for features in a GIS. This has led to the growth of a multifaceted geospatial community with members of varying degrees of expertise ranging from novice to expert.

Medical geologists can now move beyond simply noting spatial coincidences of environmental features and disease patterns. By taking advantage of increasing computational speed and capabilities, sophisticated spatial statistics can be used in conjunction with GIS to reduce bias and correct for such potentially confounding effects as non-constant variance and autocorrelation (Haining 1998). Moreover, spatial statistical models can rigorously test for clustering versus random distributions, and can incorporate a fourth, temporal dimension to better assess correlation and offer clues into disease etiology (Kulldorff 1998).

28.4 Case Study 1: Lyme Disease

The first is a study designed to identify environmental determinants of tick abundance in the Mid-Atlantic region of the United States (Bunnell et al. 2003). Lyme disease is the most commonly reported vector-borne disease in the United States and it is still rapidly growing with over

10,000 new cases annually (Centers for Disease Control and Prevention 2001). In this part of the country, the blacklegged, or deer, tick (Ixodes scapularis) transmits the microbial agents, that cause Lyme disease, ehrlichiosis and babesiosis, and other human and veterinary ailments. Tick abundance is likely a more reliable measure of the effect of landscape features on Lyme disease risk than human case data for several reasons, most notably because the location of Lyme disease cases will be, at best, the patients' home address, while many if not most of the cases are actually acquired elsewhere. Furthermore, by using tick distribution patterns, one avoids potentially misleading interpretations resulting from over- or underreporting due to the challenges in accurately diagnosing Lyme disease in humans. By better understanding the effects of environmental parameters on tick distribution, public health intervention strategies will likely be improved. Note that the word "vector" has a specialized meaning in the context of GIS (a mathematical definition, as above); in the biomedical community, a vector is an insect or other arthropod that actively transmits a pathogen from an infected reservoir host animal to another individual. Chapter 29 offers a thorough discussion of GIS technology applied to vector-borne diseases.

Environmental factors (covariates) that were previously known or suspected to correlate to tick abundance patterns included elevation, land cover, forest distribution, watersheds, and soil type (Glass et al. 1995; Ostfeld et al. 1996; Kitron and Kazmierczak 1997; Jensen et al. 2000). Digital elevation model (DEM) databases were obtained in a raster format (U.S. Geological Survey, Reston, VA). Land cover attributes were obtained from the remotely sensed multiresolution landscape characterization (MRLC) Landsat thematic mapper (TM) source data, managed by the Earth Resources Observation Systems (EROS), an entity within the U.S. Geological Survey (USGS). Initially, soils data were obtained from the state soil geographic database (STATSGO) maintained by the Natural Resources Conservation Service (U.S. Department of Agriculture, National Soil Survey Center, Lincoln, NE).

From a five-state region, 320 field sites were randomly selected and ticks were collected along transects at each site. Latitude and longitude were recorded at the beginning and end of each transect. At first, locations of the transects were noted on a paper map, 7.5-min topographical quadrangles were digitized by hand, and the sites were matched up. Digitizing a paper map requires a digitizing table and specialized hardware and computer software. The digitizing process was not required when latitudes and longitudes were recorded directly to a global positioning system (GPS) device, and then entered into a desktop personal computer. Newer GPS devices can further streamline the process by coupling directly with a laptop or desktop computer. This

obviates the need for data entry by hand. Each field site, or transect, became a unique identifier, and the latitude and longitude were the link to the environmental data downloaded. DEM data were used as is so that elevation in meters was obtained at each transect. Land cover data were of limited usefulness, as they only indicated whether a given field site was located in forest, low-intensity residential, open water, etc. Because tick population densities are positively associated with forest edges (ecotones), and because ticks are not found in open water, the GIS was used to calculate the distance from the midpoint of each transect to the nearest specific type of forest and body of water. The databases were thus manipulated from their native state, which resulted in new databases of particular utility to this specific research project.

Newly developed spatial statistics that incorporated spatial autocorrelation were applied to the data, and multiple regression analysis was performed (Das et al. 2002). These techniques revealed significant associations between tick abundance and certain environmental covariates that included soil type. This latter finding was particularly intriguing, and since the inception of the project, some soil data at much higher resolution were made available digitally. The soil survey geographic database (SSURGO) was released county by county as it became available (U.S. Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE). Only 75 of the 320 field sites happened to be located in counties with SSURGO data available at the time of analysis, and a second analysis was conducted on that subset of field sites. Because of the much finer resolution (1:24,000 vs. 1:250,000 for SSURGO and STATSGO, respectively), interpretations were made with greater precision (Fig. 28.2).

The enhanced resolution available with SSURGO data, combined with the more extensive set of attributes of this database, revealed some surprising results. For example, with STATSGO data, well-drained soils were found to be positively associated with tick abundance, in keeping with previous reports in the literature. However, upon analysis using SSURGO data, it was found that poorly drained soils, too, could be positively associated with tick abundance. This seeming contradiction was apparently resolved by considering precipitation factors and water-holding capacity of the soil. This example demonstrates the power of a GIS approach to examining environmental influences on factors controlling human disease risk. Observation of previously obscured patterns has enabled the generation of hypotheses now being tested to explain factors responsible for spatioanalytical trends in biological terms. Important advances in our understanding of basic Lyme disease ecology are likely to follow from this application of newly acquired and improved computational technology.

28.5 Case Study 2: Fluorosis in China

Elucidating the causes of fluorosis in the People's Republic of China offers another example of how GIS can be used to address the relationship between human health problems and geologic materials. Fluorosis, an abnormal condition of bones and teeth caused by exposure to excessive amounts of fluorine, affects millions of people throughout China. There are three principal pathways of exposure: drinking high-fluorine water, drinking tea made from tea leaves rich in fluorine, and exposure to fumes from residential combustion of highfluorine coal or briquettes made with fluorine-rich clays as a binder (Zhang and Cao 1996; Ando et al. 1998) (see also Chap. 13).

Until recently, only general information existed on the epidemiology of fluorosis in China. For example, it was known that Kazakhs in the Xinjiang Autonomous Region in northwestern China were exposed to high levels of fluorine due to their preference for "brick tea" made from tea leaves rich in fluorine (Ben et al. 2000).

To determine where fluorosis was likely to be caused by exposure to fluorine-rich coal or coal briquettes, two GIS layers were required: the distribution of fluorosis and the distribution of coal deposits in China. No digital versions of either layer could be located. A map of the distribution and prevalence rates of dental fluorosis by county in China was located (Jianan 1989) and a map of the coal deposits of China was obtained (Ruiling et al. 1996). Both paper maps were digitized into electronic format at a computer workstation. Once in electronic form, the individual features of the maps (i.e., areas with the same prevalence rate of dental fluorosis) were assigned unique identifiers (attributes, in this case different colors). Parameters that control the way the map is displayed (projection) were adjusted so that the digital maps, representing the same geographic areas, would perfectly overlap each other (Karlsen et al. 2001).

In a GIS environment, the digital map of prevalence rates for dental fluorosis was overlain with the digital map showing coal distribution (Fig. 28.3). The combined maps confirm the association of fluorosis and coal in Guizhou Province, where more than ten million people are known to suffer from fluorosis (Zheng and Huang 1989). Figure 28.3 indicates that the high incidence of fluorosis in north central China (Shaanxi Province, which is the largest coalproducing province in China) may not be related to coal use.

In Guizhou Province the fluorosis is caused primarily by combining moderately high fluorine coals (average of about 200 ppm) with clays having very high fluorine contents (average of about 800 ppm) to form briquettes (Belkin et al. 1999). The high-fluorine clays are the residual products from intensive leaching of the limestone substrate that



Fig. 28.3 Relationship of high prevalence rates of dental fluorosis and coal deposits in the People's Republic of China (From Karlsen et al. 2001)

formed the beautiful karst landforms for which the region is noted. In Shaanxi Province the substrate is primarily loess, a silicate-rich, wind-deposited sediment that is unlikely to have high-fluorine contents. Therefore, unless the coals in Shaanxi Province have exceptionally high fluorine contents, it is unlikely that the high incidence of dental fluorosis in that region is due to residential coal use.

Surprisingly, in the Xinjiang Autonomous Region the incidence of fluorosis also parallels the coal deposits. Perhaps this indicates that the distribution of fluorosis may be controlled by sedimentary rocks that favor the growth of the trees from which the fluorine-bearing tea leaves are obtained.

28.6 Other Case Studies

A number of other examples of GIS applications to medical geology problems may be found. These include the examples below.

African trypanosomiasis—Environmental factors that influence temporal and spatial distributions of African trypanosomiasis (sleeping sickness) were analyzed in a GIS that incorporated temporal Fourier analysis and discriminating analytical techniques such as Mahalanobis distance metric to aid in data interpretation (Rogers 2000). A relationship between the climate covariate included in the analysis was found to exist with vegetation patterns, which in turn influenced suitability of grazing for cattle, the main reservoir hosts for the tsetse fly (Glossina spp.) vector of the trypanosome parasites. Sequential statistical modeling of the tsetse fly populations and trypanosome disease transmission, when linked to biological modeling based on known differences due to the different species of tsetse, helped explain differences in the patterns of disease observed in different regions in Africa.

Hurricane Mitch—In 1998, one of the most powerful and deadly hurricanes in recorded history struck Central America. At least 6,500 people died and over 11,000 went missing in Honduras alone as a result of Mitch's fury. Many cases of human disease and death were caused by flooding, even in areas not directly hit by the hurricane itself. Some of these floods, in turn, triggered lethal outbreaks of waterborne infectious diseases such as cholera, leptospirosis, Dengue fever, and malaria. GIS was used to predict high-risk areas for flood potential based on themes including river network configurations, elevation, and slope. This tool may have helped keep the casualty count low following this major disaster. Lessons learned from this experience may be helpful in using GIS to plan and execute preparedness and relief efforts before and after future catastrophic events (PAHO 2000).

Cadmium in The Netherlands—From 1892 until 1973, a zinc works in the Kempen area of The Netherlands discharged zinc and cadmium (Cd) into the environment in an uncontrolled fashion and seriously contaminated the soil with up to 8 ppm Cd (Stein et al. 1995). Cleanup efforts undertaken in the 1980s made use of a GIS and geostatistics to contour the cadmium distribution and improve sampling efficiency. Data from more than 1,700 soil samples were used as point data, and semi-variograms were created to compare stratified and ordinary kriging methods to interpolate the Cd concentrations. Neither mapping technique was uniformly superior; depending on the application (e.g., proximity to urban centers), one or the other map proved more useful. Had the GIS been used interactively, Stein et al. (1995) concluded that the number of soil samples necessary for testing could have been reduced approximately tenfold.

Malaria—A GIS analysis of malaria conducted in the Chiapas region, Mexico, and Peten, Guatemala, provides an example of how this analytical tool can be useful in active and iterative generation of testable research hypotheses. A priori hypotheses pertaining to environmental factors that influence malaria incidence by their impacts on the *Anopheles* spp. mosquito vectors invoked altitude, temperature, rainfall, land use, and vegetation type. In the course of developing the GIS, researchers observed that high-risk areas were often in close proximity to agricultural lands (SHA 2000). Further analysis led to the generation of a novel hypothesis that relates malaria risk to deforestation, a potential linkage that is presently being investigated by several groups.

Conclusions

In this chapter, the conceptual framework for GIS databases has been described, as have strategies and tools for conducting medical geology research projects. We have explained how recently developed GIS technology has truly revolutionized the study of human disease systems, which makes possible the simultaneous analysis of numerous interrelated factors that may exert unapparent and synergistic effects. Previously, such complex systems could only be addressed looking at one (or just a few) variable(s) at a time. With the case studies

provided, the reader has seen examples of how to approach rigorous investigation into causes of human disease patterns that have strongly suspected environmental influences. Finally, we have supplied database resources that may provide a starting point for researchers wishing to conduct GIS studies of their own. In the time between the original publication of this chapter and this updated edition, computational technology has advanced dramatically, and geospatial data have become much more accessible.

See Also the Following Chapters. Chapter 12 (Arsenic in Groundwater and the Environment) • Chapter 13 (Fluoride in Natural Waters) • Chapter 29 (Investigating Vector-Borne and Zoonotic Diseases with Remote Sensing and GIS)

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Other Sources

A. Sources of Earth Science/Geospatial Information FGDC (http://www.fgdc.gov/)

The FGDC coordinates the sharing of geographic data, maps, and online services, that searches metadata held within the NSDI Clearinghouse Network. The National Geospatial Program (http://www.usgs.gov/ngpo/) organizes data through various portals which are listed here:

http://nationalmap.gov – base data, map products and geospatial web services

http://geo.data.gov – geopatial information discovery and access, communities, and partnership marketplace

http://nationalatlas.gov – maps of America for everyone's use

http://geonames.usgs.gov/domestic – geographic names authority and gazetteer for the nation

http://cegis.usgs.gov – leadership for geospatial information research

Seamless Data Warehouse (http://seamless.usgs.gov/)

The Seamless Data Warehouse is the ideal location to explore and retrieve data. U.S. Geological Survey (USGS) and the Earth Resources Observation and Science (EROS) are committed to providing access to geospatial data through The National Map. An approach is to provide free downloads of national base layers, as well as other geospatial data layers. These layers are divided into framework categories:

Places, Structures, Transportation, Boundaries, Hydrography, Orthoimagery, Land Cover, and Elevation

Along with providing access to the data, this site contains: Tutorial to help with downloads

Information about the downloadable products

Frequently Asked Questions (FAQs)

Links to product homepages and information pages

The Seamless Data Warehouse is always growing with new data, tools, features, and much more.

B. Libraries (for Further Research)

U.S. Geological Survey Library 950 National Center 12201 Sunrise Valley Drive Reston, VA 20192 e-mail: library@usgs.gov

U.S. Library of Congress 101 Independence Avenue, S. E. Washington, DC 20540 e-mail: lcweb@loc.gov

U.S. National Library of Medicine National Institutes of Health 8600 Rockville Pike Bethesda, MD 20894 e-mail: NIHInfo@OD.NIH.GOV

C. Where Does One Start a Search for Relevant Databases?

The FGDC Web site http://www.fgdc.gov provides access to over 38 simultaneously searchable data clearinghouses in the United States and internationally. These include databases related to Earth sciences, geography, landform information, ecosystem health, biological resources, and satellite imagery (see Other Sources, part A). The focus of this chapter has been on electronic sources, but don't forget to check your library's reference section, trade journals, or other specialized periodicals and books. To find databases on the Internet, you might use a search engine. Be aware that different search engines work in different ways, and that what may be overlooked by one search engine might be found by another one. There are also metasearch engines that use several search engines simultaneously (Hock 2001). Of course, another very efficient way to find out what databases are used by experts in a given field is to simply ask them. Contact information for university professors is often listed on their institution's Web site, which can be

found on any search engine. Even if the principal investigator is hard to reach in person, his or her postdoctoral fellows, graduate students, and technicians may be willing to help.

An efficient strategy when starting out on medical geology research projects is to seek out relevant database clearinghouses. Using clearinghouses also offers some protection from rapidly changing unique or uniform resource locators (URLs), which are often referred to as Web site addresses. One example is the U.S. Geological Survey (USGS), which is a major clearinghouse for Earth science data. The URL for some particular databases contained therein may change, but the URL for a clearinghouse such as USGS generally remains stable over time. The primary clearinghouse organization will maintain proper internal links and keep access to all of their individual databases current.

The geographic and temporal range of the data needed must be ascertained at the outset of any medical geology GIS. It is better to err on the side of obtaining more information then deleting unnecessary elements, because it can be difficult to add data later if it is decided to examine additional parameters. But the initial cost of the data and the cost in resources to store data must also be taken into account. Because different databases will likely contain data archived in a variety of formats, it is advisable to store the initial downloaded data as is and make copies of it before any subsequent manipulation. The text-only ASCII file format is a "common denominator" useful for merging data from different sources into a single data set.

The use of Internet-derived databases can be made frustrating and difficult by two realities of this medium. One reality is that URLs change quickly, and so the Web site address that worked in the past may not take you to the same page today. This potential pitfall can be avoided by using the "gatekeeper" URL to a database clearinghouse as mentioned above, rather than by using direct URLs to individual databases. For example, one is advised to use a main clearinghouse Web site rather than a more specific URL for some individual database, such as for water table depths in India. The other major problem is the so-called Invisible Web (Sherman and Price 2001). There are a great many databases accessible via the Internet with no easy way to find them or to find out about them. Many databases can only be accessed after registering and entering a password. Search engines will miss these and other relevant sites, and they will often come up with totally irrelevant sites. Investigators must be mindful, too, of the reliability of database sources accessible via the Internet. If associated metadata are not available, that database should not be used.

Once a database of interest has been identified and the legitimacy of the organization that maintains it is verified, you are ready to download. Make sure you have the minimum requirements and sufficient memory space on your computer before proceeding. As always when downloading any software or data to a personal computer, remember to have some tool in place for screening computer viruses. It is critical to ensure that once downloaded, the data were not corrupted in the process. You must examine the source data carefully and confirm that they match the data in the form that has been downloaded. Problems can arise, for example, if the source data are tab delimited and your default download is space delimited. As soon as you have downloaded the source data, you should make a backup copy before doing anything with the data. It is generally convenient to keep such files on a compact disc (CD). Now you are ready to open up your data with your spreadsheet software package and import it to your GIS application or to a statistical analysis package. In a GIS environment, you can easily query the data. That is, by clicking with a mouse on a location visibly displayed on a map, you can extract attributes of that point.

You will need to join data from different databases for use in a GIS project. Get to know the raw data well as you must always maintain quality assurance/quality control (QA/QC). It is easy to mix up or somehow corrupt data when manipulating it. For instance, if you sort the data for some reason, make sure you keep a copy of the original unsorted data. Also be careful not to sort only one field, but rather keep your unique identifiers tied to the data in the proper order. If your ultimate aim is to do some statistical analysis of the data, you should work closely with a statistician right from the start. The statistician will help you determine the appropriate data you need to answer the questions you are asking.