Exploring the Utilization of Geographic Information Systems in Health Promotion and Public Health

Candace I. J. Nykiforuk, PhD and Laura M. Flaman, BSc

August 2008

The Centre for Health Promotion Studies is committed to sharing knowledge about health promotion issues in order to positively influence policy, practice, and ultimately health for all people. This technical report was published for this purpose.

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CENTRE FOR HEALTH PROMOTION STUDIES

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Executive Summary

The purpose of this technical report is to identify and review how Geographic Information System (GIS) applications have been used in health-related research (e.g. policy development, planning, monitoring, and surveillance). The intention of this review is to generate a broader understanding of how GIS-related methodological techniques and tools developed in other disciplines can be meaningfully applied to applications in health policy, promotion, and practice.

GIS approaches are quickly gaining recognition as an effective means to answer complex, ecological questions in health promotion, public health, community medicine, and epidemiology. It is a unique tool that allows for the integration of multiple data sources, visual representations of complex geographic data, and the application of various spatial analytic techniques to answer a variety of questions. GIS is seen as an “enabling technology” that allows people with a range of expertise in a variety of settings to integrate and analyze spatial data to answer pertinent questions in a vivid and meaningful way.

This review revealed that health promotion and public health applications of GIS could be generally categorized into four predominant themes: i) disease surveillance (n=227); ii) risk analysis (n=189); iii) health access and planning (n=138); and iv) community profiling (n=115). These themes are not entirely distinct from one another and often overlap.

The most common and longstanding use of GIS in public health and health promotion is for disease surveillance, which is the compilation and tracking of information on the incidence, prevalence, and spread of disease. There are two interrelated components of disease surveillance including disease mapping and disease modeling. Disease mapping is used to understand the geographical distribution and spread of disease in the past or present and involves the construction and tracking of mortality and morbidity patterns related to a single disease or a set of diseases. Disease mapping applications were subdivided into a number of subcategories, including mapping of: vector-borne diseases, communicable diseases, infectious diseases, various types of cancer, individual health issues, morbidity and mortality, exposure to pesticides and air pollutants, injury prevalence, and an assortment of unique applications. As outlined in the many articles reviewed and highlighted in this section, disease mapping is an effective public health tool for helping to prevent the spread of diseases, facilitating the development of interventions, evaluating health outcomes, and appraising population risks for summarizing and displaying health indicators. Ultimately, simple applications of mapping technologies can be beneficial in summarizing and displaying health indicators in a way that can be utilized by health care providers, public health managers, and policy makers in practice.

Disease modeling is used to forecast future disease spread or epidemic outbreaks and to identify those factors that may foster or inhibit disease transmission. Specific disease modeling applications fall into the following categories including the modeling of: vector-borne diseases, infectious diseases, tick and tick-borne diseases, and exposure to pollutants. The information generated through disease modeling can be used to generate policy that will best meet needs for immunization, vector control, or other public health initiatives.

There are also numerous examples of GIS approaches being used for risk analysis. Risk analysis is typically linked with ecological or environmental health, and includes some aspects of risk assessment, management, communication, or monitoring - relative to impacts on health. The risk analysis projects reviewed have been subdivided into several categories including risk analysis for:
environmental exposure to water contaminants, environmental exposure to soil contaminants, environmental exposure to air contaminants, hazards, association with particular diseases and illnesses, virus transmission due to landscape ecology, and other risk applications. The many examples in this category demonstrate that use of GIS approaches for risk analysis have the potential to help policy makers and decision makers understand the spatial relationship between hazards, pollution, and health.

Health access and planning applications of GIS approaches can be generally operationalized as those related to network analysis and market segmentation for the analysis of health services and delivery. Health access and planning can be subdivided into two categories: network analysis and health care utilization and market segmentation. Network analysis applications of GIS are those related to “location of” and “access to” health services with the purpose of addressing questions about route, distance, and proximity. Within network analysis there are a number of subcategories including: accessing health services for specific health conditions; access to health care services for low socioeconomic populations; general access to health care services; using GIS to analyze emergency response times; assessing patient characteristics, patient flow, and distance to assist in planning; assisting with health system planning; and estimating health care costs to assist with planning. Finally, tools for network analysis are identified. Within the category of health care utilization and market segmentation there are a few subcategories including: assessing the number of people using services, market segmentation, and characteristics of populations associated with particular service areas. Generating visual depictions of the distribution of health care providers allows the public, health care providers, and policy makers to effectively use research data to better target the public health needs of the community.

The final category of community health profiling includes compiling and mapping information regarding the health of a population in a community. These approaches can be used to better understand the links between people and their environments; this helps ensure that the health needs of the target communities are better met. Although the volume of literature on this type of GIS application is sparse relative to that of disease surveillance, risk analysis, and health access and planning, this category could be seen as a culmination of them all as it treats the community as an over-arching environment or context in which all of these health-related variables co-exist and interact. Sub-categories of the community health profiling section include: exploring access to non-medical facilities, exploring community needs through GIS, and using GIS to explore disparities in health outcomes between communities. Public health officials can use the information provided through this review to identify and examine potential environmental exposures in a community and justify screening tests and other interventions. This type of application may be important for community development initiatives and valuable to decision makers in the creation of both health policy and healthy policies.

The final chapter in this review provides an overview of some of the common methodological challenges and limitations associated with health-related GIS applications. This section is divided into three main sections: spatial statistics in GIS, data treatment, and mapping considerations.

The fundamental goal of this literature review was to identify the extent to which GIS approaches have been used for health related applications. GIS approaches can be used to bridge the interface between science and practice by using a spatial aspect to link health outcomes to individual behaviours and environmental factors. It can be effectively utilized to monitor and assess program and policy
interventions within a defined environment, but this use must be carefully designed and evaluated to ensure validity, reliability, and transparency and to increase accountability for evidence-based policy and practice.

In summary, the potential applications of GIS for subsequent work in health promotion and public health are numerous and limited only by the imagination. Opportunities for collaboration between disciplines such as geography and health should be maximized for the mutual benefit of researchers, practitioners, decision makers, and communities.
Chapter 1: Introduction

There is growing recognition in health promotion and public health literature that the consideration of context or settings is essential for a clear understanding of public health policy and practice, as well as for the development of best practices in those areas. This implies that researchers must endeavor to bring together the critical variables that represent the people, environments, and political processes that comprise the contexts fundamental to the examination or development of health programs and policies. For example, in the case of municipal bylaws to restrict smoking, if policy makers consider community characteristics within the context of broader social, political, and economic climates when developing and implementing this kind of public policy, then so should the researchers who study those policy processes. Therefore, it would be useful to have an approach for linking and examining those variables in a way that holds relevance and utility for both science and practice.

It is feasible to assume that to better understand the role of context in public health, it would be useful to examine the environment, or the spatial component, of the health behaviours at which programs and policies are directed. Naturally, this bespeaks the relevance of taking a multidisciplinary approach to examine the issue from the perspectives of health promotion/public health and geography.

One potential approach for exploring the role of context in health promotion and public health research is to incorporate a Geographic Information System (GIS) when examining health questions. A GIS combines cartography and multivariate statistical analysis to allow for the investigation of sophisticated spatial relationships (i.e., linking ‘people’ to ‘place’) while presenting the information in a vivid, visual manner. This technique can be applied at a range of aggregations to gain insight into the relationship between health outcomes and social, demographic, economic, and political variables at various jurisdictional levels. The use of GIS is rapidly emerging as a means to effectively link and analyze the range of data necessary to address complex questions in public health, community medicine, epidemiology, and in a range of other fields.

The purpose of this technical report is to identify and review how GIS applications have been used in health-related research (e.g., policy development, planning, monitoring and surveillance) and to critically examine the issues, strengths, and challenges inherent to those approaches. We explore how GIS has been used to inform decision making and discuss the extent to which GIS approaches can be applied to address health promotion and public health questions. Finally, the complex, methodological data linkage and manipulation challenges inherent to using GIS will be identified and an overview of some internet-enabled GIS tools provided.

The contribution of this comprehensive review will be to generate a broader understanding of how GIS-related methodological techniques and tools developed in other disciplines can be meaningfully applied to public health policy, promotion, and practice.

BACKGROUND

This comprehensive literature review of health-related GIS applications was guided by conceptualizations of context and public health policy, and thus, an overview of these fields of study is warranted. As the bodies of literature that comprise these areas are quite vast, they will be only briefly outlined in the sub-sections below. References for papers that discuss these topics in greater detail are provided.
**Introduction**

Recent ecological and environmental examinations concerning lifestyle-related interventions continue to suggest that ‘context,’ ‘environment,’ or ‘setting’ are central to the success of health promotion interventions, policy, and practice (Ball & Crawford, 2005; Brownson, Baker, Housemann, Brennan, & Bacak, 2001; M. J. Duncan, Spence, & Memmery, 2005; Egger & Swinburn, 1997; Humpel, Owen, & Leslie, 2002; Canadian Institute for Health Information, 2006; Jack, Liburd, Spencer, & Airhihenbuwa, 2004; Jeffrey & Linde, 2005; Lobstein, Baur, Uauy, & IASO International Obesity Task Force, 2004; N. Owen, Humpel, Leslie, Bauman, & Sallis, 2004; Puska, Toumilehto, Nissinen, & Vartiainen, 1995; Raine, 2005; Sallis, Bauman, & Pratt, 1998; Vartiainen et al., 1994). Yet, the conceptual nature of that role and the methods of discerning it are current topics of study in a wide range of disciplinary literatures. In health literature, context is often defined as the role of population, group, or macro-level variables on health at any given level of jurisdiction (Diez-Roux, 1998; Frohlich, Potvin, Chabot, & Corin, 2002; N. A. Ross & Taylor, 1998; Whitelaw et al., 2001). These macro-level, or environmental variables may include such things as: social norms or cultural traditions; collective lifestyles; level of urbanization, economic, political, or sociodemographic profiles; social (or health) equity, and so on. These environmental factors may be either compositional or contextual in nature. Compositional variables are those comprised by the individuals within the area (i.e., the aggregated characteristics of that population such as demographics) while contextual factors are those that describe the properties of the area itself and may influence the behaviour of the population within (e.g., land use, built environment) (Diez-Roux, 2001; Macintyre & Ellaway, 2000). Although health is understood to be influenced by both environmental and individual level characteristics, these two levels traditionally have been examined separately (Verheij, 1996). A surge of methodological and theoretical research exploring methods for multi-level modeling and small-area, or neighbourhood analysis, suggested that researchers with interest in public health questions have come to consider examination of environment-level variables with as much enthusiasm as individual-level variables (Diez-Roux, 1998, 2001; C. Duncan, Jones, & Moon, 1993, 1996, 1999; Jones & Duncan, 1995; Kaplan, Everson, & Lynch, 2000; Macintyre, Maciver, & Soomans, 1993; Shouls, Congdon, & Curtis, 1996; Twigg, Moon, & Jones, 2000). Multi-level modeling is a statistical approach that attempts to acknowledge the influence and interplay of factors at a range of levels on a single dependent variable. This is achieved by including group-level variables as well as individual-level variables in the analysis to examine the characteristics of individuals and the contexts in which they are located at different levels, simultaneously (Jones & Duncan, 1995). However, care must be taken that data must be collected at the same level at which inferences are made in order to overcome methodological problems such as the ecological and atomistic fallacies (i.e., drawing individual-level inferences based on group data and vice versa) (Diez-Roux, 2001).

Research on statistical techniques such as multi-level modeling is complimented by conceptual research that acknowledges the role of context and different levels of influence on health behaviour. For example, the social ecological model of health behaviour recognizes that influences on behaviour include intrapersonal, interpersonal, institutional, and community factors as well as public policy (Emmons, 2000; L. W. Green & Kreuter, 1999; L. W. Green, Richard, & Potvin, 1996; Stokols, 1996). Other reports examine the interplay between biological, behavioural, and social influences on behaviour, and discuss the relationship between the biophysical, and socioeconomic environment (Marmot, 2000;
Pellmer, Brandt, & Baird, 2002; VanLeeuwen, Waltner-Toews, Abernathy, & Smit, 1999). All of this work culminates in a disciplinary call for action towards building a greater understanding of the patterns of how and why environment influences behaviour.

Another important consideration of context is the transferability of research findings and practice guidelines between different groups and to different places and times (Bowen & Martens, 2005; L. W. Green, 2001; Landry, Amara, & Lamari, 2001; Lavis, Robertson, Woodside, McLeod, & Abelson, 2003; Thompson, Estabrooks, & Degner, 2006) – merely one aspect of the knowledge synthesis, transfer, dissemination, and exchange (KSTE) domain. This premise underlies much of the recent efforts by health researchers to develop best practices and by health practitioners to systematize evidence-based decision making. The intent of best practices frameworks is to mitigate the gap between science and practice (Cameron, Jolin, Walker, McDermott, & Gough, 2001; Kahan & Goodstadt, 2001). Ideally, this is done by creating a cyclical process that encourages dissemination of research findings to practitioners able to use them, and the generation and transfer of relevant and timely questions by practitioners to researchers. ‘Best’ or ‘better practices’ must not only be practices that can be assessed via criteria of effectiveness, plausibility, and practicality, but they must be flexible enough to be adopted by practitioners in a range of communities with different populations, characteristics, and needs. This underscores the importance of contextual literacy or the ability to identify and interpret key differences in setting and context.

Clearly, issues of context should be critical aspects of any examination of health behaviour, program or policy aimed at intervening with a health behaviour. Recent methodological and theoretical models aimed at understanding this construct can be combined with a geographical and spatial perspective within a GIS environment. This disciplinary marriage could enhance identification of patterns and relationships between context and behaviour and better inform health promotion and public health interventions.
CHAPTER SUMMARY
The conceptual overview of the role of context in public health and health promotion illustrated the importance and utility of adopting a multi-disciplinary perspective for integrating and synthesizing the vast scope of information pertinent to health research, policy, and practice. The interplay of factors at different contextual levels, from biological to behavioural to environmental, is consistent with a social determinants of health perspective and must be considered along with individual-level variables. Further, this is consistent with the notion that, although an intervention at any given level may influence behaviour change, concurrent influence at several levels (within an ecological framework) may result in a greater and more sustainable behaviour change. While understanding these relationships may be extremely complex, the importance of doing so cannot be ignored.

Researchers interested in health questions have done a great deal of work to examine these relationships both scientifically and theoretically. Yet, there remains a need for a mechanism by which to visualize these patterns and gaps at the different levels and to hypothesize relationships among the variables. Geographic Information Systems have the potential to meet this need, while simultaneously introducing the examination of the spatial aspect of health behaviours and public health policy.
Chapter 2: Literature Review Methodology

This comprehensive literature review was first conducted in the spring of 2002. The original literature review criteria was used to conduct a follow-up review in the summer of 2007. Articles were identified through a combination of computerized database searches and hand searches of the reference lists in relevant papers. The databases PubMed [Medline], PsychInfo, and ISI Web of Science (each for 1990-2007), CancerLit (1966-2002), Geography (1990-2002), and CurrentContents (2000-2002) were utilized. The search was restricted to studies reported in English language journals and indexed with the keyword strategy outlined in Table 1 below.

### TABLE 1  
**Keyword strategy for literature review**

<table>
<thead>
<tr>
<th>SET</th>
<th>SEARCH TERMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>001</td>
<td>GIS OR Geographic Information System* AND Health</td>
</tr>
<tr>
<td>002</td>
<td>#1 AND Policy</td>
</tr>
<tr>
<td>003</td>
<td>GIS OR Geographic Information System* AND Decision Support</td>
</tr>
<tr>
<td>004</td>
<td>#3 AND Policy</td>
</tr>
<tr>
<td>005</td>
<td>#3 AND Health</td>
</tr>
<tr>
<td>006</td>
<td>GIS OR Geographic Information System* AND Bylaw*</td>
</tr>
<tr>
<td>007</td>
<td>GIS OR Geographic Information System* AND Regulation</td>
</tr>
<tr>
<td>008</td>
<td>#7 AND Health</td>
</tr>
<tr>
<td>009</td>
<td>#7 AND Policy OR Decision Support</td>
</tr>
<tr>
<td>010</td>
<td>GIS OR Geographic Information System* AND Legislation</td>
</tr>
<tr>
<td>011</td>
<td>#10 AND Health</td>
</tr>
<tr>
<td>012</td>
<td>#10 AND Policy and Decision Support</td>
</tr>
<tr>
<td>013</td>
<td>GIS OR Geographic Information System* AND Prevention AND Health</td>
</tr>
<tr>
<td>014</td>
<td>GIS OR Geographic Information System* AND Prevention AND Policy</td>
</tr>
<tr>
<td>015</td>
<td>GIS OR Geographic Information System* AND Prevention AND Disease</td>
</tr>
</tbody>
</table>

Only papers that addressed GIS methodology or human health-related GIS applications were selected. Papers that addressed veterinary or ecological applications, as well as those that were only tangentially related to human health (e.g., landscape ecology) were excluded from the review. A specific emphasis on policy and decision making was included in the literature review strategy to ensure practice- and policy-related papers were captured as thoroughly as those with a research focus. Resource material from various applied GIS websites were consulted to supplement the journal review.

**SYNTHESIS OF REVIEW: USE OF GIS IN PUBLIC HEALTH**

The final review was comprised of 621 journal articles and book chapters reporting health-related applications of Geographic Information Systems, which were organized into categories based on main
type of application reported: i) disease surveillance (n = 227); ii) risk analysis (n = 189); iii) health access and planning (n = 138); iv) community health profiling (n = 115); and (v) general/methodological (n=17). The categorization of the literature is summarized in Figure 1.

**FIGURE 1 Categorization of literature by GIS application**

It is important to note that although these application categories were treated as distinct for the purposes of organizing this report; they were not mutually exclusive and often overlapped. For example, many applications that focused on disease surveillance also had components of risk analysis and vice versa. In some cases, single studies reported utilizing aspects of each of the four categories. Where there was more than one application reported, the paper was assigned to the category most closely aligned with the primary GIS application used.

The findings from the literature review will be discussed in order of most common to least common category of application, beginning with an overview of disease surveillance applications and concluding with a summary of work in the area of community health profiling. As apparent in the pie chart representing the relative distribution of papers across the four categories, research reported in this area has traditionally focused on disease and risk-based GIS applications. This is not surprising given that these applications are natural extensions of the historical foci of medical geography and spatial modeling. Despite this, GIS applications pertaining to health access and planning and to community health profiling have become more prevalent in recent literature.

The synthesis of this review will progress as follows. First, geographic information systems will be defined, uses of GIS will be identified, and this will be followed by a discussion of the methodological
issues and challenges. The technical report will conclude with a discussion of implications for use of GIS in health promotion and public health.

**Geographic Information Systems**

Understanding relationships between environmental factors (e.g., sociodemographic, economic, political, and physical variables) and health is a complex undertaking, and implies consideration of a range of variables at micro, macro, and intermediary levels. A Geographic Information System (GIS) can act as a facilitating mechanism to allow appropriate integration and presentation of the databases that encompass these variables. A GIS is also used to investigate statistical relationships that may vary from place to place. This spatial analysis is valuable for identifying significant relationships among those variables that influence health outcomes at a range of aggregations from local to international, data permitting. The GIS can then be used to present results from the analysis (i.e., patterns in the data) in the form of visually appealing, high-impact maps. These maps can tell powerful stories and communicate relationships in a way that otherwise may not be possible with other techniques (Mullner, Chung, Croke, & Mensah, 2004; Parchman, Ferreer, & Blanchard, 2002). To this end, GIS has been used in the domains of environmental health, disease ecology, and public health as a tool for processing, analyzing, and visualizing data (Kistemann, Dangendorf, & Schweikart, 2002).

There are many definitions for Geographic Information Systems, yet it is generally acknowledged that it is a computer-based system used for the integration and analysis of spatial data, which has the ability to generate extensive relational databases. A GIS can be defined as a organized collection of five key components: i) computer hardware, ii) computer software, iii) geographic (cartographic) and attribute (other variables) data, iv) GIS-trained personnel, and v) statistical techniques and methods for data modeling and analysis (Chung, Yang, & Bell, 2004; Cromley & McLafferty, 2002; T. B. Richards, Croner, & Novick, 1999b, 1999c; G. I. Thrall, 1999).

GIS software provides the functions and tools designed to easily capture, store, update, manipulate, analyze, and display all forms of geographically referenced information efficiently (Bernardi, 2001; Riner, Cunningham, & Johnson, 2004; S. E. Thrall, 1999). A GIS database is similar to other relational databases, with the exception that one of the database fields encodes the location of the item on the surface of the earth using x, y coordinates. In this way, a GIS can be used to integrate spatial data, or data that are characterized by location, and related qualitative or quantitative information (e.g., social, economic, health, environmental conditions), which are listed as ‘attributes’ of the spatial location. This is done within a single system and allows for the analysis of these attributes by geographic location. It is a powerful tool that is highly effective at combining disparate data sources to visually illustrate complex relationships within that data.

Thus, a Geographic Information System can be used to address research questions or practical applications of: condition – what is at …?; location – where is …?; trend - what has changed since…?; pattern – what spatial patterns exist?; and modeling or scenario-building – what if…? In other words, it can be used to track the geographic location of people, places, events, actions, or impacts, to conduct spatial or statistical analysis on the variables of interest, and to create maps that display the spatial distributions and relationships of those variables (Bedard & Henriques, 2002; Phillips, Kinman, Schnitzer, Lindbloo, & Ewigman, 2000; T. B. Richards, Croner, Rushton, Brown, & Fowler, 1999; Schlundt, Mushi, Larson, & Marrs, 2001; Sheppard, Leitner, McMaster, & Tian, 1999).
The implementation of a GIS in data analysis brings consistency to the way in which data are perceived. Other benefits include the ability to conduct rapid comparisons with data from neighbouring populations and the relative ease and speed with which data can be modified or updated. A GIS platform can also facilitate use of geo-referenced data, thus enabling links between health outcome results and other inputs of the decision-making process such as disease transmission, health equity, and high risk populations or areas. It enables researchers, practitioners, and policy makers to generate representations of the data and to clearly interpret the results. In addition, because the applications are easily customized, users are able to add new functions according to their needs. This substantially reduces the time and effort required for software development and/or testing (Albert, Gesler, & Wittie, 1995; Contini, Bellezza, Christou, & Kirchsteiger, 2000; Higgs & Gould, 2001).

Use of Geographic Information Systems is quickly gaining recognition as an effective means to answer complex, ecological questions in health promotion, public health, medicine, and epidemiology (Clarke, McLafferty, & Tempalski, 1996; Cromley & McLafferty, 2002; Foody, 2006; Goldman & Schmalz, 2000; McLafferty, 2003; Melnick & Fleming, 1999; Miranda et al., 2005; Riner et al., 2004; Yasnoff & Sondik, 1999). It is a unique tool that allows for the integration of multiple data sources, visual representations of complex geographic data, and the application of various spatial analytic techniques to answer questions like, “How do asthma rates vary across the country?” or “Are there higher rates in communities closer to industrial areas?”

**CHAPTER SUMMARY**

GIS is an enabling technology that allows people with a range of expertise in a variety of settings to integrate and analyze spatial data to answer pertinent questions in a vivid and meaningful way.
Chapter 3: Disease Surveillance

One of the most common and longstanding uses of GIS in public health is for disease surveillance, which is the compilation and tracking of information on the incidence, prevalence, and spread of disease (Rushton, 1998; Wall & Devine, 2000). There are two interrelated components of disease surveillance – disease mapping and disease modeling. Disease mapping is used to understand the geographical distribution and spread of disease in the past or present (Myers, Rogers, Cox, Flahault, & Hay, 2000; Robinson, 2000). Disease modeling is closely related to risk analysis and is used to forecast future disease spread or epidemic outbreaks and to identify those factors that may foster or inhibit disease transmission (Myers et al., 2000; Robinson, 2000). The characteristics of a place, including its demography (population characteristics) and environment, are often critical factors in determining the origin and spread of disease and may offer insight to its prevention and control (Forcen & Salazar, 2000).

Recently, a review was compiled by Cromley (2003) to examine how GIS has been utilized to investigate disease. This review focused on research conducted in the United States of America (USA) and divided previous studies into three sections: i) reviewing surveys related to the sources and distribution of disease agents; ii) exploring how GIS has been used to examine exposure to disease agents; and iii) examining how studies have integrated and analyzed information on all stages of the hazard-exposure-outcome process. In this literature review, Cromley’s (2003) work is expanded on by also exploring literature that has investigated disease surveillance on a global scale. For example, a recent report by Kyle and colleagues (2006) outlines an environmental public tracking tool that was developed by the USA Department of Health and Human Services in combination with state and local health departments. This tool has been used to support policy strategies and interventions for disease prevention at the local, state, and federal levels. Similarly, Weis and colleagues (2005) have created a toolbox of methods for measuring external (environmental) and internal (biologic) exposure. This framework concentrates on understanding complex human diseases by exploring exposure-disease relationships and their interaction with genetic and environmental factors.

DISEASE MAPPING

Disease mapping is the construction and tracking of mortality (death) and morbidity (illness) patterns related to a single disease or set of diseases. Although greatly enhanced by GIS applications, disease mapping has a long history that pre-dates the development of this particular technology. As early as 1798, maps were produced to understand the geographical distribution of yellow fever in New York City, USA, and in the 1850s, John Snow mapped the locations of cholera cases in Soho, London, contributing to the conclusion that water from the Broad Street Pump was responsible for the outbreak (Schellenberg et al., 1998; Walter, 2000). As disease outbreaks are often a result of the combination of social, environmental, and individual variables – each with a unique spatial expression – disease mapping is a natural application of GIS as it facilitates the integration of all of these variables for analysis. This geographic epidemiology of infectious diseases can help in identifying point source outbreaks or clusters of disease beyond a containment zone, elucidating dispersion patterns, and giving direction and coordination to control strategies. In these cases, a GIS is a map-based tool that can be used to study the distribution, dynamics, and environmental correlates of diseases as statistical relationships often exist between mapped features and diseases (Boone et al., 2000).
In a Canadian example, the Public Health Agency of Canada maintains a website that provides information on the incidence of cancer, cardiovascular diseases, notifiable diseases, major chronic diseases, and injuries in Canada. This website, called Disease Surveillance On-Line, is open to the public and allows the user to view current disease statistics and trends in disease incidence and mortality by sex, age group, and province/territory over time (http://dsol-smed.hc-sc.gc.ca/dsol-smed/). The user is able to manipulate the maps produced by selecting different mapping criteria for each of the variables – disease (e.g., all cancers or by each of 39 different cancer sites), year, sex, region, and data type (e.g., crude death rates vs. age-standardized death rates).

There are numerous disease-mapping applications reported in the GIS literature. Many of these applications involve surveillance and monitoring of the disease incidence and prevalence to support control efforts, while others are focused on generating atlases to track the historical trends of the disease. Disease-related applications cover a wide range of diseases from vector-borne illnesses to communicable disease to cancer, in both rural and urban areas of industrial and developing countries.

**Vector-Borne Diseases**

Our enumeration of GIS studies of vector-borne diseases in developing countries revealed a wide range of applications. These include:

- surveillance of malaria in Kenya (Schellenberg et al., 1998), Sri Lanka (Klinkenberg, van der Hoek, & Amerasinghe, 2004) and Tanzania (Oesterholt et al., 2006);
- sleeping sickness in Africa (Cattand, Jannin, & Lucas, 2001) and Uganda (Odiit et al., 2004);
- human helminth infection in Sub-Saharan Africa (Brooker & Michael, 2000; Brooker, Rowlands, Haller, Savioli, & Bundy, 2000; Handzel et al., 2003);
- onchocerciasis in Africa (Seketeli et al., 2002);
- Ascaris lumbricoides infection in schoolchildren in South Africa (Saathoff et al., 2005);
- American visceral leishmaniasis in Brazil (Bavia, Carneiro, Gurgel, Madureira-Filho, & Barbosa, 2005);
- onchocerciasis in Venezuela (Botto et al., 2005);
- the distribution of hemorrhagic fever with renal syndrome in China (Fang et al., 2006);
- a dengue fever outbreak in India (Nisha et al., 2005) and Bangladesh (Ali, Wagatsuma, Emch, & Breiman, 2003);
- the distribution of active trachoma in Tanzania (Polack et al., 2005);
- viral encephalitis in Thailand (Henrich et al., 2003); and
- dengue vectors in Taiwan (Su & Chang, 1994), Brazil (Barcellos, Pustai, Weber, & Brito, 2005) and Trinidad (Chadee, Williams, & Kitron, 2005).

An interesting study by Owen and Slaymaker (2005) identified hot spots in Cambodia to determine the correlation between poverty, dengue fever, and tuberculosis. In New Zealand, four years of giardiasis data were analyzed to describe the epidemiological patterns of infection (Hoque, Hope, Scragg, Baker, & Shrestha, 2004). Giardia is the most common water-borne disease in New Zealand, therefore

1 website current at the time of printing

| Disease Surveillance | 10 |
surveillance of its infection pattern is a very important public health issue. In another unique study conducted by Uphoff and colleagues (2004), an influenza map was created by combining information from Germany and the Netherlands to understand the spread of disease. Finally, Chagas disease (human tropical parasitic disease) in Mexico was monitored to develop risk transmission maps; these served as an effective tool during the implementation of vector control programs in the region (Du-monteil & Gourbiere, 2004).

Other studies have addressed broader issues of vector surveillance and control, describing the use of satellite surveillance systems and GIS to create a global network for the control of disease (Gong, Xu, & Liang, 2006; Jarup, 2004; Malone et al., 2001; Prince, Chen, & Lun, 2005; D. J. Rogers & Randolph, 2003; Washino & Wood, 1994). For example, in Washington, DC, USA, geospatial mapping and trend analysis were used to detect disease outbreaks (M. D. Lewis et al., 2002). Similarly, Vescovi and colleagues (2005) describe how GIS can be used to assess public health risk due to extremely high temperature events, while Waring and colleagues (2005) used GIS to conduct rapid needs assessments in areas following weather-related disasters.

Communicable Diseases

GIS has also been widely used to map the incidence of communicable diseases. In Maryland, USA, the Department of Health and Mental Hygiene used a GIS for the surveillance and modeling of communicable diseases in a number of communities, including public health unit surveillance of gonorrhea in Baltimore, USA (Devasundaram, Rohn, Dwayer, & Israel, 1998). The intent was to identify core areas of disease incidence because, from a disease control perspective, an intervention to reduce disease in a core area (often characterized by poverty and poor health care access) should impact community-wide disease incidence (Becker, Glass, Brathwaite, & Zenilman, 1998; Zenilman, Ellish, Fresia, & Glass, 1999). Another GIS infectious disease surveillance system for gonorrhea and chlamydia was established at a large military post in Fort Bragg, North Carolina, USA, where findings suggested that this type of surveillance was easily and rapidly implemented and proved useful for developing preventive interventions (Zenilman et al., 2002). In other examples, GIS has been used to: i) characterize the HIV epidemic in Thai men (Torugsa et al., 2003); ii) document the non-random distribution of hepatitis C in Connecticut, USA (Trooskin, Hadler, Louis, & Navarro, 2005); iii) track the increasing incidence of leishmania and HIV co-infection in Europe (Desjeux & Alvar, 2003); iv) map the incidence of meningococcal disease in relation to socioeconomic environment (Williams, Willocks, Lake, & Hunter, 2004); and, v) create a visual display of hepatitis C prevalence within the city of Karachi, Pakistan (Mujeeb, Shahab, & Hyder, 2000).

Infectious Diseases

The use of GIS approaches is becoming increasingly popular in disease mapping applications for the prediction, management, and control of infectious diseases and other public health problems. For example, in Arizona, USA, mapping the number of cases of coccidioidomycosis led to the discovery that an increased incidence was associated with environmental and climatic changes (Park et al., 2005). In Baltimore, USA, by mapping the incidence of tuberculosis transmissions, it was evident that certain geographical areas were associated with higher incidence rates (Bishai et al., 1998). In Africa, the geographical distribution of tuberculosis transmission was monitored to direct health services to high-risk areas and to help control the spread of disease (Beyers et al., 1996; Bishai et al., 1998; J. D. Porter,
In another interesting study, a GIS was used during the development of a surveillance system to control and prevent the spread of tuberculosis. In Germany, a surveillance system was developed to link infectious disease information spatial and temporal patterns; this GIS supported the translation of information concerning prevention and control measures for infectious diseases (Rissland, van Treeck, Taeger, & Baumeister, 2003).

Cancer Type and Incidence

Disease mapping for the spatial analysis of cancer is another common application of GIS, particularly in the USA. One such study from Florida used GIS to show racial and geographic disparities in the incidence of prostate cancer (Xiao, Gwede, Kiros, & Milla, 2007). In other research, GIS has also been used to identify the association between lung cancer and residential location in Massachusetts (Vieira, Wesbster, Aschengrau, & Ozonoff, 2002), and between lung cancer and chronic exposure to fine particles in France (Nerriere et al., 2005). In Texas, the incidence of colorectal cancer mortality over the previous 15 years was used to understand the extent of demographic and geographic disparities associated with incidence (C. E. Hsu, Mas, Hickey, Miller, & Lai, 2006). In Iowa, the geographic locations of colorectal cancer were tracked to identify the differences in intrahospital services (Rushton, Peleg, Banerjee, Smith, & West, 2004).

Other studies conducted in the USA have examined the incidence of cancer and birth defects (Tobias, Roy, Alo, & Howe, 1996) in proximity to radiation sites (E. White & Aldrich, 1999), agricultural pesticides (Reynolds et al., 2002), and other National Priority List waste sites (Krautheim & Aldrich, 1997). Similarly, Kohli, Noorlind, and Lofman (2000) conducted an ecological correlation study in Sweden to examine the spatial and temporal patterns of childhood leukaemia in areas with different radon levels using a GIS and existing population and disease registries. Also in Sweden, Hjalmars and colleagues (1996) used a GIS and spatial statistics to detect clusters (i.e., detect aggregations of disease cases) for cluster detection of childhood leukaemia. In addition, Bithell and Vincent (2000) reported a thorough review of the research done on geographical variations (local, national [UK] and international levels) of childhood leukaemia incidence.

In China, GIS was used to examine the association between climate variables and esophageal cancer (K. Wu & Li, 2007). In Britain, the prevalence of breast cancer was examined to determine which geographic areas had the highest incidence (Mullee, De Stavola, Romanengo, & M.P., 2004). In a similar study in New Jersey, USA, a spatial scan was conducted to determine which areas had a significant number of women diagnosed with late-stage breast cancer (Roche, Skinner, & Weinstein, 2002). In another interesting article, Teppo (1998) discussed the problems and possibilities when using GIS to examine cancer data. Finally, in another paper from the USA, 36 state comprehensive cancer control plans were reviewed to identify those which included maps (Parrott, Hopfer, Ghetian, & Lengerich, 2007). From this review it was evident that the maps typically only reported cancer incidence and mortality and there was infrequent display of the stage at which the cancer was diagnosed creating a substantial gap in knowledge useful for planning and decision making (Parrott et al., 2007).

Mapping of Individual Level Health Issues

Just as GIS technology has been used to map the incidence and spread of vector-borne diseases, communicable diseases, infectious diseases, and cancers, it has also been used to map the occurrence of
other individual level health issues. Some examples, include:

- mapping the incidence of babies born with Down syndrome in Australia (Mugglie, McCloskey, & Halliday, 2006);
- examining at the prevalence of diabetes in Finnish children (Ranta & Penttinen, 2000);
- mapping the occurrence of diabetes to allow for the identification of high risk areas to help facilitate local diabetes prevention efforts (Kruger, Brady, & Shirey, 2007);
- mapping of birth defects in Atlanta, USA, for use during spatial surveillance and research (Siffel, Strickland, Gardner, Kirby, & Correa, 2006);
- looking at the relationship between exposure to hard water and eczema in schoolchildren in Nottingham, UK (McNally et al., 1998);
- tracking changes in the spatial pattern of low birth weight in a southern California county, USA (P. English, Kharrazi, Davies, Scalf, & Waller, 2003); and
- determining the association between tuberculosis, economic conditions and high immigration rates in Germany (Kistemann et al., 2002).

These studies all concluded that relatively simple applications of mapping technology can be useful for rapidly summarizing and displaying health indicators and related information in a contextually and spatially meaningful fashion in a form that is usable to health care providers, health managers, and policy makers.

**Mapping of Morbidity and Mortality**

Another application of disease mapping is the generation of disease morbidity or mortality atlases representing a single point in time or consisting of a time series. Examples include:

- a national register of historic and contemporary anthrax foci in the USSR (Cherkasskiy, 1999);
- mapping of mortality data in the USA (Pickle, 2000) and Britain (Mitchell, Dorling, & Shaw, 2002);
- showing geographic patterns in mortality to identify high-risk locations in Spain (Benach et al., 2003);
- exploring small-area variation in mortality in Finland (M. Rytkonen, Rusanen, & Nayha, 2001) and China (Fu et al., 2004);
- the production of time-series data for cholera and other diarrhoeal diseases in Mexico to identify social groups at risk and to target scarce resources for adequate health interventions (Cifuentes, Hernandez, Venczel, & Hurtado, 1999); and
- in Egypt, the number of mortalities and live births in the population under the age of five years was mapped (Mohamed, Nofal, Hassan, & Elkaffas, 2004).

In another example, Braga and colleagues (1998) developed a multipurpose, interactive mortality atlas of Italy with the hope that new interpretative hypotheses could be generated by means of visualization and exploration of differences in the geographical distribution of mortality events. They felt that this
technique was successful in disentangling contextual effects (due to the spatial location) from compositional effects (due to the population structure) in their study.

Furthermore, in an interesting study conducted in Ontario, Canada, a GIS was utilized to examine water pollution in the Great Lakes Areas of Concern (AOCs); from this information the potential impact on disease morbidity and mortality rates in the area was elucidated (S. J. Elliott, Eyles, & DeLuca, 2001). The purpose of this application was to generate hypotheses and facilitate the use of the information reported by International Joint Commission (the international agency that oversees the Great Lakes water quality issues) by Health Canada. This was achieved by transforming intensive tabular disease data into spatially-related maps depicting the AOCs in Canada.

**Exposure to Pesticides and Air Pollutants**

GIS technology has also been used to track variation in the incidence of symptomatic pesticide exposure (Sudakin, Horowitz, & Griffin, 2002) and to analyze the accidental release of hazardous materials relative to the demographic composition of residents in nearby communities (Margai, 2001). In one example, GIS was used to estimate the outdoor particulate matter concentrations over New York City, USA, after the World Trade Center disaster (Ng, Dimitroulopolous, Grossinho, Chen, & Kendall, 2005). It was found that although the particulate matter concentrations were below that of the National Ambient Air Quality Standards they might still be a concern for residents (Ng et al., 2005). In another study, residential location was studied to determine if certain residents of Washington County, USA, were at an increased risk for higher blood lead levels because of their close proximity to a USA Environmental Protection Agency Superfund site (Gaffney et al., 2005). This is a global application of GIS. In Tijuana, Mexico, the spatial distributions of childhood lead poisoning were used to model the potential risk to lead exposure (Gonzalez, Pham, Ericson, & Baker, 2002). In addition, in the Slovak Republic arsenic groundwater content was mapped to identify areas with high health risks (Rapant & Kremova, 2007).

**Utilizing GIS to Explore Injury Prevalence**

Mapping injury prevalence is an emerging area of GIS application. One recent study in this field examined the geography of fall injuries in the elderly (Yiannakoulias et al., 2003). By using a GIS to describe the pattern of emergency department reported falls in the elderly the highest risk areas in the Edmonton area (Alberta, Canada) were located (Yiannakoulias et al., 2003). In a similar study, GIS was used to map injury type and location in Western Kenya; this information, used in combination with the patients’ medical records led to the development of an innovative electronic injury surveillance system (Odero, Rotich, Yiannoutsos, Ouna, & Tierney, 2007).

**Unique Mapping Applications**

GIS approaches have been used in many cases to map unique events. Some examples include:

- examining the distribution of ambulance calls during extreme heat waves in Toronto, Canada (Dolney & Sheridan, 2006);
- looking at the location of out-of-hospital cardiac arrests (Lerner, Faribanks, & Shah, 2005);
exploring the incidence of acute myocardial infarction in eastern Finland (Viik-Kajander et al., 2003);

- the mapping of spatial clusters for accidental poisoning mortality in Texas, USA (Nkhoma, Hsu, Hunt, & Harris, 2004);

- investigating the geographic clustering of adult asthma hospitalizations as a result of proximity to the Peace Bridge Complex and freeways at the United States and Canada border crossing (Oyana, Rogerson, & Lwebuga-Mukasa, 2004);

- looking at the difference in rural and urban incidence of type 1 diabetes among children in Finland (M. Rytkonen et al., 2003);

- mapping of soft tissue infections in children to determine areas with increased risk (Tirabassi et al., 2005); and

- the mapping of snakebite incidences in Ghana and Nigeria to identify the potential probability of high snakebite incidence (Molesworth, Harrison, Theakston, & Laloo, 2003).

In one example from the USA, McKee and colleagues (2000) discussed using a GIS to track and control an outbreak of shigellosis in North Carolina. This study illustrated the benefits of direct visualization on the dynamics of disease transmission within a community in order to help target intervention and education programs. This study went beyond disease mapping to ensure that the results of the study were applied in the community to more effectively and appropriately target interventions and education programs to meet the needs of the community.

Summary

Clearly, GIS mapping is an effective public health tool for helping to prevent the spread of diseases, facilitating the development of interventions, evaluating health outcomes, appraising population risks, and for summarizing and displaying health indicators. Yet, researchers and practitioners must use caution when mapping patient data. A case in point is the display of geocoded patient addresses. It has been well noted that lowering the resolution of maps displaying geocoded patient addresses is not an effective means for protecting patients from being re-identified (Brownstein, Cassa, Kohane, & Mandl, 2006; Curtis, Mills, & Leitner, 2006). Therefore, it is necessary that when researchers are displaying maps to the public that a series of point-level spatial confidentiality guidelines are met before government decisions are made to ensure that patients anonymity is maintained (Curtis et al., 2006).

In addition, maps created using a GIS can be an effective tool for displaying the incidence and location of diseases, both latent and life-threatening. The key is to understand what kind of display is most effective. For example, Ogao (2006) sought to determine the usefulness of spatio-temporal maps for looking at geospatial structures encompassing disease, urban, and census mapping. Through this review it was evident that interactivity in animation is preferential when identifying, interpreting, and providing explanations about observed geospatial phenomena.

Finally, integration of GIS technology into routine monitoring of health events offers a rapid quantitative means for identification of unusual disease patterns. This provides a vehicle for disease investigation as well as a tool for measuring the success of interventions. When a GIS is coupled with spatial statistics or other analytical techniques, patterns of disease spread can be readily discerned and predictive.
models generated to facilitate intervention (McKee et al., 2000). In addition, GIS mapping is a useful administrative tool for evaluating health outcomes, appraising population risks, creating scenarios, and planning intervention strategies (Garnelo, Brandao, & Levino, 2005). Simple applications of mapping technologies can be beneficial in summarizing and displaying health indicators in a way that can be utilized by healthcare providers, public health managers, and policy makers in practice (Sabesan & Raju, 2005).

**DISEASE MODELING**

Disease modeling takes the disease mapping application one step further to: i) predict the future spread of disease, ii) identify factors that may foster or inhibit the transmission of disease, iii) pinpoint high-risk areas for disease prevention or intervention, iv) target control efforts, (v) identify gaps, and, vi) increase stimulus for data collection in these areas. This use of GIS is often one component of risk analysis applications associated with vector-borne or sexually transmitted diseases. Information generated through disease modeling can be used to generate policy that will best meet needs for immunization, vector control, or other public health initiatives. Duncanson suggests that in this application, “a GIS enables the user to animate the data, moving backwards and forwards in time to look for patterns and waves of epidemics” (1996, p. 680).

**Vector-Borne Diseases**

One of the most predominant applications of disease modeling using GIS in conjunction with a range of spatial analysis techniques has been for the examination of factors influencing malaria transmission. This body of work addresses a variety of influential factors or combinations of factors in a number of countries and over a range of time periods. For example, a GIS and multiple regression were used to examine the combined effects of the physical environment, the presence of efficient vector species, and a mobile population along international borders in relation to the incidence of malaria in the Yunnan Province of China in different time periods (Hu et al., 1998). Another study examined the interrelationships between macro-political, social, and economic policies; human migration; and agricultural development on malaria on the Amazon frontier (Singer & de Castro, 2001). Furthermore, in a review study, GIS was used in combination with historical maps to quantify the anthropogenic impact of the distribution of malaria in the 20th century (Hay, Guerra, Tatem, Noor, & Snow, 2004).

Malaria-focused research using GIS has linked spatial and temporal incidence patterns with different vector populations (i.e., parasitic populations) associated with malaria in a range of locales including Trinidad (Chadee & Kitron, 1999), Israel (U. Kitron et al., 1994), Sub-Saharan Africa (Hay, Omumbo, Craig, & Snow, 2000), Thailand (Indaratna et al., 1998; Nakhapakorn & Tripathi, 2005), Mali (Gaudart et al., 2006), and Guinea (Cano et al., 2006). Other works report on the incidence of malaria in relation to different malaria control techniques (Bretas, 1995; Ghebreyesus et al., 2000; Mnzava et al., 2001), health and economic resources (Ghebreyesus et al., 2000; Indaratna et al., 1998), and the prevention and control of epidemics (Najera, 1999). Although GIS can be a very effective tool in fighting malaria, there have been a host of challenges reported. One particular review identified three broad problems (i.e., inadequate data, insufficient technological training, and no agreement on how to analysis the information); the article concluded by discussing strategies to overcome these barriers (Sipe & Dale, 2003). In another study, a GIS-based information management system was outlined that served to help urban malaria control in India (Srivastava et al., 2003). This system was used to pinpoint
high-risk areas, identify risk factors, and to monitor and evaluate control measures. In South Africa, a similar system was developed; this system helped to ensure that appropriate malaria control measures were followed to inform tourism and social and economic development (C. Martin, Curtis, Fraser, & Sharp, 2002). In Columbia, researchers examined whether remote sensing provided valuable information to malaria early warning systems (Ceccato, Connor, Jeanne, & Thomson, 2005). Although the authors found this system to be useful, they also discussed problems and issues with implementing the system on a global scale (Ceccato et al., 2005). In a review article by Pinzon and colleagues (2005), recent classic and research materials were explored to outline how remote sensing and GIS have been used in public health to provide spatial and temporal climatic patterns that can be used to control the intensity of vector-borne diseases such as malaria. In a similar review article, Jaishankar and Jhonson (2006) present an overview of geomatics and describe the potential impacts of climate change on vector-borne diseases; they also review how remote sensing applications have been used for disease vector surveillance.

Malaria is not the only vector-borne disease of interest to researchers who have used GIS for disease modeling (for general overviews of the literature see U. Kitron, 1998; Molyneux, 2001; Mott, Nuttall, Desjeux, & Cattand, 1995). Disease modeling has also occurred extensively with West Nile virus. For example, in Mississippi, USA, modeling of West Nile virus indicated that a higher presence of dead birds was positively correlated with human West Nile virus risk (Cooke, Grala, & Wallis, 2006). Similarly, in Georgia, USA, GIS and logistic regression were used to model the distribution of West Nile virus (Gibbs et al., 2006). In British Columbia, Canada, GIS was used to identify areas of greater potential risk prior to the West Nile virus introduction (Tachiiri, Klinkenberg, Mak, & Kazmi, 2006). Also in Canada, real-time surveillance, real-time GIS, and open GIS technology were coupled to improve the surveillance of West Nile virus (Shuai, Buck, Sockett, Aramini, & Pollari, 2006). Prior to the development of this pilot system, a real-time GIS for public health monitoring was developed in Quebec, Canada, to be used in all regions of the province for West Nile virus monitoring (Gosselin, Lebel, Rivest, & Douville-Fradet, 2005).

GIS can be used to better understand complex processes of disease transmission and spread. This information can help public health authorities plan and develop geographically coordinated immunization campaigns targeted at communities at greatest risk, and then move outward to those less at risk. GIS can then be utilized to track and assess the effects of vaccinations as well as coordinate the administrative collaboration, risk assessment, and mobilization of local authorities to conduct necessary vector control measures (U. Kitron et al., 1994). In one example, a web-based GIS urgent medical system was developed for Severe Acute Respiratory Syndrome (SARS) (Lu, 2004). The system combined Web-GIS, computer supported cooperative work Java, and multimedia technologies to isolate the area of the outbreak; this information was used by public health officials to control the spread of the disease (Lu, 2004).

Infectious Diseases

GIS has also been used to model the socio-environmental determinants, the spatial and temporal dynamics, and the environmental factors related to the transmission and control of various infectious diseases. Some examples of these include exploring:

- cholera in southern Africa (Fleming, van der Merwe, & McFerren, 2007);
In a specific example from England and Wales, a GIS was utilized to assist in determining whether the system used for surveillance of infectious diseases was representative of the general population (Harcourt, Edwards, Fleming, Smith, & Smith, 2004). Through this study it was evident that those clinical practices that provided surveillance data were less deprived than the general population (Harcourt et al., 2004).

In another example, Duncanson (1996) reported using a GIS to map child mortalities due to infectious disease and suggested that a GIS could be used to identify health problem ‘hot spots’ through the examination of outbreaks. This information could then be used to evaluate the efficacy of drug therapy after implementation at those hot spots. In other words, identification of high-risk areas can lead to more effective health service provision and vaccination programs and could provide insights that may then act as an ‘early-warning’ system. A similar study examined the distribution of LaCrosse encephalitis in Illinois, USA using a GIS and spatial statistics to identify hot spots and potential transmission paths of the disease (U. Kitron, Michael, Swanson, & Haramis, 1997).

**Tick and Tick-Borne Diseases**

GIS can also be used for predicting potential disease outbreaks and for the targeting of intervention programs for various tick and tick-borne diseases. For example, in Connecticut, USA, a GIS was combined with methods of spatial analysis to provide a tool for improving disease prevention and for controlling the spread of newly recognized tick-borne diseases and human granulocytic ehrlichiosis (Chaput, Meek, & Heimer, 2002). In another study, Daniel, Kolar and Zeman (2004), offer a review of studies which have used GIS as a means of addressing many problems associated with tick ecology.

**Exposure to Pollutants**

Disease modeling has also been applied as a method for predicting the impact that exposure to pollution has on the incidence of cancer. In one such study, an exposure simulation model was used to
pinpoint the exact place and time that an urban population was exposed to airborne dioxin (Poulstrup & Hansen, 2004). This information can be used to identify the exposed population and recognize cancers related to the pollution (Poulstrup & Hansen, 2004).

Disease modeling has also been used to map exposure to pollutants to estimate the impact of potential health risks. For example:

- in Bangladesh, spatial mitigation was used to identify problem regions and high risk zones for arsenic poisoning (M. M. Hassan, 2005);
- in Switzerland, residential histories coupled with GIS modeling were used to provide individual long-term air pollutant exposure estimates (Ackermann-Liebrich et al., 2005);
- in California, USA, a framework was developed to assess community health risk implications of alternative land use by linking land use planning policy and the spatial patterns of exposure to toxic emissions (Willis & Keller, 2007); and
- in Sweden, a kriging technique was used to link addresses to increased levels of cadmium and lead; this method was used to estimate human exposure to lead and cadmium (Hellstrom, Jarup, Persson, & Axelson, 2004).

**Other Disease Modeling Applications**

As the area of disease modeling continues to develop, new applications for this approach continue to emerge in the literature. Some recent examples include: i) the creation of an overview for forecasting disease risk and increased epidemic preparedness in public health through sentinel or early warning systems for the surveillance of disease (Myers et al., 2000); ii) the development of a global stochastic cellular automata model to represent the progression of diseases to facilitate optimal use of public health resources for prevention, control, and surveillance (Mikler, Venkatachalam, & Abbas, 2005); iii) the assessment of health inequity and disease transmission with regards to proximity of home to roads, where better access to roads was found to be highly correlated with increased prevalence (and risk) of HIV (Tanser, Le Sueur, Solarsh, & Wilkinson, 2000); and, iv) use of spatial microsimulation to analyze health inequalities in British regions over a 30-year period (Ballas, Clarke, Dorling, Rigby, & Wheeler, 2006). Each of these applications offers a unique opportunity to inform public health efforts in disease prevention and control.
Disease mapping and disease modeling applications of GIS provide a systematic way to spatially link known epidemiologic data on disease systems with relevant features in the environment to develop models that can then be used, by extrapolation, to predict risk of disease over broad geographic areas where data are not available. This creates the possibility of using GIS to systematically represent the spatial distribution of disease in a way that allows discovery and exploration of the relationships between the variables that may not be as readily apparent using traditional tools and techniques (Bavia et al., 1999). From a social determinants of health lens, modeling disease transmission could also play a critical role in the geography of human rights and social inequalities, and in demonstrating how processes such as climate change interact with human rights to favour disease emergence (e.g., related to health equity of vector-borne disease) (Winch, 1998).

Interactive mapping of epidemiological data with geographic and environmental features can be used to help develop hypotheses and identify relationships regarding the spatial patterns of disease. For example, the development of models around the hypothetical transmission of disease can help health planners target immunization and screening initiatives as well as resources and personnel. Spatial analysis can also indicate where structural and environmental interventions to promote behaviour change might be most effective. Furthermore, there is an increased call for using GIS applications in medicine to facilitate improved medical and ecological applications (Appelrath, Friebe, Grawunder, & Wellman, 2001). While GIS for disease surveillance is the most established and well-developed application for public health, the findings from this review suggest that there is still ample opportunity for growth and innovation in this area.
Chapter 4: Risk Analysis

Use of GIS approaches for risk analysis is typically linked with ecological or environmental health, and includes some aspect(s) of risk - assessment, management, communication, or monitoring - relative to impacts on health. Typical risk analysis projects examine: exposure to hazardous waste or pollution, proximity to industrial sites or traffic, or residence in a locality with characteristics that may foster disease (e.g., landscapes favorable to vectors, poor social conditions, or lack of access to health care) (Bergquist, 2001; S. D. Brody, Peck, & Highfield, 2004; Dale et al., 1998). The use of GIS frameworks to enhance risk analysis is a well-established application that allows researchers and practitioners to relate many different sources of environmental exposure to the residential locations of people over time in a simple, objective manner (Jarup, 2000). The goal of these analyses is to identify urgent need, increase the effectiveness of control efforts, and prevent outbreaks and epidemics. In many cases, epidemiological knowledge of disease outbreaks is combined with GIS to help prevent additional victims from being harmed by disease aftershocks (Cromley, 2002; Guptill, 2001). Furthermore, GIS approaches have been shown to be an effective tool for displaying environmental risk factors and the associated potential health effects (Adamek, Adamek, Orlowski, & Zielinska-Psuja, 2001; Ali, Emch, Ashley, & Streatfield, 2001; Choi, Afzal, & Sattler, 2006).

Nyerges and colleagues’ (1997) review of risk analysis publications concluded that, although much of the work reported in the literature focused on risk analysis or assessment rather than on risk monitoring or management, there was still a great opportunity for the application of GIS in current and future risk research. More recent literature has demonstrated that the scope of risk-related analysis (also referred to as risk mapping, risk management, risk communication, risk monitoring, risk evaluation, vulnerability analysis, or emergency planning) has been used to explore the potential impacts of physical environment, landscape ecology, or climate change on human health (Contini et al., 2000; McMichael, Martens, Kovats, & Lele, 2000). This type of work has valuable potential for situational analysis and policy development. For example, the World Health Organization (WHO) uses GIS tools to map environmental health risks in the European region to monitor the effects of disease control policies on the improvement of environment and health in the population (Kuchuk, Krzyzanowski, & Huysmans, 1998). The further development of this system, called the HealthMapper (http://www.who.int/emc/healthmap/healthmap.html)\(^2\), has global mapping capability for snail-borne disease epidemics. This information is presented in a way such that it facilitates management at the county or district level to relate it to population distribution, environmental data, and basic health and social infrastructure, and allow it to be regularly monitored and updated using national health statistics and survey results (Brooker et al., 2000; Myers et al., 2000).

Risk analysis is information intensive as it encompasses data from secondary, field (primary), and satellite (remote sensing) sources in ‘scenario-building’ exercises. This is necessary to facilitate risk modeling and prediction; as such, it is often combined with disease modeling to estimate and evaluate environmental disease hazards for a given population. For instance, Njemanze et al. (1999) combined risk analysis (via probabilistic layer analysis) and GIS to evaluate the health impact of water sources in the prevention of diarrheal diseases in Nigeria. In this case, GIS was used to convert the results of the risk analysis into meaningful information that was easy to understand and enabled decision makers to apply the results during policy development for water resource management in developing countries.

\(^2\) website current at the time of printing
ENVIRONMENTAL EXPOSURE TO WATER CONTAMINANTS

There have been several other reports of water-source risk assessments using GIS approaches in the literature including:

- linking water quality and sanitation to risk of diarrheal disease in young children in sentinel areas of Mexico City (Cifuentes, Suarez, Solano, & Santos, 2002);
- examining the association between water sources and supply structures with diarrheal illnesses in Germany (Dangendorf, Herbst, Reintjes, & Kistemann, 2002);
- determining the health risk to infants from groundwater contamination by nitrates associated with intensive potato cultures in Quebec, Canada (Levallois et al., 1998);
- exploring possible links between breast cancer risk and drinking water supply in Cape Cod, Canada (Swartz, Rudel, Kachajian, & Brody, 2003); and
- examining drinking water supply structures to assess microbial risk of water-borne disease in Germany and abroad (Kistemann, Herbst, Dangendorf, & Exner, 2001).

Related applications examined entire water pathways to determine potential exposure to harmful contaminants. For example, one study reported an examination of the thresholds of acceptability and danger regarding the chemical presence route along the river model of the Rhine in Germany (Matthies, Koormann, Boeije, & Feijtel, 1997). Another study discussed the creation of time series population exposure data for pre- and post-regulatory action regarding volatile organic chemicals in the New Jersey, USA, water system (Cohn, Savrin, & Fagliano, 1999). In Germany, a GIS was used for drinking water surveillance in a pilot project; the method was deemed to be successful and the Public Health Office has since been using the system regularly to measure values of drinking water wells (Hellmeier, Queste, & Woltering, 2001). In New Zealand, a GIS was used to examine the public health risks associated with community water supplies relative to social status (Hales, Black, Skelly, Salmond, & Weinstein, 2003). In the UK, a GIS framework was used to trace the source of each individual water supply right to the groundwater abstraction point. This information then was used to link water health risks to the source of contamination (Harrison & Lake, 2006). Similarly, in Finland, a GIS was used to investigate the risk of developing cancer for those individuals living near the River Kymijoki (Verkasalo et al., 2004). This study found that there was an increased cancer risk for all residents living within five kilometers of the river. Another study reported on the development of a GIS tool to assist in locating areas with high levels of fluoride in the water in Central Europe; findings from this study were used to determine where water treatment technologies should be aimed (Fordyce et al., 2007).

ENVIRONMENTAL EXPOSURE TO SOIL CONTAMINANTS

In addition to examining water supplies to conduct risk assessments, several studies have explored risks associated with soil contamination. For example, in China, the soil was examined for arsenic to determine the potential health impacts of ingestion or inhalation for those individuals residing in close proximity to industrial sites (Liao, Chen, Xie, & Liu, 2005). In Hong Kong, soil pollution developed using a GIS identified trace metals in surface soils (C. S. Lee, Li, Shi, Cheung, & Thornton, 2006). In Ireland, GIS mapping was used as a tool to pinpoint possible sources of pollutants in urban soils (C. Zhang, 2006). Along the St. Lawrence River in New York State, USA, and Ontario and Quebec, Canada, soil samples were used to assess a Native American community’s (Mohawks in Akwasasne) risk of environmental exposure to polychlorinated biphenyls (PCB) (Hwang et al., 1999). Others have
used GIS approaches and spatial statistics for the reconstruction of historical crop patterns in relation to residential communities to identify populations potentially exposed to agricultural pesticides in population epidemiologic studies of non-Hodgkin lymphoma (M.H. Ward et al., 2000; M.H. Ward et al., 2000) and breast cancer (J. G. Brody et al., 2002). Finally, in one review study conducted by Kaminska and colleagues (2004) exemplary studies that utilized a GIS for exploring the impact of pesticide pollution on public health were explored.

ENVIRONMENTAL EXPOSURE TO AIR CONTAMINANTS

Although many studies have examined the risks associated with exposure to water and soil pollutants, there are also numerous reports on the risks associated with exposure to air pollution. In some of these examples, a GIS is combined with ambient air concentration data (e.g., nitrogen dioxide) to estimate personal and population exposure to particular pollutants and health outcomes such as increased respiratory symptoms or asthma cases (Boudet, Zmirou, & Vestri, 2001; Levy, Houseman, Spengler, Loh, & Ryan, 2001; Pikhart et al., 2000; Pikhart et al., 1997). Some specific examples whereby airborne particulate has been compared with children’s lung function include:

- studying the relationship between asthma in children and exposure to second-hand smoke and road vehicle traffic (S. A. Lewis et al., 2005);
- associations between childhood asthma, location of residence and traffic flow in California, USA (P. English et al., 1999), Germany (Gehring et al., 2002) and Alaska (Gordian, Haese, & Wakefield, 2006);
- examining the effects of housing and ambient environmental hazards on childhood asthma (Corburn, Osleeb, & Porter, 2006);
- looking into the effects of long-term exposure to air pollution on respiratory symptoms and hospitalizations for children with asthma in Slovakia (Hruba, Fabianova, Koppova, & Vandenbergm, 2001);
- examining the relationship between types of traffic, traffic volume, and wheezing among infants (P. H. Ryan et al., 2005);
- looking at the association between long-term exposure to air pollution and children’s lung function (Dubnov et al., 2007); and
- examining the association between exposure to air pollution and adverse respiratory and cardiovascular health outcomes in African American children and adults (Huen et al., 2006).

Additional studies that have explored the effects of various types of air pollution on asthma in general include:

- assessing the impact that housing conditions, neighbourhood physical quality, income indicators, and access to health care have on the incidence of asthma (Allacci, 2005);
- the impact that living near noxious land has on asthma hospitalizations (Maantay, 2005);
- comparing traffic-related air pollution with the prevalence of asthma (Brauer et al., 2003); and
- assessing the influence of environmental stimuli on respiratory health (Crabbe et al., 2004).
The GIS application for geographic exposure modeling of individual exposure to environmental air pollutants is purported to result in more precise estimations of exposure (Beyea, 1999). It can also increase the effectiveness and efficiency of research on the long term effects of outdoor air pollution, as long as the need for continuous monitoring data of air pollution (i.e., particulate matter) is met (Kunzli & Tager, 2000). An example of this is the study of air pollution from traffic. These kinds of studies attempt to ascertain if exposure to toxic vehicular emissions is associated with an increased risk of developing certain diseases, illnesses, or conditions.

Some studies have explored the effects of traffic-related exposure to air pollution on respiratory health including:

- comparing traffic-related air pollution and respiratory health (Morgenstern, Cyrys, Zutavern, Wichmann, & Heinrich, 2006);
- examining populations’ exposure to particulate matter (motor vehicle emissions) and the resultant effects on hospital admission rates for respiratory diagnoses (Buckeridge, Glazier et al., 2002);
- determining the association between exposure to vehicular emissions and chronic respiratory disease in adults (Garshick, Laden, Hart, & Caron, 2003);
- investigating the long-term effects of exposure to traffic-related air pollution on mortality resulting from cardio pulmonary disease (Hoek, Fischer, Van Den Brandt, Goldbohm, & Brunekreef, 2001); and
- looking at the association between long-term exposure to air pollution and cardiopulmonary mortality in women (Gehring et al., 2006).

Additional examples have explored the association between air pollution from traffic and various health conditions including:

- examining a population’s exposure to urban air pollution in Stockholm, Sweden (including smoking and vehicle emissions) and comparing it with lung cancer incidence in the area (Nyberg et al., 2000);
- estimating adverse health effects from long-term exposure to traffic-related air pollutants (Morgenstern et al., 2007);
- identifying child care centres where children are at risk of being exposed to toxic concentrations of vehicle-exhaust pollutants (Ong, Graham, & Houtson, 2006);
- identifying populations at risk of adverse health effects due to close proximity to diesel emissions (Fisher, Kelly, & Romm, 2006); and
- investigating the relationship between long-term exposure to ambient particulate matter and atherosclerosis (Kunzli et al., 2005).

Finally, one unique study outlined how the development of a regression-based method for mapping traffic-related air pollution in four contrasting urban environments in the UK was used to develop appropriate policy interventions (D. J. Briggs et al., 2000).
There are numerous other studies that reported on air quality monitoring as part of risk analysis. Examples include:

- a health hazard GIS assessment of air pollutants in industrial towns in India to assess air quality associated with five pollutants and the level of industrialism (Sengupta & Venkatachalam, 1994);
- quantifying the potential health effects on the surrounding urban population resulting from air pollution emitted from a local waste facility (Mindell & Barrowcliffe, 2005);
- developing an approach whereby long-term air monitoring is used to establish patterns or changes in exposure to hydrogen sulfide (Inserra, Phifer, Pierson, & Campagna, 2002);
- looking at air pollution and the association with stroke deaths (Maheswaran et al., 2005; Maheswaran et al., 2006); and
- relating ambient air pollution levels in Auckland (Scoggins, Kjellstrom, Fisher, Connor, & Gimson, 2004) and the Netherlands (Beelen, Roek, Fischer, van den Brandt, & Brunekreef, 2007) to mortality.

In one specific example from Texas, USA, local perceptions of air quality were compared with air quality readings from air monitoring stations to determine that individuals perceptions were not significantly correlated with the actual air quality reading (S. D. Brody et al., 2004). Similarly in Germany, it was found that self-reported levels of air pollution and modeled assessments were weakly associated (Heinrich et al., 2005).

Utilization of GIS-based tools can also serve to help public health officials identify local hazards and create other opportunities to protect community health through prevention strategies aimed at pollution prevention and environmental equity of exposure to harmful airborne substances (Bouton & Fraser, 1999). Environmental equity assessments using GIS approaches in conjunction with air dispersion modeling of pollution are common for the study of exposure to airborne toxins emitted from industrial towers or waste sites, spills of hazardous materials, and traffic pollution (Dent, Fowler, Kaplan, Zarus, & Henriques, 2000). These types of studies attempt to ascertain whether low-income or minority populations are disproportionately exposed to airborne toxic chemicals and industrial pollution (Sheppard et al., 1999). Some results from studies that evaluated community demographics in relation to exposure to harmful pollutants indicated that:

- in Los Angeles, USA, school sites with a large proportion of minority students were more likely to be located near hazardous facilities (Pastor, Sadd, & Morello-Frosch, 2002);
- in California, USA, low-income and children of color were at a higher risk of being exposed to vehicle emissions (Gunier, Hertz, Von Behren, & Reynolds, 2003);
- also in California, USA, a considerable portion of children attended schools in close proximity to major roads with heavy traffic flow in addition, a disproportionate number of those children were economically disadvantaged and caucasian (R. S. Green, Smorodinsky, Kim, McLaughlin, & Ostro, 2004);
- in Seattle and Portland, USA, key neighbourhoods were found to be at a higher risk of developing adverse health effects as a result of exposure to freeway air pollution (Bae, Sandlin, Bassok, & Kim, 2007);
Many studies have used GIS to create models to determine the potential risks associated with exposure to air pollutants. In one such study, a model was developed using GIS to determine air quality in urban areas of Argentina (Puliafito, Guevara, & Puliafito, 2003). This model was used to identify the environmental impact of new industries and to determine if they were compliant with local air-quality standards (Puliafito et al., 2003). In the UK a model was developed to examine individuals’ journey-time exposures to traffic-related air pollution (Gulliver & Briggs, 2005). In Poland, GIS was used to integrate climatic and urban anthropogenic parameters to assess the spatio-temporal spread of air pollutants; this information was used to ensure that air-quality standards were maintained to reduce the risk to human health (Oudinet et al., 2006). Similarly, in California, USA, a GIS model used to predict nitrogen dioxide levels (an indicator of traffic pollution) and the long-term health effects of traffic-related pollution (Z. Ross et al., 2006). In New York City, USA, a method was developed to estimate the distribution of air toxins in urban neighbourhoods; this method can be used to estimate toxic concentrations of hazardous substances in the air (Corburn, 2007). In Toronto, Canada, a similar model was developed to detect ambient concentrations of nitrogen dioxide; this model can detect health effects that would go unnoticed with other exposure estimates (Jerrett et al., 2007). In another study from the USA, a GIS was used to create maps of Baltimore to determine populations at risk for potential smoke and chemical exposure due to an urban chemical fire with a hazardous materials spill (E. B. Hsu et al., 2002). In India, a model was developed utilizing online and real-time monitoring systems to evaluate air pollution; this system correlated respiratory infections with air pollution (Anjaneyulu et al., 2005). Finally, in a review article by Briggs (2005), some of the techniques used for air pollution epidemiology and air quality policy were outlined and the implications of using these different techniques were discussed.

HAZARDS

GIS can also be used to enhance the study of potential population exposure to toxins as a result of major accidents in the transportation of hazardous materials. This type of risk assessment is done for planning and management purposes as well as for emergency response, and is often used in conjunction with network analysis GIS applications (e.g., origin-destination or shortest route questions, which are discussed in Chapter 5 – Health Access and Planning). In one study, the authors examined risks associated with routes along highways in Ontario and Quebec, Canada, that minimized transport distance, population exposure, expected number of people to be evacuated in case of an incident, and the probability of an incident occurring while dangerous goods were being transported (Verter & Kara, 2001). This information was used to identify issues of risk equity and to inform policy creation.

In addition to examining the effects of exposure to hazardous substances as a result of acute events, there have been many studies conducted to date that used GIS approaches to analyze exposure to hazardous substances and the population at risk of exposure. In one such study, a GIS was used to determine the distribution of agricultural pesticide use and the number of potentially exposed children.
(Gunier, Harnly, Reynolds, Hertz, & Von Behren, 2001). In a similar study, GIS was used to estimate population exposure to herbicides in Vietnam (Stellman et al., 2003). In another study, the risk of infants born with malformations was determined by looking at the maternal residence and its proximity to the nearest hazardous waste site in Washington, USA (Kuehn, Mueller, Checkoway, & Williams, 2007) and in Texas, USA (Brender et al., 2006). In Denmark, it was found that there was no association between proximity to waste landfills and congenital anomalies (Kloppenborg, Brandt, Gulis, & Ejstrup, 2005). In Poland, evaluations were conducted to look at regional environmental and health hazards due to chemical contamination (Dutkiewicz, Konczalik, & Murowaniecki, 1998). Finally, in Sweden, a risk assessment was performed to look at residents at risk because of their close proximity to high levels of background radon (Kohli et al., 1997).

There have also been several studies to date that have assessed the risk of elevated blood lead levels. For example, in Los Angeles County, USA, a GIS was used to test environmental racism claims that minorities were disproportionately exposed to environmental lead (Macey, Her, Reibling, & Ericson, 2001). That study found that proximity to transportation corridors was the strongest indicator of environmental lead exposure and median home values were significantly associated. In a similar study in Venezuela, the relationship between blood lead levels and sociodemographic parameters was examined (Rojas, Espinosa, & Seijas, 2003). In the USA, another risk-based application helped to aid health departments decision making and prevention planning for childhood risk of lead poisoning for those children living in housing built prior to 1950 (Reissman, Staley, Curtis, & Kaufmann, 2001; Roberts, Hulsey, Curtis, & Reigart, 2003). In a similar study from New Jersey, USA, the potential for childhood lead poisoning was examined as a result of industrial sites emitting lead and other hazardous substances (Guthe et al., 1992). Also in the USA, a GIS was used to link blood lead screening information with drinking water source and the age of households; it was determined that change to chloramines disinfection may lead to an increase in blood lead concentrations (Miranda, Kim, Hull, Paul, & Galeano, 2007). Finally, in New York State, USA, the association between blood lead levels and socioeconomic status was examined; the results of this study indicated that older housing, lower proportion of high school graduates, and higher percentage of births to African-American mothers were associated with communities that had high blood lead levels (Haley & Talbot, 2004).

ASSOCIATION WITH PARTICULAR DISEASES AND ILLNESSES

A variety of other studies reported on GIS risk-related applications exploring a wide range of contaminants and their association with particular diseases and illnesses. For example, to date, there have been several studies that have examined the effect of toxic agents on reproductive outcomes including:

- conducting surveillance around hazardous waste sites to identify populations at risk for poor reproductive outcomes (Stallones, Nuckols, & Berry, 1992);
- examining maternal residential proximity to agricultural pesticide applications and the association with neural tube defects (Rull, Ritz, & Shaw, 2006); and
- using exploratory spatial data analysis methods to identify environmental risk factors for birth defects (J. Wu et al., 2004).

Other studies have examined whether exposure to particular airborne particles is associated with different types of cancer. For example, one study established whether high levels of bromoform are associated with rectal cancer in Western New York State, USA (Bove, Rogerson, & Vena, 2007). In China,
researchers used a GIS to determine the association between residential petrochemical exposure and leukemia risk (C.L. Yu et al., 2006). Furthermore, in a study conducted by Speer and colleagues (2002), GIS tools were combined with case control studies in the examination of acute myeloid leukemia (AML) and multiple myeloma (MM). In this study, the authors sought to assess whether exposure to toxic chemicals in tobacco smoke, emissions from industrial operations, and petroleum refinery waste dumps in Orange County, California, USA, were associated with AML and MM risk factors in the population such as smoking history, occupational history, and residence in a census tract with a petroleum refinery waste dump (Speer et al., 2002). They found that, when used together, GIS and case control methods demonstrated increased sensitivity and increased power to identify effect over case control alone.

There are various additional studies that have identified the environmental risk factors associated with different diseases. For example, Bakker and colleagues (2004) examined the spatial distribution of leprosy to identify which disease characteristics significantly affect the spread of the disease. In another study, the environmental risk factors associated with development of cholera including proximity to surface water, high population density, and poor education levels were identified (Ali, Emch, Donnay, Yunus, & Sack, 2002). In another unique study, a GIS was used to identify environmental exposures that led to the development of l-transposition of the great arteries (l-tga) in children (congential cardiovascular malformation) (Kuehl & Loffredo, 2003). It was found that potential risk factors for l-tga include parental exposure to hair dye, smoking, and laboratory chemicals. In another example, Dunn and colleagues (2007) used a GIS and point pattern modeling to determine the spatial epidemiology of Legionnaire’s disease.

Finally, GIS studies have also explored effects of exposure on general health, for example, Mora and colleagues (2006) quantified the human health risks associated with being in close proximity to industrial sources which emit dangerous pollutants. Also, in a study conducted by Bevc and colleagues (2007), a spatial model was developed that enabled researchers to identify potential contamination zones due to hazardous waste sites and determine what factors contribute to mental and physical health problems.

GIS-based tools can help public health officials to develop measures to evaluate differential exposure to acute pollution events (Chakraborty, 2001a). Some examples of studies that used GIS approaches to determine the potential health risks associated with acute events include:

- assessing health and development issues in children who were exposed to pollutants emitted as a result of the World Trade Center disaster (Lederman et al., 2004);
- looking at the incidence of asthma and bronchitis amongst Gulf War veterans exposed to the Kuwait oil (Lange, Schwartz, Doebbeling, Heller, & Thorne, 2002);
- investigating whether schools in North Carolina, USA, that were already at an elevated risk of respiratory illness were disproportionately burdened by flooding from Hurricane Floyd (Guidry & Margolis, 2005);
- analyzing schoolchildren’s exposure to accidental releases of hazardous substances in a large county in Florida, USA, led to the development of emergency response plans and evacuation routes (Chakraborty, 2001b); and
- assessing and describing the immediate threats associated with a terrestrial chemical spill (Bryant & Abkowitz, 2006).
All of these examples utilized GIS methods during humanitarian emergencies. Although the initial investment in equipment and training is substantial, GIS approaches can save resources and help to reduce error when determining areas that should be attended to first (Kaiser, Speigel, Henderson, & Gerber, 2003). Therefore, as new and innovative uses evolve, it will become more practical for GIS to be used for risk analysis purposes during acute pollution events.

**Virus Transmission Due to Landscape Ecology and Other Risk Applications**

Exposure assessments of a slightly different nature can be used to analyze the risk of virus transmission based on landscape characteristics that may predispose humans to infection by bacterial or insect vectors. These studies require the use of remotely sensed data (digital images of terrain captured by satellite) in conjunction with a GIS to identify landscapes that are hospitable to vector growth and spread or to determine vector abundance in a specified area. For example, researchers in the USA have used remotely sensed elements of landscape composition to evaluate the propensity for Lyme disease exposure in New York (Dister, Fish, Bros, Frank, & Wood, 1997), Rhode Island (Nicholson & Mather, 1996), Baltimore City (Glass et al., 1995), and the North Central USA (Guerra et al., 2002). Additional applications concerning exposure and landscape ecology include:

- prediction of malaria transmission risk in rural Mexico (Beck et al., 1994; Beck et al., 1997; Pope et al., 1994);
- an assessment of malaria transmission intensity in Kenya (Oumbo et al., 1998);
- examination of specific crop system and agricultural pesticides that may increase the risk of malaria (Matthys et al., 2006);
- determination of the risk of eastern encephalomyelitis virus transmission in Massachusetts, USA (Moncayo, Edman, & Finn, 2000);
- analysis of rural and urban populations exposure to fungal contaminants in maize, a staple food of the population, which is associated with high levels of esophageal cancer in South Africa (Chelule, Gqaleni, Dutton, & Chuturgoon, 2001); and
- the development of risk models for the control and program management of schistosomiasis in Egypt (Abdel-Rahman, El Bahy, Malone, Thompson, & El Bahy, 2001) and Brazil (Bavia et al., 2001).

The literature review also revealed several interesting and unique GIS applications in risk analysis. One paper reported that this type of approach could be used to safeguard agricultural and natural ecosystems against bio-terrorism and other accidentally or intentionally introduced pest outbreaks in the USA and internationally. This can be achieved by using a GIS and satellite data for scenario building and development of emergency response policy (Sequeira, 1999). For example, Peek-Asa and colleagues (2000) used data on earthquake-related deaths and hospital admissions from the 1994 Northridge, California, USA, earthquake to map injury severity and density in relation to distance from earthquake epicenter. Their goal was to build a risk hazard model capable of predicting injury rates from seismic events in order to inform policy efforts addressing earthquake response and recovery. Another interesting example of how a GIS can be used to investigate potential risk analysis is to examine the association between nosocomial infections and factors that contribute to their spread (Kho, Johnston, Wilson, & Wilson, 2006). In San Francisco, USA, a GIS was used to investigate
the spatial distribution of community noise exposures and annoyance (Seto, Holt, Rivard, & Bhatia, 2007). In this study, it was determined that urban noise varies considerably between neighbourhoods, thus a GIS-based noise model was developed that can be used to evaluate the health implications of environmental noise (Seto et al., 2007). Furthermore, in another interesting risk analysis study, GIS was used to assist in the prevention of injuries, by analyzing the location of patients treated for falls and their associated demographic status (Cusimano, Chipman, Glazier, Rinner, & Marshall, 2007). One final example used GIS to examine whether residential exposure to magnetic fields generated by power lines is associated with an increased risk of cancer (for example, see Valjus et al., 1995; Wartenberg, Greenberg, & Lathrop, 1993). These types of studies use a GIS to model the power-grid network and then identify and characterize those populations living in proximity to it. However, the value of this type of exposure analysis is considered controversial by some and has been a subject of debate within the discipline (Cromley & McLafferty, 2002).

Finally, in a more general application of GIS, researchers developed the Health Index/Risk Evaluation Tool (HIRET) to integrate risk assessment and spatial planning with GIS capabilities (Bien, ter Meer, Rulkens, & Rijnaarts, 2004). This tool can be used to detect immediate risks to human health as well those long-term risks of contamination. The valuable information this tool provides can be used by decision makers and site owners to inform them about the potential of human health risk with respect to land use.
This chapter has demonstrated that use of GIS approaches for risk analysis has the potential to help policy makers and decision makers understand the spatial relationship between pollution and health (Maantay, 2002). In a 2002 review article, Maantay also suggested that some factors to be considered when undertaking future risk analysis studies include: i) refining exposure indices; ii) using dispersion modeling and advanced proximity analysis; iii) applying neighbourhood scale analysis; and iv) considering the influence of additional factors such as zoning and planning policies. Implementation of these features will enable the generation of more conclusive and influential findings. While a GIS is not the only way for understanding the distributions of disease and how environment influences exposure, it is an efficient way to effectively demonstrate how humans interact with the environment to create or deter health (Ricketts, 2003). Moreover, the literature has shown that use of GIS in environmental epidemiology studies is feasible and can lead to public health policy makers having a greater understanding of the association between environmental contaminants, disease, and health (Cutchin, 2007; Nuckols, Ward, & Jarup, 2004). The integration of a GIS into environmental exposure and epidemiological research can not only inform policy and help prevent exposure in the future, but it can also enhance the translation of information to the community by facilitating the presentation of complicated relationships in relatively easy-to-interpret ways (Miranda & Dolinoy, 2005).
Chapter 5: Health Access and Planning

Health access and planning applications of Geographic Information Systems can be generally operationalized as those related to network analysis and market segmentation for the analysis of health services and delivery. Access is a construct that describes a population’s ability to use health services when needed, i.e., it describes relationships between variables associated with service need and the attributes of the service delivery system (Cromley & McLafferty, 2002). Studies of geographic accessibility have been traditionally focused on individuals’ access to health services in time and space, and may offer valuable insights into health decision making. For instance, market segmentation (or client profiling) of individuals accessing a particular health service or set of services can aid planners and administrators in targeting resources and tailoring delivery to groups with certain characteristics or needs. Another aspect of accessibility is the physical location of health services and the distance and ability to travel between them, or the network of health services in an area. Network analysis can be used to determine client catchment areas or to identify the proportion of the population in a given area with potential access to services within a defined network. Finally, market utilization applications are used to identify and characterize realized access to services within a network or catchment area, i.e. describe patterns of health service utilization. While often interrelated, market segmentation, network analysis, and market utilization applications each have useful properties for independently addressing a variety of health planning questions within a GIS framework. As such, an overview of each of these applications is provided below.

Network Analysis

Network analysis applications of GIS are those related to ‘location of’ and ‘access to’ health services with the purpose of addressing questions of route (i.e., origin to destinations), distance, and proximity. These analyses can be instrumental in the effective planning of health care delivery and design of coordinated emergency response systems to best meet the needs of the community or region in question. For example, overviews of health care coverage and degree of regionalization (Florin, Gesler, Savitz, & Fondren, 1994); distance from and access to health care (for example, Kivell & Mason, 1999; Kohli et al., 1995); and access for specific sub-populations (for example, Love & Lindquist, 1995; Tanser et al., 2000) can be constructed by utilizing a GIS system to examine, plan, and evaluate the system.

Access to Health Services for Specific Health Conditions

The literature search revealed a wide range of health-related network analysis studies. Several papers reported use of GIS frameworks to explore access to community health services for a specific health conditions, for example, for the early diagnosis and treatment of malaria in rural Ethiopia (Ghebreyesus et al., 1999), the accessibility of malaria services in Kenya (Noor, Zurovac, Hay, Ochola, & Snow, 2003), and the accessibility of tuberculosis services in Africa (Tanser & Wilkinson, 1999; Wilkinson & Tanser, 1999). Additional studies that have illustrated access to a variety of health services for various health conditions include:

- examining the association between childhood pertussis and access to immunization services in Australia (Chen, Waters, & Green, 2002);
- also in Australia, Clark and colleagues (2007) explored the unequal distribution of chronic heart failure management and general practice services;
in Wales, referral rates to multicentre cancer genetics services were monitored to identify
service utilization patterns and accessibility (Tempest et al., 2005);
in Scotland, the geographical accessibility of imaging facilities for stroke patients was
explored (Seymour, Cairns, Wilkie, Sandercock, & Wardlaw, 2006);
in California, USA, the accessibility and availability of culturally responsive breast and
cervical cancer services for Southeast Asian and Pacific Islander women was investigated
(Tanjasiiri et al., 2004);
in Israel, locations with inadequate treatment centres for childhood asthma were defined
(Peled et al., 2006);
in South Africa, the geographic accessibility of cancer treatment centres was determined
taking into account the under-reporting of the disease (D. Scott, Curtis, & Twumasi,
2002); and
also in South Africa, Tanser and colleagues (2000) explored the prevalence of HIV
heterogeneity among pregnant women and correlated it with the proximity of the
women’s homesteads to roads to define catchment areas for community clinics.

Further studies have explored the accessibility of HIV services; notably, in Chicago, USA, one study
found that there was a lower proportion of HIV service providers where a large proportion of young
black men who have intercourse with other men reside (Pierce, Miller, Morales, & Forney, 2007). In
Toronto, Canada, it was evident that those neighbourhoods with higher levels of disadvantaged
populations also had decreased access to HIV services (Fulcher & Kaukinene, 2005). This work was compli-
mented by a follow-up study conducted by Kaukinen and Fulcher (2006), which indicated that policy
makers should use GIS approaches to better understand populations that are potentially underserved
with respect to health and social services. In a similar study, GIS was used to develop an HIV Preven-
tion Services Database, which mapped the distribution of HIV prevention services on a national level
in the USA (Hanchette, Gibbs, Gilliam, Fogarty, & Bruhn, 2005). Furthermore, in Kenya, a GIS was
used to systematically evaluate spatial accessibility to medical treatment facilities; this information was
used as a means to help reduce the prevalence of HIV/AIDS, tuberculosis, and malaria (Noor, Amin
et al., 2006). This study also indicated that approximately six million people in Kenya were incorrectly
estimated to have access to health services within a one-hour drive (Noor, Amin et al., 2006), an im-
portant public health finding with global implications.

Access to Health Care Services for Low Socioeconomic Populations
GIS approaches have also been used in studies exploring lower socioeconomic population groups’ access
to health care services, for example: evaluating access to general health care facilities in Buffalo, New
York, USA, (Niewczyk & Lwebuga-Mukasa, 2006); and in Brooklyn, USA, identifying the availability
of prenatal clinic services for low-income mothers (McLafferty & Grady, 2004). In another interesting
study, the geographic disparity of children’s mental health care services was explored. Findings sugges-
ted that rates of use and unmet needs were not dictated by racial/ethnic or sociodemographic makeup
across states, instead the differences in service were attributed to differences in state policies and health
care market segmentation (Strum, Ringel, & Andreyeva, 2003). Finally, in a book chapter by Skinner
and colleagues (2005), methods for using a GIS to explore and visualize distances that working poor
families (that have children with disabilities) have to travel to services are described.
General Access to Health Care Services

Not only have GIS approaches been utilized to map access to health care services for specific health conditions and low socioeconomic populations, but also to examine general population access to an assortment of health services including a variety of medical facilities and medical professionals. This information can be used in a GIS platform to visually display community health care needs, identify the needs of potentially underserved populations and to ultimately influence decision and policy makers. In one interesting case, a GIS was used to describe physical access to primary care in remote and impoverished areas of mountainous areas of Bolivia (Perry & Gesler, 2000). This work was instrumental in identifying gaps in health services (as it is traditionally difficult to get cartographic data for rural mountainous areas) and contributed to improved health services, decision making, and resource allocation. Examples that have explored population access to hospital facilities include: defining hospital catchment areas in Natal and KwaZulu, Brazil (Zwarenstein, Krige, & Wolff, 1991); examining accessibility to neurosurgical emergency hospitals for elderly individuals (Ohta et al., 2007); and analyzing geographic accessibility of hospitals for the aged in Illinois, USA, specifically with respect to distance and distribution of services (Love & Lindquist, 1995). Other studies have explored access to general health care services including:

- identifying areas in need of health services and public utilities in Buenos Ares, Argentina (Aguglino & Rodriguez, 1994);
- identifying areas in Illinois, USA, that had disproportionately poor access to health care services and resultant improvements that should be made to future policies to prevent gaps in services (Luo, Wang, & Douglass, 2004);
- assembling an inventory of health service facilities in Costa Rica to identify which communities had inadequate access to health care (Rosero-Bixby, 2004);
- exploring the extent to which different geographical areas in New Zealand had varying access to general practitioners, particularly distinct population groups (Brabyn & Barnett, 2004);
- identifying elderly populations access to pharmacies (S.J. Lin, 2004) and pain management medication in Illinois, USA (S.J. Lin, Crawford, & Salmon, 2005); and
- evaluating the distribution and availability of and access to diagnostic and dental x-ray services in South Africa undertaken to inform policies about the optimal utilization of services and resources (Walters, Zietsman, & Bhagwandin, 1998).

In another study, a comparison of community- and individual-level indicators was made to determine the most effective method for identifying pediatric health care needs (Zlotnick, 2007). This examination identified that one community-level indicator (i.e., determining medically underserved areas using GIS) was almost as good as the most effective individual level indicators (i.e. quality of life scales).

Clearly, understanding access to health services is a public health issue of global concern. In a study from Illinois, USA, the author used a GIS-based floating catchment method to identify areas with a shortage of physicians (Luo, 2004). Similarly, in the UK, car travel times and accessibility by bus to general practitioners was explored to conclude that those populations living in rural areas with the highest health care needs did not have access to appropriate bus services (Lovett, Haynes, Sunnenberg, & Gale, 2002). In addition, spatial accessibility to primary health care was explored in Chicago, USA,
from 1990 to 2000; through this study, it was evident that access to primary care physicians improved over the ten-year period (Luo et al., 2004). Accessibility to primary health care was also examined in rural South Africa where it was found that as distance to health care facilities increased, usage decreased (Tsoka & le Sueur, 2004). The results of this study lead to the development of new clinics in rural areas to increase usage of primary health care facilities. Two final examples associated with examining specific population’s access to health care services include: exploring how family planning affected women’s choice of contraceptive method in Thailand (Entwisle, Rindfuss, Walsh, Evans, & Curran, 1997); and identifying practitioners in rural areas that were able to meet the needs of rural culturally diverse communities (C. E. Hsu, Mas, Jacobson et al., 2006).

In addition to examining access to health services, GIS network analyses have also been used to model catchment areas to improve representation of access to hospital-based health care services. Examples include:

- focusing on services available in rural areas of British Columbia, Canada (Schuurman, Fielder, Grzybowksi, & Grund, 2006);
- evaluating and visually representing the nursing workforce distribution in Missouri, USA; from this it was evident that current policy definitions were not effective in defining areas of nursing shortages (Courtney, 2005);
- assessing access to hospital emergency departments was explored in relation to how this impacted health reforms (Brabyn & Beere, 2006);
- using GIS in rural India to map all private health care providers in the area, these results were used to create an enhanced foundation for health services research (Deshpande et al., 2004);
- determining the quality of vaccination services provided to children, this information allowed for the identification of areas where children were not being fully vaccinated (Alkoy, Ulugtekin, & Dogrun, 2007); and
- identifying whether access to reproductive health services was associated with the use of modern contraceptives in Malawi (Heard, Larsen, & Hozumi, 2004).

In one particularly illustrative example, a GIS was used to combine complex data to illustrate problems related to community health care access needs and their association with access, poverty, and political boundaries; it was concluded that this system could be used to help evaluate interventions, inform research, and guide health care policy development (Phillips et al., 2000). Similarly, Kaneko and colleagues (2003) performed community health needs assessments using a GIS to help inform rational decision making in public health services. Finally, in a study conducted by Wood and colleagues (2004), a GIS was used to identify hospice and palliative care services. This information was important considering that even countries with well developed palliative care systems have problems with access and equity of services (Wood et al., 2004).

**Using GIS to Analyze Emergency Response Times**

GIS studies of health transportation and service networks have been instrumental in the assessment and development of locations and catchment areas for trauma systems and major injury centre options and for decreasing times for emergency response and trauma patient transport (Furbee, 1995; Kivell &
Mason, 1999). For instance, Lerner and colleagues (1999) used historical records to develop helicopter and ambulance service areas to identify the most effective means of patient transport. In Israel, ambulance response times were mapped using GIS to improve deployment and to reduce response times (Peleg & Pliskin, 2004). In another example, Scott and associates (1998) conducted an analysis of the Canadian population to assess potential access to specialized treatment within three hours of the onset of acute ischemic stroke and created a model that coordinated emergency medical services response for stroke to maximize coverage in the population. In addition, in a study conducted in Japan, a GIS was used to determine average travel times from all municipalities in Japan to the nearest tertiary care centre (i.e. centres that accept patients who require 24-hour monitoring) (Miwa, Kawaguchi, Arima, & Kawahara, 2006). This study identified gaps in travel times to tertiary care centres to allow for more effective planning to reduce those travel times. Furthermore, in Wales, a GIS was used to compare accessibility of accident and emergency departments drive time to those reported by local residents; through this examination, it was evident that residents’ perceptions were related to measures of spatial accessibility (Fone, Christie, & Lester, 2006). In a variation of this theme, Rafalski and Zun (2004) used GIS to better understand utilization patterns of the Chicago, USA, fire department and the resultant consequences on the number of trauma cases who leave the scene without being treated. Finally, in British Columbia, Canada, a GIS was used to establish what proportion of the population was served by existing or proposed health care services; this information was used to identify what populations had adequate access to emergency care (McGрегor, Hanlon, Emmons, Voaklander, & Kelly, 2005).

**Assessing Patient Characteristics, Patient Flow, and Distance to Assist in Planning**

GIS platforms can also be used to create normative models of health care providers, patient characteristics, patient flow, and distance (e.g., estimated travel time). This information can be linked with demographic information and transportation networks to simulate potential demand on the health care delivery system (Bullen, Moon, & Jones, 1996; Murad, 2004; Walsh, Page, & Gesler, 1997). These normative models can then be used to generate alternative scenarios to help inform health planning exercises. For example, Lapierre, Myrick and Russell (1999) suggested that GIS approaches are useful tools for planning the delivery of public health services through the creation of a public health network model. They proposed that a health care service delivery network, including fixed health centres, satellite facilities, and mobile health units, could be effectively designed using a five-step process: i) collecting data of the necessary elements within the model specific to the region in question; ii) modeling client behaviour in the decision to seek health services based on travel distance and size of facility; iii) establishing costs and a minimum number of clients for each facility; iv) locating the health centres first, then satellite facilities, and last, the base locations of mobile facilities within the model; and v) scheduling services, staff, and mobile facilities. They concluded that this type of scenario-building planning exercise had potential to increase the effectiveness and efficiency of health care delivery in the USA.

There have also been many studies conducted to date that utilize GIS approaches to better understand access to services and the associated travel time and distance. In an interesting study in the UK, an index of multiple deprivation was developed to identify populations with poor geographical access to local services such as general practitioners (Niggebrugge, Haynes, Jones, Lovett, & Harvey, 2005). In this study, travel times to general practitioners and bus availability were generated using a GIS. The results of the study indicated that the predictive power of the index was most effective in urban areas. In
a similar study, a GIS was used to determine the travel times for patients to the nearest hospital; from this examination it was evident that proximity to the hospital was positively associated with in-hospital mortality due to myocardial infarction (O’Neill, 2003). In addition, in Illinois, USA, a GIS was used to measure spatial accessibility to health professionals based on travel time; this information was used to identify areas with a shortage of health professionals (Wang & Luo, 2005). Other examples relevant for public health planning and resource allocation include:

- a study conducted in South Africa which found that, with an increase in travel time to health clinics, there was an associated decline in usage (Tanser, Gijsbertsen, & Herbst, 2006);
- a study from New Zealand which identified that GIS accessibility models provided valuable information on accessibility of maternity units based on travel time (Beere & Brabyn, 2006);
- a study conducted by Baumgardner and colleagues (2006) that found that the proximity of individuals homes to health centres was not correlated with primary immunization completion for children and adults’ blood pressure; and
- a study that examined travel distance in relation to avoidable hospitalizations made evident that hospitalization rates are inversely related to distance to hospital (G. Lin, Allan, & Penning, 2002).

Although there have been numerous studies that have utilized GIS approaches to estimate travel times to various medical facilities and professionals, caution needs to be taken when interpreting the findings. For example, Haynes and colleagues (2006) compared GIS estimates of travel times to actual reported travel times and found that the GIS estimations of travel times were moderately close approximations to the true travel times.

**Utilizing GIS Approaches to Assist with Health System Planning**

The literature review also revealed some creative network-based applications for health policy assessment. For example, Bullen and colleagues (1996) noted that GIS frameworks would be beneficial in the identification of localities for health planning. They suggested that they could be used to generate multiple alternatives for health services catchment areas, as traditional definitions of localities by administrative boundaries may be useful in meeting the needs of the population. Bamford et al. (1999) used a GIS to create a ‘remoteness’ index for health service planning in rural Australia as a decision support system to estimate the population’s future need of health services and to evaluate options for doctor recruitment. In a third example, Stern (1998) modeled international population movements between neighbouring countries and public health centers in the Mekong Region of Thailand to illustrate the need for trans-border public health planning and disease control, given that the existing national policies did not address the local realities of health service utilization by border populations. In New York, USA, Allacci (2005) used a GIS to help determine the most suitable location for asthma care. In a study conducted in Chicago, USA, GIS was used to illustrate community-level immunization coverage; the information gathered from this study was used to direct resources to communities with the greatest need (Ramirez, Bulim, Kraus, & Morita, 2006). Similarly, Gesler and colleagues (2004) explored where people live and carry out activities using a GIS to help health care providers.
plan a diabetes prevention program. Other examples of GIS for health system planning from around the world include:

- a geographic focused assessment that was performed to help ensure that specific community health needs were being met (Plescia, Koontz, & Laurent, 2001);
- employing GIS approaches to explore the geographic distribution, patronage patterns, and loyalty of clients to community pharmacies (Ryan, Norris, & Becket, 2005);
- using a GIS to map health utilization indices and rates, this information was used to provide valuable information to health care planners (Klauss, Staub, Widmer, & Busato, 2005);
- exploring the possibility of using a GIS to manage short-term care service planning for informal carers in England (Foley, 2002); and
- using a GIS to represent information about the distance between patients and facilities to ensure effective utilization of available resources in Greece (Mitropoulos, Mitropoulos, Giannikos, & Sissouras, 2006).

In another study, a web-based GIS (Web-GIS) was developed for end-stage renal disease in order to determine the demand and the supply of care; this information has been readily used by professionals and public health care decision makers in the end-stage renal disease domain (Richard et al., 2005). From these studies, it is evident that GIS approaches are a valuable and necessary tool, which can be used to regulate the health care system and assist in strategic planning.

**Utilization of GIS to Estimate Health Care Costs to Assist with Planning**

A final application of GIS for network analysis is related to the planning and implementation of health research surveys. Hyndman (1997) reported that a GIS could be used to identify distance and time for travel along survey routes to generate an estimation of cost to conduct interviews and to establish a guideline for interviewer contract rates. Another use of a GIS was to equitably distribute fieldworker labour and estimate cost and completion time for a large health survey in a remote area of South Africa characterized by vast social, physical, and spatial differences (Tanser, 2002). Other studies have used a GIS to help determine which geographical regions were using higher levels of Veterans Affairs health care services (Cowper et al., 2004; W. Yu et al., 2004). Finally, in a paper written by Barnard & Hu (2005), a health geographical information system developed by Vancouver Island Health Authority, Canada, was described and the authors further outlined how this system could be utilized to support health services and program planning.

**Tools for Network Analysis**

In a few cases, papers in this area focused on describing innovations in GIS tools for network analysis. In one interesting study, differing spatial representations of populations were compared to signify that a dasymetric model (dasymetric modeling has been used extensively in crime mapping, but has not been explored as a potential tool for exploring accessibility in health studies) produces lower accessibility scores than a standard pro rata model; these findings revealed that the degree of disadvantage experienced by rural populations may be greater than documented (Langford & Higgs, 2006). In another unique study conducted by Yang and colleagues (2006), two different GIS systems were compared
for examining accessibility to services, including: a two-step floating catchment area (2SFCA) and a kernel density (KD) method. From this study, it was evident that the 2SFCA method was a better tool for determining accessibility ratios.

HEALTH CARE UTILIZATION AND MARKET SEGMENTATION

Health care utilization and market segmentation applications of GIS essentially address questions of health service supply and demand. As outlined previously in Chapter 5, geographic accessibility has been traditionally defined as proximity to local health services, but limited physical access to primary health care can be a major contributing factor to poor health care and underutilization of services, especially in developing countries (Phillips et al., 2000; Tanser & Le Sueur, 2002).

Assessing the Number of People Using Services

Much of the network-analysis literature described above included assessments of health care utilization as part of their investigations (e.g., distribution of dental health services or physicians), however the measurement of access to and utilization of primary care must take care to identify and define those variables that influence the intensity and scope of use of health services by the population (D. Martin, Wrigley, Barnett, & Roderick, 2002; Parker & Campbell, 1998). For example, one program of research assessed the effect of distance and social disadvantage on the responses to invitations to attend mammography screening (Hyndman & Holman, 2000; Hyndman, Holman, & Dawes, 2000). The authors discussed client response to travel time and distance to different social groups and found that access to screening was linked with social inequity. They recommended that increased public response, especially target population response, could be achieved by strategically locating clinics in a way that considered inequities in resource allocation and minimized travel times for disadvantaged groups.

Another interesting example focused on the evaluation of a public health intervention to increase physical activity of the population through the use of an environmental approach. In this case, a GIS was used to assess social and physical barriers obstructing the use of a community paths and trails in Arlington, Massachusetts, USA (Troped et al., 2001).

Health care utilization applications play an important role in identifying access to needs and in targeting resources at a local level. A GIS enables planners and researchers to format data in a way that is relevant to policy makers and persuasive to funding agencies, as well as to illustrate health planning problems in a way that is meaningful to both experts and non-experts (Phillips et al., 2000). Some examples of studies that have used a GIS to explore health care utilization include:

- in Mexico, geographical coverage of the Mexican Healthcare System and the corresponding utilization of their general hospitals (Hernandez-Avila et al., 2002);
- utilization discrepancies between secondary and tertiary care hospitals in Japan (Toyabe & Kouhei, 2006);
- identifying communities’ health status in order to make comparisons with utilization of health care services (Faruque, Lofton, Doddato, & Mangum, 2003); and
- classifying geographic accessibility to hearing clinics to determine if it was associated with service utilization for older adults with cognitive impairment (Fortney, Chumbler, Cody, & Beck., 2002).
In a specific example relevant to public health policy, one study examined the effects of geography and spatial behaviour on health care utilization amongst residents of a rural region in North Carolina, USA (Arcury et al., 2005). The results demonstrated the inequity in rural health care utilization and the need for ongoing inequities to be addressed through public policy (Arcury et al., 2005).

**Market Segmentation**

Market segmentation is related to health care utilization in that it is used to create client or patient profiles to better meet the needs of a population, to target health services for underserved groups, or to set guidelines for insurance rates. GIS tools have become increasingly popular, particularly with insurance companies, because they enable the companies to conduct market penetration analyses, generate customer profiles and target specific sub-groups of the population, and to set premiums (Boysen, 2000; Cross, 1998; Evans, 1998). In these cases, GIS is used in conjunction with the Internet to research service demand, plan locations of new facilities, display accessibility of a health plan’s provider network, and for customer service so that insurance group members can access directories and create customized searches of health providers in their local area, or that are covered by their health plan (Villalon, 1999).

**Characteristics of Populations Associated with Particular Service Areas**

Traditional uses of GIS approaches for this subject area are: i) to identify population characteristics associated with the particular service areas of healthcare providers, or ii) to develop a spatial profile of the patient registry of a single practice. For example, White and colleagues (2000) developed three GIS applications to investigate provision of dental services in Birmingham, UK: i) to determine gaps in access to services within a defined region, ii) to spatially display the distribution of patients with specialized needs such as cleft lip and palate patients, and iii) to create a spatial profile of a general practice patient base. A similar example examined the location and distribution of orthodontic care delivery in New Zealand along with a spatial profile of the patient base population (Marriott, Harding, Devlin, & Benwell, 2001). In another example, in the USA an internet GIS has been developed to visualize the health care infrastructure across the country; this information is being used to help reduce health disparities by informing policy (Fulcher & Kaukinene, 2004). In summary, properly designed GIS network models and analyses can act as decision-support systems for community health planning through the spatial analysis of the distribution of health services and the identification of catchment areas for different health care services. It can also be used to produce demographic, social, and residential profiles for patients who use those services and conduct health service needs assessments to establish priorities for interventions, policies, and programs (Brazil & Anderson, 1996; Hirschfield, Brown, & Bundred, 1995).
CHAPTER SUMMARY

Generating visual depictions of the distribution of health care providers allows the public, health care providers, and policy makers to effectively use research data to better target the needs of the community. This chapter has overviewed a wide variety of GIS applications for health access and planning reported from both developed and developing countries. This suggests that GIS can be an accessible and useful public health tool provided that appropriate training and support are available for users. In addition, care must be taken to ensure that, if a GIS framework is utilized (or considered for utilization), that surveillance data is collected in such a way as to be used for that purpose.
Chapter 6: Community Health Profiling

Our final category for the discussion of GIS use in public health is that of community health profiling. This includes compiling and mapping information regarding the health of a population in a community. Profiles can include data on variables that may influence health as well as health outcomes, for example: sociodemographic factors; disease morbidity and mortality; health behaviours such as physical activity, alcohol or tobacco use, and drug addiction; and policy environment such as smoking bans or pesticide legislation. This information can be combined with the spatial location of community infrastructure such as churches, restaurants, schools, grocery stores, hospitals and clinics, roads, and public utilities. This allows for the general relationships between the environment and health outcome data to be examined. In addition, this knowledge can be used to identify potential environmental exposures, predict disease spread, track changes in the health of the community, plan prevention activities, or to justify screening tests and other health interventions such as sexually transmitted infections testing or flu shots (Latkin, Glass, & Duncan, 1998; Pine & Diaz, 2000, 2001).

GIS approaches can be used to better understand the links between people and their environments; this helps ensure that the health needs of the target communities are better met (Plescia et al., 2001). Although the volume of literature on this type of GIS application is sparse relative to that of disease surveillance, risk analysis, and health access and planning, this category could be seen as a culmination of them all as it treats the community as an over-arching environment or context in which all of these health-related variables co-exist and interact.

EXPLORING ACCESS TO NON-MEDICAL FACILITIES

GIS frameworks provide a means for integrating multi-sectoral data and allow for the easy visualization of the extent of health problems in relation to the surrounding environment and existing health and social infrastructure such as health facilities, schools, and roads (Brooker & Michael, 2000). Mapping this information creates a powerful tool for monitoring and managing programs allowing for more efficient targeting of resources to those communities most in need and the development of policies that effectively support public health. In addition, exploring access to non-medical facilities using GIS tools can assist researchers and practitioners involved in community-specific projects to focus on specific populations and their resource environments (Hirshorn & Stewar, 2003). Some examples of studies that have used GIS to visualize access to facilities include: examining patterns of social service use in community-based interventions in Philadelphia, USA (Wong & Hillier, 2001); looking at community accessibility to shopping, education, recreation, and health facilities in New Zealand (Pearce, Witten, & Bartie, 2006); and in Mozambique, exploring the accessibility of emergency shelters for vulnerable populations (Gall, 2004).

Moreover, studies that have specifically explored access of special populations to food resource facilities include: investigating the availability of food resources accessible to new mothers (Brown, 2004); looking at the spatial accessibility of large chain supermarkets in relation to neighbourhood racial composition and poverty (Zenk et al., 2005); in Australia, the availability and accessibility of supermarkets was compared with socioeconomic status (O’Dwyer & Coveney, 2006); and in Minnesota, USA, the proximity to food resources for homeless was examined to determine whether the shelter environment and surrounding community influenced lifestyle factors (R. Richards & Smith, 2006).
In one unique study in rural Kenya, the travel time to mosquito net distributors was modeled using a GIS; this led to the development of approaches that sought to increase the access of less educated mothers living in poor and remote areas to nets (Noor, Omumbo, Amin, Zurovac, & Snow, 2006). In another interesting study, a GIS was used to determine whether the density of alcohol distributors was correlated with heavy and frequent drinking and drinking-related problems in college students (Weitzman, Folkman, Folkman, & Wechsler, 2003).

In other relevant studies the accessibility to dental facilities was explored, for example: in New York City, USA, geographic accessibility of dental providers serving older adults was compared to the proximity to the subway system (Borrell et al., 2006); in Ohio, USA, regional inequities in dental provider locations was identified (Horner & Mascarenhas, 2007; Susi & Mascarenhas, 2002); and in Mississippi, USA, the availability of dentists in various counties was explored over a four-decade time period, to explore the geographic distribution of dentists, the change in distribution and how the distribution related to population (Krause, Frate, & May, 2005). Accessibility of dental facilities has been outlined in the community health profiling section rather than the health access and planning section because it is not a specific medical health service and therefore fits better with identifying services available in the community.

**EXPLORING COMMUNITY NEEDS THROUGH GIS**

The exploration of access to various facilities can also be used for the evaluation of community interventions, in that maps generated using a GIS enable health planners and policy makers to quickly see and understand their community’s assets and needs in greater detail than is possible with tables and charts (Schlundt et al., 2001). Thus, GIS is a tool for contributing to improved public health as it can be used to: identify those individuals most at risk, implement a plan to communicate effectively with them, and facilitate provision of services that meet the health needs or foster changes in their health behaviours. Some examples of studies that have conducted community and neighbourhood assessments to gain a greater understanding of a community’s assets and needs include:

- using neighbourhood mapping to examine the local context of community health programs (Aronson, Wallis, O’Campo, & Schafer, 2007);
- using a GIS to explore the complexity of human-environment interactions (Tatalovich, Wilson, Milan, Jerrett, & McConnell, 2006);
- exploring whether individuals region of residence in the USA was related to children’s health, health outcomes, and disparity (Goldhagen et al., 2005);
- in Chicago, USA, a GIS and small area analysis were performed to uncover local-level disparities (i.e., mortality rates, birth outcomes, and infectious diseases) (Whitman, Silva, Shah, & Ansell, 2004); and
- in Tennessee, USA, a GIS was used to gain a better understanding of how neighbourhood environments contributed to health outcomes through discouraging or encouraging healthy lifestyles (Schlundt, Hargreaves, & McClellan, 2006).

Another study of this nature aimed to develop and test a GIS system that was to be used by a local university and community to share routinely collected health data; this project sought to improve access to community health information (Buckeridge, Mason et al., 2002). Finally, in an example of
knowledge exchange in action, Pickle and colleagues (2006) discussed a workshop that was developed to demonstrate how a GIS could be used in cancer control. At this workshop, consensus was built on public policy, roadblocks to action were identified, and recommendations were made to overcome these roadblocks.

Community profiling is a GIS application that makes best use of demographic data for decision making to improve public health (Gatrell & Loytonen, 1998; Pine & Diaz, 2000; T. B. Richards, Croner, & Novick, 1999a; Tempalski & McLafferty, 1997; Wain, 1997). Thus, in a profiled community, GIS approaches can also be used to target communities in need and prioritize health care delivery in times of limited funding or resources. For example, Gobalet and Thomas (1996) employed demographic techniques and perspectives to produce information used by USA public health officials to plan health education campaigns and services. In another study from the USA, researchers used within-state geographic patterns of health insurance coverage and health risk factors associated with the incidence and mortality of common diseases to create risk factor maps at a local (within-state) level (Pickle & Su, 2002). These maps were used to foster an improved understanding of localized patterns of health risk behaviours and access to health care, as well as to help target intervention activities in the areas of the USA with the greatest need. Similarly, the USA National Cancer Institute used a GIS to identify patients for cancer outreach programs and to develop an intervention program and communication plan for women in Almeda County, California, USA, who were seen as being at the greatest risk for developing breast cancer (Lubenow & Tolson, 2001). The authors reported that this approach allowed them to make best use of relevant and reliable integrated data, while maximizing funds and resources and contributing to improved public health. In a comparable study, researchers explored ways to maximize the usage of cancer registry data using a GIS and other data tracking systems to help identify and eliminate social disparities in cancer (Koh, Juge, Ferrer, & Gershman, 2005). Additional examples whereby a GIS has been applied to help identify and target community needs include:

- exploring the spatial correlation of alcohol consumption and injuries in Western Australia to inform prevention efforts and target local planning and policy (Midford et al., 1998);
- mapping of unmarried teen births and sociodemographic variables in Texas, USA (Blake & Bentov, 2001);
- using spatial targeting via linkage of diverse spatial data sets that include multiple indicators of risk to predict communities at risk for low birth weights in New York City, USA (Tempalski & McLafferty, 1997); and
- identifying that when conducting community-based studies GIS approaches and cluster analysis can be used to select comparable and contrasting communities (X. Zhang, Christoffel, Mason, & Liu, 2006)

In one unique study, in London, UK, a map was created to highlight locations of sexually transmitted infections diagnoses (Boulos, Russell, & Smith, 2005). This information identified the rising occurrence of sexually transmitted infections in London and was used to help support health planners and decision makers in their planning activities (Boulos et al., 2005).

There have also been numerous studies that have explored the association between communities and substance abusing individuals living within the communities. For example, in one study assessing spatial patterns of drug use, this information was used to identify implications for the location of drug use prevention, needle exchange, and other HIV prevention activities (Latkin et al., 1998).
study, Mason and colleagues (2004b) used a GIS to explore whether or not there was an association between the location of substance abusing youth homes and the locations that they identified as being ‘risky’ and ‘safe’ places. The results of this study indicated that users’ homes were three times closer to risky locations than to the areas which they identified as being safe places (Mason et al., 2004b). This study was complimented by two additional studies which i) explored the association between substance abusing teens’ perceptions of environment and objective environmental information (Mason, Cheung, & Walker, 2004a), and ii) geographical risk factors for potential drug use (Walker, Mason, & Cheung, 2006). In a similar study, geographic and community variables were related to substance abuse; the results of this study were important for understanding patient functioning in the community following inpatient treatment (Stahler et al., 2007). Finally, in another interesting study, GIS was used to assess teenagers’ exposure to tobacco, alcohol, and fast-food restaurants in China (Jerrett et al., 2006).

Additional studies that have explored individuals’ proximity to fast-food outlets include: a study in New Orleans, USA, that looked at the geographic distribution of fast food restaurants and compared their location with sociodemographic characteristics of the neighbourhood (Block, Scribner, & De-Salvo, 2004; Pearce, Blakely, Witten, & Bartie, 2007); another where the distance between children’s residence, playgrounds, and fast-food restaurants were compared (Burdette & Whitaker, 2004) to the obesity levels in children aged 3 to 18 (Liu, Wilson, Qi, & Ying, 2007). In a separate study conducted in Melbourne, Australia, the accessibility of healthy foods and fast foods was explored using a GIS accessibility program (Burns & Inglis, 2007). In this study, it was evident that those in disadvantaged areas lived in closer proximity to fast-food restaurants; in contrast, more advantaged areas were closer to supermarkets.

Given the growing concerns around rising obesity rates, GIS has been employed as a tool to help us understand our relationship to food in our environments. To illustrate, there are also numerous studies that have explored the association between environmental characteristics and physical activity patterns. For example, neighbourhood characteristics have been compared with physical activity and sedentary behaviours in youths (Roemmich, Epstein, Raja, & Yin, 2007) and adolescents (Norman et al., 2006). In another study observed, self-reported environmental features and GIS sources of data were compared to determine if there was an association between environment and adolescents’ physical activity levels (Jago, Baranwoski, & Baranowski, 2006). GIS approaches have also been used to investigate how recreation and leisure activities can be used to help prevent emotional and behavioural disorders (Stanton-Chapman & Chapman, 2007), while another example compared perceived and objectively measured proximity to physical activity supports (Kirtland et al., 2003; Wilson, Kirtland, Ainsworth, & Addy, 2004). In a different study, the perceived and objectively measured proximity to physical activity resources was examined for low-income, mid-life women (Jilcott, Evenson, Laraia, & Ammerman, 2007). Finally, in two similar studies, the built environment (McGinn, Evenson, Herring, Huston, & Rodriguez, 2007) and natural environment (McGinn, Evenson, Herring, & Huston, 2007) were examined to determine if there were associated declines in physical activity as a result of non-motorized transportation (i.e. walking and transportation activity) becoming inconvenient.

There are numerous other studies that have explored the association between the outdoor physical environment and physical activity. Some examples include:

- examining the effects of green space on health, well being, and safety (Groenewegen, de Vries, & Verheij, 2006);
· investigating street connectivity and proximity to parkland with physical activity levels (M. Duncan & Mummery, 2005);

· determining whether the availability and accessibility of physical activity resources differs by neighbourhood socioeconomic status (Estabrooks, Lee, & Gyurcsik, 2003; Gordon-Larsen, Nelson, Page, & Popkin, 2006);

· exploring whether neighbourhood environment influences physical activity patterns of post-menopausal women (W. C. King et al., 2005);

· examining whether community design is associated with physical activity participation levels (Frank, Schmid, Sallis, Chapman, & Saelens, 2005);

· exploring whether green space is associated with physical activity and investigating the association with neighbourhood physical and social environments with recreation physical activity (C. Lee, 2007); and

· looking at the association between neighbourhood and home television environments with young children’s physical activity (Roemmich et al., 2006).

One interesting paper illustrated how GIS can be used to objectively measure the built environment and the influences it has on physical activity (Forsyth, Schmitz, Oakes, Zimmerman, & Koepp, 2006). This paper provides a model for developing protocols to enable high quality comparisons on the relationships between physical activity, the environment, and additional health outcomes. Although Forsyth and colleagues (2006) have developed a protocol for ensuring high quality comparisons between the environment and physical activity, in a contrasting article by Porter and colleagues (2004) it is suggested that caution be employed when utilizing a GIS to study environmental supports for physical activity. In this article it is proposed that researchers thoroughly investigate available data, make certain that there are trained personnel, and consider issues such as data quality, analyses, and confidentiality (D. E. Porter et al., 2004). These are key considerations for any GIS project.

In addition to examining how community design and access to resources affects physical activity, there are also various studies that have associated physical activity patterns to the walkability of neighbourhoods and awareness of community walking trails (Kligerman, Sallis, Ryan, Frank, & Nader, 2007; Leslie et al., 2007; Leslie et al., 2005; Michael, Beard, Choi, Farquhar, & Carlson, 2006; Moudon et al., 2007; Reed, Ainsworth, Wilson, Mixon, & Cook, 2004; Tilt, Unfried, & Roca, 2007). Many studies have also explored how neighbourhood design influences active commuting. For example, in one study, the personal, family, social, and environmental correlates of active commuting to school were explored for children (Timperio et al., 2006). In another study, the association between access to destinations and walking for transportation was explored (Cerin, Leslie, du Troit, Owen, & Frank, 2007). Similarly, individual and neighbourhood effects were compared to active lifestyles and social isolation in elderly individuals (D. K. King, 2006). Another study showed that urban trail use was associated with neighbourhood characteristics such as population density, neighbourhood commercial use, vegetative health, and amount of parking (Lindsey, Han, Wilson, & Yang, 2006). Finally, two physical activity studies examined health outcomes, neighbourhood walkability, and the built environment in association with depression in older men (Berke, Bottlieb, Moudon, & Larson, 2007) and with obesity in older adults (Berke, Koepsell, Moudon, Hoskins, & Larson, 2007).
Other studies have examined factors in the physical environment associated with cycling for transportation and cycling for health benefits. For example, Moudon and colleagues (2005) explored how different environmental conditions were associated with cycling; the results of this study indicated that an individual’s decision to cycle was independent of environmental support. In another study, the aim was to identify factors in the physical environment that were associated with an increased proportion of time spent walking and cycling (Wendel-Vos et al., 2004). The results of this study indicated that green and recreational space, particularly parks and sports fields, increased the likelihood that individuals would partake in walking or cycling. In a similar study, Krizek and Johnson (2006) found that proximity to retail and bicycling facilities was associated with increased active transportation (i.e. human-powered transportation).

**USING GIS TO EXPLORE DISPARITIES IN HEALTH OUTCOMES BETWEEN COMMUNITIES**

GIS frameworks for community profiling have been used to investigate disparity of health outcomes relative to the socioeconomic status of impoverished groups and ethnic minorities worldwide including specific examples from the USA (Schlundt et al., 2001), the UK (Mitchell et al., 2002), and Brazil (Szwarcwald, Bastos, Barcellos, Pina, & Esteves, 2000). For example, Hanchette (1999) described the use of a GIS for health programming and policy formation in public health agencies regarding childhood lead poisoning and welfare reform and to implement 1997 Centres for Disease Control (CDC) Lead Screening Guidelines. In another example, a GIS was used to create a historical profile of Charles Booth’s inquiry of the social and economic conditions of the people of London, UK, at the end of the 19th century (Orford, Dorling, Mitchell, Shaw, & Smith, 2002). In that study, the social classes of inner London were displayed on a street by street basis and, using a derived index of relative poverty for then and for the 1991 census, historical and contemporary patterns of poverty were compared.

There were three other interesting community profile GIS applications reported in the literature. In the first, a GIS was used to identify and map community vulnerability to disasters based on the premise that disaster vulnerability is socially constructed as it arises out of the social and economic circumstances of everyday living (Morrow, 1999). As expected, this study noted that hazards and risk may be concentrated in certain groups of people based on social and political patterns of disparity, and that local planning for emergency response should acknowledge socioeconomic variables in association with inequitable risk. Another unique study used GIS data and analysis to describe the locations and characteristics of tobacco billboards and to assess the extent to which tobacco companies located billboard advertising in proximity to minority neighborhoods and schools in St. Louis, Missouri, USA (Luke, Esmundo, & Bloom, 2000). Furthermore, in another example, social and physical environment characteristics were related to individuals’ perceptions of traffic stress (Song, Gee, Fan, & Takeuchi, 2007). Through this study it was evident that perceived traffic stress was linked with higher depression and poorer health status, which has implications for policy makers and urban planners. Finally, on a more global scale, GIS has been used to understand patterns in health and how this effects travelers around the world (Bauer & Puotinen, 2002).
CHAPTER SUMMARY

The literature suggests there are many potential, but under explored, GIS applications of community health profiling. Community profiles could be used (on a limited basis) to: i) develop hypotheses and act as a catalyst for obtaining more information about individuals, families or neighbourhoods, ii) observe general relationships between the environment and health outcomes, and iii) make suggestions for follow-up analysis and research (Melnick, Seigal, Hildner, & Troxel, 1999; Pine & Diaz, 2000; Plescia et al., 2001). This could facilitate improved access to data by local health consumers and planners and allow local governments to engage diverse stakeholders within the health region in a partnership to improve community health. For example, a GIS has been used by nurses to understand spatial, numeric health and population relationships in order to enhance their provision of services to populations (Moss & Schell, 2004). In addition, public health officials and providers could use the data obtained from a GIS-based profile to identify and examine potential environmental exposures in a community and justify screening tests and other interventions, including medical diagnosis and treatment (Dean, 1999; Pine & Diaz, 2000). This type of application may be important for community development initiatives and valuable to decision makers in the creation of both health policy and healthy policy. Furthermore, in their 2006 review article Scotch and colleagues explore how GIS technology, which goes beyond spatial displaying of data, can be better used by public health professionals to play a stronger role during community health assessment problem solving.

Visual presentation of community needs can help ensure that future interventions, projects and facilities are in locations were there is a demand for services and to limit overlap with current services. Thus, the creation of maps can help other program staff and decision makers to manage and measure community-based public health initiatives (Schlundt et al., 2001). Due to the changing nature of disease and health in different locations and at different times, there is the need for health care planners and policy makers to use GIS to more effectively meet the needs of communities (Boulos, 2004; Boulos, Roudsari, & Carson, 2001).
Chapter 7: Overview of Methodological Issues and Challenges

This section will provide an overview of some of the common methodological challenges and limitations associated with the health-related GIS applications discussed in the previous chapters of this review. There are a number of critical methodological issues that must be considered when using Geographic Information Systems in order to ensure that the results generated from the analysis are valid, reliable, and meaningful. As with other research, neglect of these issues could severely limit the quality and applicability of study findings, and therefore need to be acknowledged in the development of the study design and analysis protocol. This section will be divided into three parts – spatial statistics in GIS, data treatment, and mapping considerations.

SPATIAL STATISTICS IN GIS

Spatial statistics are the methodological backbone for studies employing the use of Geographic Information Systems. As with other quantitative analyses, it is important that the appropriate statistical technique be used to address the hypothesis of interest in a GIS project. Many of the spatial statistics used in GIS analyses were developed as methodologies for addressing questions of spatial epidemiology (e.g., disease transmission and risk exposure), and as such, have a large and growing body of literature from that of GIS (for example, see Cromley & McLafferty, 2002; P. Elliott, Wakefield, Best, & Briggs, 2000; Gatrell & Loytonen, 1998; Ricketts, Savitz, Gesler, & Osborne, 1994).

Spatial Clusters of Health Events

Spatial clusters can be described as unusual concentrations of health events (e.g., disease cases) in space and time. There are two types of analysis for the examination of spatial clusters; exploratory, which is used to look for patterns of events, and confirmatory, which is used to verify a suspected or pre-existing pattern (Koch & Denike, 2001; Olsen, Martuzzi, & Elliott, 1996). Cluster analysis, whether exploratory or confirmatory, must address the following conditions: i) the number of cases relative to the population risk for the health event must be identified, ii) the geographical extent or scale at which clustering occurs must be defined, and iii) a set of decision criteria for assessing how much clustering exists and levels of significance must be operationalized. This decision criteria must be generated using a probability distribution such as the Poisson distribution which is used to model rare binary events in large populations, or through Monte Carlo simulation models which can be used to yield a large number of random possible outcomes (Cromley & McLafferty, 2002; Wakefield, Kelsall, & Morris, 2000).

It is important to be aware of the potential for the small numbers problem when examining incidence or prevalence rates using techniques such as spatial clustering. The small numbers problem occurs when comparing data from areas that differ in population size. The calculated rates of disease for small areas vary more and are less reliable than those for large areas, i.e., in small areas; a difference of one or two cases can greatly influence prevalence or incidence rates (Jon, 2001; Ricketts et al., 1994). This can be addressed through the use of statistical probability mapping, where the statistical significance of rates are mapped rather than the incidence or prevalence rates themselves. Statistical significance is measured by probability values that show the likelihood of the disease rate occurring given the normal rate of disease in the corresponding regional or national population and can be computed using the Poisson distribution test (Cromley & McLafferty, 2002).
There are several limitations associated with the analysis of spatial clusters. Varying latency periods, or the length of time between exposure to a disease causing agent and appearance of symptoms, may go unaccounted or be miscalculated in the assessment of incidence rates or predictions of prevalence. Similarly, a spatial mitigation bias may not be accurately reflected in the data. For example, the current address of an individual may have little or no connection to the environmental exposures to elements that may directly or cumulatively influence their health status. Confounding factors, such as known risk factors for disease including demographics (age, gender, SES), health behaviours (smoking), and genetic predisposition, must also be identified and controlled for in the study design. Finally, the theoretical basis of different types of health event clusters must guide the interpretation of analysis (Cromley & McLafferty, 2002). For instance, spatial patterns of hazardous materials exposure resulting from accidents during transportation must account for routes along road or railway networks and, similarly, in the case of communicable disease transmission, theories of human interaction must be considered.

**Smoothing Techniques and Spatial Filtering**

The small area numbers problem can also be addressed using a technique known as Empirical Bayes smoothing, which is a combination of mapping and simple interval display of rates. Disease rates are adjusted upward or downward- or smoothed- according to the size of the population on which they are based. This pulls rates more towards the population base rate, thus making them less variable. As a result, small area rates are smoothed more than those in large areas and reflect the differences in the reliability of rates linked to population size (Devine & Louis, 1994; Kulldorff, 1999; Ranta & Penttinen, 2000). An example of this can be seen in Wall and Devine’s (2000) work on lung cancer mortality in Ohio, USA, where they created an interface between GIS and spatial analysis logarithms to examine unusual aggregations of disease and reduce random noise in the variables. This approach allowed the authors to review the mortality data by smoothing along demographic factors taken from the analysis tables.

Spatial filter models are methods of exploratory spatial analysis that smooth point data (e.g., numbers of health events), allowing the values for central data points to be calculated. The traditional spatial filter technique involves placing a grid over the investigated area, with the intersections of the grid lines providing the centres of a series of overlapping circles. Disease rates are then calculated for these circles to give a continuous surface. This approach has the potential to better model the distribution of disease because patterns of disease are not necessarily subject to the political boundaries of administratively defined areas. It is important to consider the size of the spatial filter, or circle, i.e., the area over which the analysis is performed, as this can affect the results. A GIS can be used to modify the shape of the filter to include a buffer that follows the exact shape of a boundary (as defined by the user) and to extend the size of the filter as a buffer beyond that boundary. The total number of points that fall within the filter are then randomly distributed across the area, and this randomization is repeated 100 times. This is done to average error that is inherent to the data. If the number of randomly generated points in the investigated area is lower than the actual number of surveillance points in fewer of 5 of the 100 random runs, there is a 95% chance that a significantly low frequency (number of cases) was reported from that area.

It is critical when using this technique that the spatial locations (x,y coordinates) of cases be as precise as possible because, if used correctly, this technique is a quick and accurate method for identifying
statistically significant data gaps in a mapped surface of cases. A decision can then be made as to whether the gap is expected or needs further investigation. This technique can be applied to any point data surface where the identification of a gap is important, for example, if one part of a province has fewer disease cases than its surrounding areas. It is commonly used to enhance satellite imagery data for visual interpretation or to create smoothed maps of health data or exposure estimates as it can remove random noise caused by inaccurate records or mislocated cases and can address the influence of neighbours on disease process (M. Ali, M. Emch, & J.P. Donnay, 2002; Curtis, 1999).

**Kriging**

Kriging is a technique used to portray measurements taken at a discrete set of points as a continuous surface; it considers not only the distances between points, but also the spatial autocorrelation of measurements along those points (D. Briggs & Elliott, 1995). It is a logarithmic method in which the mean is estimated from the best linear-weighted moving average and is considered the optimal method of spatial linear interpolation. Kriging creates contours of point data that can then be used to generate polygons that, in turn, can be used for GIS analysis such as the area-proportion technique for population estimates from census data (Dent et al., 2000). The area-proportion technique is used to analyze disparate types of geo-referenced data by estimating values within a given polygon based on the values of polygons in another data layer. For example, the number of people living in a contour generated by kriging could be estimated based on the number of people living in census blocks in the same area. If a contour polygon crosses a number of census blocks, then a proportion of the area of the census blocks lying within the target polygon is used to compute the population numbers. It is important to note that the area proportion technique assumes an even distribution of the event contoured and, as such, may result in a certain amount of measurable error (Dent et al., 2000).

Dent and colleagues (2000) also suggested that the key to evaluation of case locations in the context of a critical risk contour is to consider the totality of many elements including, but not limited to the spatial distribution of points, population density, and population characteristics. The advantages of using kriging to develop risk contours is that estimated values can fall outside the range of known data values, it gives a standard error for the estimated grid point values which makes it possible to compute confidence intervals around predictions, and it incorporates and models the spatial dependence in the data (Cromley & McLafferty, 2002).

**Autocorrelation**

Another consideration in the use of point data is the degree to which there is spatial dependence, or a similarity or association of the data values over space. This occurrence is known as autocorrelation and can be identified using measures such as Anselin’s local indicators of spatial autocorrelation (LISA), or the G-statistic, to measure the association between a value at a particular place and values for nearby or adjacent areas (Cromley & McLafferty, 2002; Jacquez, 1995; Vine, Degnan, & Hanchette, 1997). These approaches are useful for identifying and testing the significance of event clusters.

Another approach for identifying cluster locations is kernel estimation, which can be used to explore and display spatial patterns of health point data by generating a continuous surface of data in terms of the density of events or cases (Koch & Denike, 2001; Robinson, 2000). Cromley and McLafferty (2002) suggested this could be done utilizing a geographical analysis machine (GAM) which includes
testing for statistical significance of disease clusters and a spatial scan statistic which accounts for multiple testing. Other methods include Rushton and Lolonis’s method that uses Monte Carlo procedures to simulate possible spatial patterns of health events within a fixed geographical population to create alternative maps of health events, and Besag and Newell’s method of examining only clusters that occur around cases, as opposed to those dispersed throughout a bounded area of interest.

**Regression Mapping**

Regression mapping is a common approach used to estimate the mean annual concentrations of air pollution as a basis for examining small-area variations in air quality and chronic respiratory health due to the relative ease of programming regression models into a GIS framework (D. J. Briggs et al., 2000; Robinson, 2000). It is based on the principles that: i) environmental conditions for the variable of interest can be estimated from a small number of readily measurable predictor variables, and ii) that the relationship between the variable of interest and the predictors can be assessed on the basis of a data from a small sample survey.

The association between air pollution (and other variables) on health outcomes can be estimated at three levels - individual, ecological or environmental, and multi-level (individual and environmental levels) (Pikhart et al., 1997). For individual-level analysis, logistic regression can be used to investigate the influence of selected variables on the health outcome. At the level of ecological analysis, the variation in the odds of the health outcome between different areas of interest can be modeled using the method of weighted least squares regression. Multi-level, or hierarchical modeling, is an ideal approach for the examination of health outcomes where cases at one level (e.g., individuals) are nested within units at a higher level (e.g. schools). This approach could be used to examine individuals within communities and within health regions to assess variations in the health outcomes at each of those levels. Multi-level modelling can be used to account for the premise that cases within the same study area will be more alike on average than cases from different study areas. This implies that care must be taken in the identification and definition of study areas at the different levels.

**Accessibility Measures**

Spatial analyses of accessibility to health care tends to be focused on the relative location of clients to points of health service delivery and the travel distance (in time and space) between those locations. There are various aspects of distance including travel time, linear distance, aerial distance, or road time in addition to constructs of perceived distance and accessibility (whether the client views the facility as unavailable in spite of physical proximity (e.g., due to hours of operation, cost, or friendliness of staff, etc.) (Ricketts et al., 1994). Although apparently straightforward, adequate representation of distance is a complex undertaking and requires consideration of several aspects of access measurement (D. Martin et al., 2002).

Distance can be measured in several ways. Spherical distance measures distance along the curvature of the earth using latitude and longitude, or a national or regional scale, to connect two points along that curve (in spherical kilometers). Euclidean, or straight-line distance, measures the linear distance between two coordinate points using projected geographic coordinates such as the universal transverse mercator (UTM) grid system. Although most GIS systems use Euclidean distance as a default measure, it is important to keep in mind that it only addresses distance in straight lines and this does not
accurately reflect travel patterns and barriers (Cromley & McLafferty, 2002). It is often more useful and accurate to use GIS to calculate distance or time to travel along routes in a transportation network, which can be used to simulate alternatives in transportation modes and pathways as well as to model peak flow times. Perceptual distance can be measured using this technique or by calculating it using the Minkowski Metric (Ricketts et al., 1994). This operation can be used to adjust for exaggerated perceptions in distance, that is, the greater the weight placed on perceived distance, the larger the exponent will be in the calculation.

There are also several statistical models to measure spatial interaction, which are used to explore the overall accessibility of health services (Cromley & McLafferty, 2002). Accessibility potential models are based on the gravity model, where access is calculated based on measures of attractiveness of the service and distance (travel time or cost) to measure the relative access of a health service in a given area. These models also include a measure of distance friction, which is based on the principles of least effort (minimize distance or select shortest travel path) and resistance to movement over space, and suggest that services located nearby should be weighted more heavily than those farther afield. However, it must be noted that this relationship is dependent on type of services offered and that a client may be more willing to travel further or for longer (i.e., cross more barriers) to access a specialized service. Accessibility and distance models can also be used in conjunction with population distributions and mobility to define or measure catchment areas for services (Khan, Ali, Ferdousy, & Al Mamun, 2001).

**DATA TREATMENT**

Data types used in a GIS are either vector data, which are data that occur as a set of points, lines, and polygons, and raster, or grid-based, data. A layer within a GIS is a vector or raster file that contains thematic attribute data such as demographics, health behaviours, mortality rates, environmental features, or road networks. Overlay is the operation that allows the user to represent more layers together to better describe the characteristics of an area and the relationships between the variables under examination in that area. Map operators, such as spatial statistics, can be applied to layers to get new layers, thus adding new attributes to the spatial data (Contini et al., 2000; M. Y. Rogers, 1999). Although it is relatively simple to create a GIS relational database and generate maps of the attribute variables from that database, it is more challenging to ensure that this is done in a way that manipulates the data in a valid and reliable manner. Data issues of this nature will be overviewed in this section.

As with any research, the first step of a GIS project is to clearly identify the variables of interest and to determine the availability and quality of data sources for those variables (or indices of variables) based on a specifically delineated research (or applied) question of interest. Brooker and Michael (2000) suggested that the development of any spatial database is meaningless unless there is a clear identification of the goals and definitions for using the information for informed decision making. In addition, it may be useful to create a log for metadata (data about the data), which is a written detailed description of the data used in the study that includes the geographic area represented, who created it, and its intended use (Dent et al., 2000; O’Dwyer & Burton, 1998). This will help to mitigate misuse of the data, as data acquisition can be one of the most expensive and time-consuming elements of utilizing GIS technology in any area of research.
When linking data sets in a relational database, it is important to use the appropriate statistical approaches for dealing with data reduction or missing data in the analysis. For example, in the disease modeling applications, data may be integrated from multiple surveys in multiple countries, but the overall relational database is still constrained by the limits of the individual surveys such as variability in method and timing (Andes & Davies, 1995; Brooker et al., 2000). Such differences in survey methods and techniques and variation in the timings of surveys produce variation in the prevalence rates, thereby reducing the comparability of the data and the potential of the maps to represent prevalence precisely in every district of interest. However, a large, single database linking many smaller data sets offers researchers and health planners an opportunity to quickly identify gaps or inconsistencies in data collection.

The scale, or aggregation, at which the variables are collected influences the analysis of the results so it is critical that this is considered at the data preparation stage. For example, national census data may be irrelevant at a local planning level as records are likely to be aggregated too broadly. Thus, if official data are to be useful at a local level, they must be presented in a compelling manner that not only provides a factual basis for planning, but helps engage local agencies in the process (Clarke et al., 1996; Midford et al., 1998). In regards to the scale of data required for a GIS project, one must consider the level of data at which prediction is required as well as the information available for making predictions. It has been suggested that the availability and resolution of GIS data should ideally match the scale at which the health event variations occur in order to ascertain the relative importance of different environmental factors at different spatial scales (Brooker & Michael, 2000).

It is also important to consider the time and place where the data were collected. Out of date or obsolete data may create misleading results, so GIS systems that allow the continuous updating of data through an evolving database would be a valuable tool (Contini et al., 2000; Twigg, 1990). It is important to realize that case report data on time, place, and person usually collected through passive reporting systems is subject to substantial time lags in reporting and thus in the detection of patterns and variations from expected population rates (Loytonen, 1998; Zenilman et al., 2002). Further, patterns apparent in the data must be interpreted with care as they may indicate false causal relationships. For example, although disease cases appear close to a hazard source in the GIS map, this does not necessarily provide all the information necessary to establish a cause and effect relationship.

The functions and efficiency of a GIS to generate meaningful information relies heavily on the accuracy and level of detail in the geographic and attribute database. Therefore, in addition to attribute data about the area of interest, GIS tools need up-to-date digital maps of the area of interest and at the aggregation of interest, as well as accurate locational data for the cases or facilities to be mapped (e.g., address data or x,y coordinates). The availability and quality of maps at different levels and for different areas can vary substantially; when such data are not available, or are out of date, the cost and time for their acquisition may be significant (especially if using satellite-based remote sensing as a source of data images). It is important to be aware of the fact that the quality of results from analysis is directly related to the quality of data and models used and the data assumptions made at the outset.

There are also the critical issues of privacy, confidentiality, and ethics associated with the use of data in GIS studies. Data concerning place must be treated as carefully since data about individuals as the data presentations and maps in a GIS can identify core areas of health events that can be used to stigmatize places (e.g., communicable diseases) or groups of people. Potential misuses of geographic data can re-
sult from the ability to use GIS relational databases to link bits of unrelated information to create large dossiers on individuals or groups through data joins based on a common geographical location. Maps of case locations can also reveal personal information that can be used to stigmatize or discriminate against particular groups or individuals and can lead to greater health or socioeconomic inequities. For example, in some countries an individual’s access to insurance or health coverage can be denied based on geographic location. These types of issues may be resolved by aggregating the data to larger spatial levels or by displaying data on small-scale maps to make it difficult to discern exact location.

Some other challenges that need to be considered in relation to data treatment are: i) setbacks due to data management and inexperience with the software, and ii) communication with stakeholders to ensure appropriate and meaningful data collection, preparation, analysis, and display (Plescia et al., 2001). First, and most importantly, it must be realized that understanding the data sets and preparing them for analysis is a time- and effort-consuming process that must not be undervalued and should be budgeted for accordingly in terms of human resources as well as financial cost. Second, as GIS analyses for health-related applications become more widely used, there is a critical need to develop standardized procedures for descriptive analysis of geographic epidemiologic data, which would be applicable to individual localities across larger regions (Becker et al., 1998). In addition, appropriate statistical techniques must be used more systematically to adequately account for spatial autocorrelation, multicollinearity, and non-linear processes. Finally, communication and involvement of stakeholders in the development and display of knowledge in a mapped format is critical to the eventual uptake of the end product; knowing the audience is the key to the success of the map.

In summary, issues related to the accuracy of GIS-derived information needs to more fully address: i) the aggregate or ecological nature of the data, which may be relevant at the individual or ecological level, ii) the quality of the data that are input into the GIS (e.g., accuracy and completeness), iii) the appropriateness of combining multiple databases, and iv) the relevance of the map layers to the health outcome relationship of interest. Furthermore, all actors involved in the complex process of decision making in health promotion and public health need a framework for mutual understanding, communication, and conflict resolution (Contini et al., 2000; Cox, 1996). This implies that data, assumptions made, and results of each phase of the GIS analysis should be presented in an understandable and retrievable form. In a properly constructed GIS framework, it should be possible to run models using various data and assumptions, to analyze alternative scenarios, to perform sensitivity analysis, and to represent results on geographical maps relating health outcomes to other variables of interest in a way that is meaningful to the target audience(s).

MAPPING CONSIDERATIONS

The interpretation of output from a GIS analysis is directly related to the elements considered in the creation of the maps resulting from the data analysis. Maps generated from surveillance data can be generated as actual numbers, standardized rates, or mapped residuals of numbers compared with the population (Curtis, 1999). The most common way of analyzing patterns of health events using GIS is to create choropleth maps of the outcome of interest (e.g., disease incidence or prevalence rates). Choropleth maps display data values as a series of specific class intervals that are assigned a unique colour, shade or pattern so that differences in data ranges are visible by the variation of colours or pattern across the map. The key consideration in the process is choice of intervals, as different inter-
val schemes can change how the map looks and the message it sends (Boulos et al., 2001; Cromley & McLafferty, 2002; Curtis, 1999). Finally, the colour choices for the map legends should be tested for clarity on paper as well as electronically on the computer screen. In some cases, the distinctions between gradients or unique values can be difficult to distinguish due to the similarity of colours on paper, although they may seem distinct when displayed electronically.

Map sequences, or lag maps, can be used to study the spread of infectious disease or diffusion of a health program or policy implemented across space and time. This involves generating a series of maps that are displayed side by side to show distributions of the variable of interest at different points in time. Map sequences can also be an animated series that actively illustrates continuous and dynamic change (Cromley & McLafferty, 2002).

The size and shape of the area investigated (county units, postal codes, census tracts) may also produce different results depending on the chosen political unit of study. GIS can be used to define neighbourhoods via adjacency, the sharing of a common boundary, or by proximity, the distance between areas. Geo-referenced ‘neighbourhoods’ might be better geographic reference for GIS analyses than traditional administrative areas, because census tracts are re-created intermittently to take the national census, and postal codes are sometimes redesignated for mail delivery. These neighbourhoods could be defined on the basis of local information about socio-economic and cultural issues influencing patterns of residential migration and mobility (Kohli et al., 1997; Krieger, Waterman, Lemieux, Zierler, & Hogan, 2001; Plescia et al., 2001; Reissman et al., 2001). If there are no formally defined subdivisions or census tract-like boundaries that can be used for regionalization of address data, a GIS can be used to divide the area into a number of arbitrary sectors to designate boundary lines that consider residential patterns, major streets, and activity areas (Zenilman et al., 2002). If this process is used, care should be taken to represent neighbourhood clusters to the highest degree possible and boundary definitions should be operationalized and designated at the outset of the study in order to minimize bias. Furthermore, geographic definitions of communities are meaningful to the citizens comprising them, and primary data derived from surveys, focus groups, or key informant interviews should be used to document citizens’ perceptions and concerns about their area (Plescia et al., 2001).
CHAPTER SUMMARY

Information in GIS maps can help identify where current information is lacking, solicit feedback from stakeholders and others, or serve as a stimulus to collect new or additional data at the appropriate levels of aggregation. It has been suggested that further work is required to address a range of critical issues include problems of data quality, the impacts and consequences of spatial scale on relationships in the data, and the development and use of appropriate spatially-explicit statistical and modelling techniques in data analysis if the true potential of this tool to be fully realized for health-related applications (Brooker & Michael, 2000).

As many public health policy or program decisions are multi-disciplinary and cross-sectoral, GIS technology can help to establish cross-sectoral communication, not only by providing very powerful tools for the storage and analysis of multi-sectoral spatial and statistical data, but also by integrating the databases of different sectors in the same format, structure, and map projection. GIS can then be used to integrate, process, analyze, and display digital spatial and non-spatial data to generate and integrate layers of thematic information to provide new insights into health issues (Bernardi, 2001).
Chapter 8: Conclusions and Implications

This review revealed that health promotion and public health applications of GIS could be generally categorized into four predominant themes: i) disease surveillance, ii) risk analysis iii) health access and planning, and iv) community health profiling. These themes are not entirely distinct from one another and often overlap. For example, the use of GIS to examine the transmission of malaria in Sub-Saharan Africa is a disease surveillance application in that the spread of disease is mapped, but it is also a risk analysis application in that factors that foster or inhibit disease spread are identified and tracked.

The community health profiling category has the sparsest literature, likely due to the fact that disease and risk applications have historical roots to spatial analysis in epidemiology and thus were easily adapted for a GIS environment and more prolifically reported. There is a strong, inherent link between spatial analysis and disease spread and exposure risk, therefore those applications are the most common in the literature. More recently there has been an increase of work reported in the areas of geographic accessibility and health planning. This may be a result of the fact that GIS applications in these areas may be used to increase administrative effectiveness and efficiency in health services and, as such, there has been a greater uptake of these applications in the private sector, which has then diffused to public health practice and research. In addition, GIS plays an important role in strategic health planning contexts, whereby the information gathered can assist in influencing policy makers (Higgs & Gould, 2001; Higgs, Smith, & Gould, 2003, 2005; Smith, Gould, & Higgs, 2003). Community profiling applications are associated indirectly with each of the other three applications in that they are used to build understanding of a community or region as an overarching context or environment that influences the health outcomes of the population within its boundaries. In addition, community health profiles can assist with the development and implementation of population-based interventions which move beyond merely mapping the incidence and prevalence of disease, locating risk factors, and identifying access to health care services (Caley, 2004). This review identified several tools that attempt to link modern technologies (i.e., the Internet) with GIS to visually represent the incidence and prevalence of disease, location of risk factors, and access to health care services in order to have an impact on a population basis. These are summarized in the Appendix which provides a summary of tools that have been developed using GIS. Many of the studies mentioned in this review table focus on the use of GIS approaches and the Internet.

Although this review focused on exploring how GIS has been used in the health literature, there are additional methods for spatial referencing (i.e., point pattern analysis and traditional epidemiology methods) reported elsewhere. When GIS is compared with these other methods, the results complement one another rather than creating duplication or overlap in information (Dunn et al., 2001). In order to increase uptake of GIS in health promotion and public health, there is a need for a higher level of understanding on how to use the system and increased training and confidence to better analyze the information (Cockings, Dunn, Bhopal, & Walker, 2004). While as a tool GIS holds great potential for use in public health, there are also many pitfalls. For example, one study noted that when post office boxes are used to identify residents in a community, the post office boxes were not representative of the full population (Hurley, Saunders, Nivas, Hertz, & Reynolds, 2003). This is only one example of several challenges potentially encountered when utilizing GIS approaches, therefore, there is a need for experienced users to consider potential biases and errors and a need for inexperienced users to carefully consult with someone with expertise in the specific health-related GIS application they are interested.
in using. Not all maps are created equally and caution must be taken when interpreting outputs form maps created by yourself or by others (Hurley et al., 2003; M. J. Rytkonen, 2004).

In addition to the tools listed in the Appendix, Croner and colleagues (2003) provide a review on how GIS approaches and the Internet can be combined in public health research. Miller and colleagues (2007) also suggest ways in which local health departments can more efficiently collaborate by using the Internet; this article also provides advice on how pitfalls can be avoided.

Overall, this literature review provides evidence on the gaining popularity of using GIS as a tool for understanding health promotion and public health questions. It also demonstrates that GIS can be used as a natural and effective means to approach a variety of program, policy, and planning issues in public health. As the review was focused on the current and potential applications for GIS, this technical report highlighted many of the opportunities associated with its use.

The fundamental goal of this comprehensive literature review was to identify the extent to which Geographic Information Systems have been used for health-related applications. Geographic Information Systems are a type of technology that can be used to bridge the interface between science and practice by using a spatial aspect to link health outcomes to individual behaviours and environmental factors. It can be effectively utilized to monitor and assess program and policy interventions within a defined environment, but this use must be carefully designed and evaluated to ensure validity, reliability, and transparency and to increase accountability for evidence-based policy and practice. Further, communication with and involvement of stakeholders in the development and display of knowledge (data) in a mapped format is critical to the eventual uptake of the end product; knowing the audience is key to the success of the map(s).

The potential applications of GIS for subsequent work in health promotion and public health are numerous and limited only by the imagination. Opportunities for collaboration between disciplines such as geography and health should be maximized for the mutual benefit of researchers, practitioners, decision makers, and our communities.
References


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# Appendix

## Reports from the literature on examples of GIS tools applied in the practice of public health

<table>
<thead>
<tr>
<th>Tool</th>
<th>Purpose</th>
<th>Combined Sources</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Institute of Environmental Health Sciences (NIEHS) Portal</td>
<td>Aims to provide decision makers with the data, information, and the tools to: i) monitor human and environmental health impacts of disasters, ii) assess and reduce human exposures to contaminants, and iii) develop science-based remediation, rebuilding and repopulation strategies.</td>
<td>GIS, data mining/ integration, and visualization technologies</td>
<td>The NIEHS Environmental Health Sciences Data Resource Portal: Placing advanced technologies in service to vulnerable communities</td>
<td>(Pezzoli et al., 2007)</td>
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<td>GIS-EpiLink</td>
<td>Used to link environment and health data when the distance between an environmental site and the location of the maternal address of a case or control are used as proxies for exposure.</td>
<td>Spatial search tool using GIS</td>
<td>GIS-EpiLink: A spatial search tool for linking environmental and health data</td>
<td>(Zhan, Brender, Han, Suarez, &amp; Langlois, 2006)</td>
</tr>
<tr>
<td>Web-GIS</td>
<td>Created to investigate the relationship between health, air quality, and socio-economic factors.</td>
<td>Internet and GIS</td>
<td>Mapping health on the internet: A new tool for environmental justice and public health research</td>
<td>(Maclachlan, Jerrett, Abernathy, Sears, &amp; Bunch, 2007)</td>
</tr>
<tr>
<td>Internet-based Geographic Information System</td>
<td>Used to provide public health information, which focuses on community health assessment and improvement planning.</td>
<td>Florida CHARTS (Web-based data query system) and GIS</td>
<td>Implementation of an Internet-based Geographic Information System: The Florida experience</td>
<td>(Grigg, Alfred, Keler, &amp; Steele, 2006)</td>
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<tr>
<td>Web-based GIS</td>
<td>Intended to automatically update surveillance statistics for about 50 diseases as outlined by the Swedish Institute for Infectious Disease Control. The service is a way for the health community, media, and the public to easily access detailed and timely information.</td>
<td>GIS and Internet</td>
<td>Implementing a public web based GIS service for feedback of surveillance data on communicable diseases in Sweden</td>
<td>(Rolfhamre, Grabowska, &amp; Ekdahl, 2004)</td>
</tr>
<tr>
<td>Iterative Geocoding Processes</td>
<td>Used to achieve a high match rate in large population-based health studies between participants’ location and the proximity to various locations.</td>
<td>GIS and geocoding</td>
<td>Geocoding addresses from a large-population based study: Lessons learned</td>
<td>(McElroy, Remington, Trentham-Dietz, Robert, &amp; Newcomb, 2003)</td>
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<td>Raster GIS</td>
<td>Uses simple spatial filtering methods for analyzing health and environmental data. This method describes how health and environmental data can be scaled to better tackle health issues.</td>
<td>Spatial filtering</td>
<td>Spatial filtering using a raster GIS: Methods for scaling health and environmental data</td>
<td>(M. Ali, M. Emch, &amp; J.P. Donnay, 2002)</td>
</tr>
<tr>
<td>Web-based GIS</td>
<td>The system provides interactive district-level immunization coverage maps and graphs.</td>
<td>Scalable Vector Graphics (SVG); eXtensible Markup Language (XML); Expanded Program on Immunization (EPI)</td>
<td>Web-based public health GIS for resources-constrained environment using scalable vector graphics technology: A proof of concept applied to the expanded program on immunization data</td>
<td>(Kamadjeu &amp; Tolentino, 2006)</td>
</tr>
<tr>
<td>SOVAT (Spatial OLAP [On-Line Analytical Processing] Visualization and Analysis Tool)</td>
<td>Provides powerful numerical-spatial decision support in community health analysis.</td>
<td>OLAP and GIS</td>
<td>Development of SOVAT: A numerical-spatial decision support system for community health assessment research</td>
<td>(Scotch &amp; Parmanto, 2006)</td>
</tr>
<tr>
<td>MetaSurv</td>
<td>Web-based Geographic Information System designed for monitoring communicable diseases. Useful tool for supporting decision making.</td>
<td>Internet and GIS</td>
<td>MetaSurv: Web-platform generator for the monitoring of health indicators and interactive geographical information system</td>
<td>(Toubiana, Moreau, &amp; Bonnard, 2005)</td>
</tr>
<tr>
<td>No Name</td>
<td>Integrating GIS and public health experience may provide support for practitioners for risk assessment and prevention planning. Can provide valuable information for health research and management.</td>
<td>Internet and GIS</td>
<td>Geographical information systems and on-line GIServices for health data sharing and management</td>
<td>(Paolino, Sebillo, &amp; Cringoli, 2005)</td>
</tr>
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<td>EB-GIS4HEALTH UK</td>
<td>Attempts to construct an evidence based foundation for the UK and modular conceptual models for GIS application and programmes to be used in health and health care to improve on the current poor utilization of GIS within NHS.</td>
<td>NHS and GIS</td>
<td>Research protocol: EB-GIS4HEALTH UK – foundation evidence base and ontology-based framework of modular, reusable models for UK/NHS health and healthcare GIS applications</td>
<td>(Boulos, 2005)</td>
</tr>
<tr>
<td>Internet-based GIS</td>
<td>To assist in addressing disparities in health and access to health care. Specifically related to characteristics that promote or impede the provision of HIV-related services.</td>
<td>ESRI’s Arc Internet Map Server (ARC IMS)</td>
<td>HIV/AIDS community health information system</td>
<td>(Fulcher &amp; Kaukinen, 2003)</td>
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<tr>
<td>Multi-Agency Internet Geographic Information Service (MAIGIS)</td>
<td>An interactive map-based website used for sharing health and health related data for the West Midlands Region in England.</td>
<td>Using Internet GIS technology for sharing health and health related data for the West Midlands Region</td>
<td>(Theseira, 2002)</td>
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