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Geographic Information Systems (GIS) for Health Promotion and Public Health: A Review

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The purpose of this literature review is to identify how geographic information system (GIS) applications have been used in health-related research and to critically examine the issues, strengths, and challenges inherent to those approaches from the lenses of health promotion and public health. Through the review process, conducted in 2007, it is evident that health promotion and public health applications of GIS can be generally categorized into four predominant themes: disease surveillance (n = 227), risk analysis (n = 189), health access and planning (n = 138), and community health profiling (n = 115). This review explores how GIS approaches have been used to inform decision making and discusses the extent to which GIS can be applied to address health promotion and public health questions. The contribution of this literature 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 applications in public health policy, promotion, and practice.

Keywords: *geographic information system (GIS); health promotion; public health*

There is growing recognition in health promotion that consideration of *context* or *settings* is essential for effective public health research, practice, and policy. Contextual understanding also contributes to the implementation and evolution of best practices in the field. A deliberate consideration of context requires researchers to bring together variables that represent the people, environments and political processes

that comprise the settings in which programs and policies flourish or fail. Decision makers routinely consider community characteristics within the setting of broader social, political, and economic climates when developing policy, as should the researchers who study those policy processes. It is clear that setting is also of particular relevance to practitioners who need to address the question of “. . . but will it work *here*?” when implementing new programs or best practices. Researchers interested in advancing knowledge in health promotion must then endeavor to systematically examine contextual variables in a way that holds meaning and utility for both science and practice.

A first step in examining context is to investigate the spatial component of the health behaviors at which health programs and policies are directed. One approach for exploring the role of context in health initiatives is to use geographic information systems (GIS) in research. 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. GIS is a tool that can be applied at a range of aggregations to gain insight into the relationships between health outcomes and social, demographic, economic, and political variables. Use of GIS is rapidly emerging as a means to effectively link and analyze the range of data necessary to address complex questions in health promotion, public health, community medicine, epidemiology, and in a range of other fields (Nykiforuk & Flaman, 2008). The relevance of taking a multidisciplinary approach, particularly from the perspectives of health promotion, public health, and geography, is central to investigations of health and place.

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Our team undertook a systematic literature review of GIS use in health research to explore what we suspected was a growing potential for the tool to be used, particularly in health promotion. The specific purpose of this review was twofold: (a) to identify how GIS applications have been used in health-related research, including policy development, planning, monitoring, and surveillance and (b) to critically examine the issues, strengths, and challenges inherent to those applications. In this article we explore how GIS has been used to inform policy-making and discuss the extent to which GIS can be applied to address health promotion and public health questions in the future. Our review contributes to a broader understanding of how GIS methodological techniques and tools developed in other disciplines can be meaningfully applied to health policy, promotion, and practice.

► LITERATURE REVIEW

This comprehensive literature review was first conducted in the spring of 2002. The original literature review criterion was used to conduct a follow-up review 5 years later in the summer of 2007. Articles were systematically identified through a combination of computerized database searches and hand searches of the reference lists in relevant articles. 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 used. The search was restricted to studies reported in English-language journals and indexed with the keyword strategy outlined in Table 1. Only articles that addressed GIS methodology or human health-related GIS applications were selected for review. Articles that primarily addressed veterinary or physical environment applications (e.g., landscape ecology) were excluded. A specific emphasis on policy and decision making was included in the review strategy to ensure that practice- and policy-relevant articles were captured

TABLE 1
Keyword Strategy for Literature Review

Set	Search Terms
001	GIS OR Geographic Information System* AND Health
002	#1 AND Policy
003	GIS OR Geographic Information System* AND Decision Support
004	#3 AND Policy
005	#3 AND Health
006	GIS OR Geographic Information System* AND Bylaw*
007	GIS OR Geographic Information System* AND Regulation
008	#7 AND Health
009	#7 AND Policy OR Decision Support
010	GIS OR Geographic Information System* AND Legislation
011	#10 AND Health
012	#10 AND Policy and Decision Support
013	GIS OR Geographic Information System* AND Prevention AND Health
014	GIS OR Geographic Information System* AND Prevention AND Policy
015	GIS OR Geographic Information System* AND Prevention AND Disease

as thoroughly as those with a research focus. Resource material from various applied GIS Web sites was consulted to supplement the journal review and contextualize findings.

The final review was composed of 621 journal articles and book chapters reporting health-related applications of GIS. These articles were organized into categories based on the main type of application reported: (a) disease surveillance ($n = 227$), (b) risk analysis ($n = 189$), (c) health access and planning ($n = 138$), (d) community profiling ($n = 115$), and (e) general or methodological ($n = 17$). The relative distribution of articles in this categorization is summarized in Figure 1 and is discussed in subsequent sections.

It must be noted that although the four GIS content categories were treated as distinct for the purposes of organizing the review, in application they are not mutually exclusive and often overlap. For example, many applications that focused on disease surveillance also had components of risk analysis and vice versa. In some cases, single studies reported using aspects of each of the four categories. When more than one application was reported, the article was assigned to the

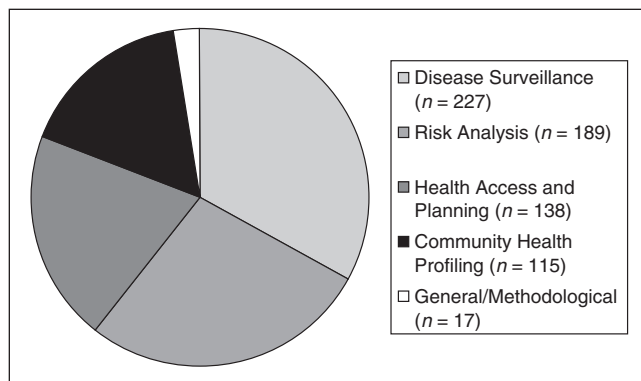


FIGURE 1 Categorization of Literature by GIS Application

category most closely aligned with the primary GIS application used.

This review will begin by defining GIS and providing an overview of the GIS application categories. The four content categories will be discussed in order of descending prevalence, beginning with an overview of disease surveillance applications and concluding with a summary of community profiling. General and methodological issues will be highlighted throughout the discussion.

Geographic Information Systems

Understanding relationships between health and contextual factors (e.g., sociodemographic, economic, political, and environmental variables) can be a complex undertaking. This complexity implies inclusion of variables at the micro, macro, and intermediary levels, typically organized in an ecological framework (Green, Richard, & Potvin, 1996). A GIS can facilitate appropriate integration and presentation of the disparate databases that encompass these ecological variables (Cromley & McLafferty, 2002). It can also be used to investigate statistical relationships that may vary from place to place. *Spatial analysis* of health outcomes and related variables can be undertaken 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 stories and communicate relationships in a way that otherwise may not be possible with other data presentation techniques (Mullner, Chung, Croke, & Mensah, 2004). Figure 2 presents an example of how a map has been used to communicate an important public health message about access to hospital services.

GIS has been used in the domains of environmental health, disease ecology, and public health as a tool for

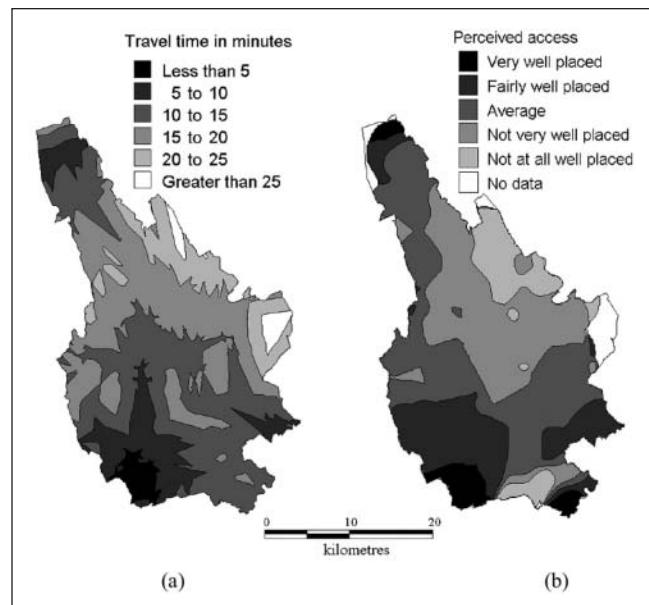


FIGURE 2 (a) Drive-Time to Nearest Hospital Accident and Emergency Department, (b) Residents' Perceived Access to Hospital Accident and Emergency Departments

SOURCE: Reprinted from Fone, D. L., Christie, S., & Lester, N. (2006). Comparison of perceived and modelled geographical access to accident and emergency departments: A cross-sectional analysis from the Caerphilly Health and Social Needs Study. *International Journal of Health Geographics*, 5(16). Retrieved December 5, 2008, from <http://www.ij-healthgeographics.com/content/5/1/16>. With permission from BioMed Central.

processing, analyzing, and visualizing data (Kistemann, Dangendorf, & Schweikart, 2002). Its use is quickly gaining recognition as an effective means to answer complex ecological questions in health promotion, medicine, and epidemiology (e.g., see Cromley & McLafferty, 2002; Foody, 2006; McLafferty, 2003). It is a unique tool that allows for the integration of multiple data sources, visual representations of complex data patterns, and the application of various spatial analytic techniques to answer a variety of questions. Some examples of questions that GIS approaches may seek to answer include identifying how asthma rates vary across the country or exploring whether there are higher rates of asthma in communities closer to industrial areas. 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.

Disease Surveillance

One of the most common and long-standing uses of GIS in public health is for disease surveillance, which

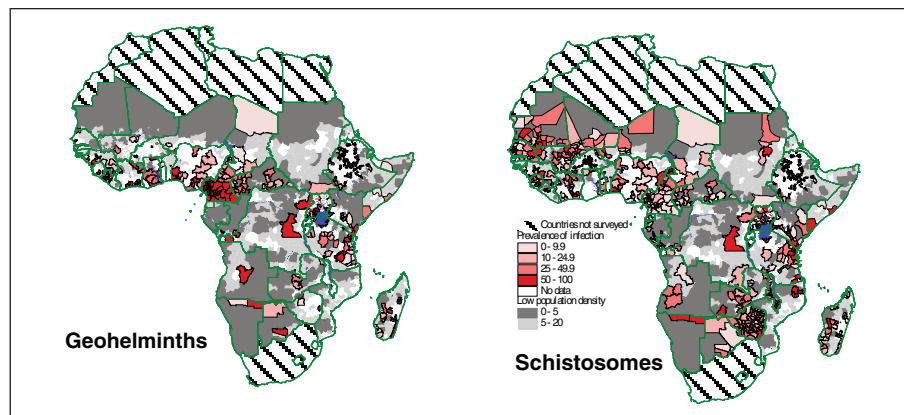


FIGURE 3 Maps Are Shown Detailing (a) Geohelminths in Africa: *Ascaris*, *Trichuris*, and Hookworm by District and (b) Schistosomiasis in Africa: *Schistosoma mansoni* and *S. haematobium* by District

SOURCE: Reprinted from Brooker, S., Rowlands, M., Haller, L., Savioli, L., & Bundy, D. A. (2000). Towards an atlas of human helminth infection in sub-Saharan Africa: The use of geographical information systems (GIS). *Parasitology Today*, 16, 303-307. With permission from Elsevier.

NOTE: The geohelminth species with the highest prevalence is taken to represent the prevalence of geohelminth infection. Similarly, the schistosome species with the highest prevalence is taken to represent the total prevalence in schistosome infection. The maps show data for sub-Saharan Africa only.

is the compilation and tracking of data on the incidence, prevalence, and spread of disease (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-mapping applications cover vector-borne illnesses to communicable diseases to cancer, in both rural and urban areas of industrial and developing countries (for a detailed synthesis, see Nykiforuk & Flaman, 2008). Many of these applications involve surveillance of disease incidence and prevalence to support control efforts. Others are focused on generating atlases to track the historical trends of disease. Figure 3 provides an example of a disease surveillance map depicting prevalence of human helminth infection in sub-Saharan Africa.

Disease mapping has emerged as an effective public health tool for disease prevention: by facilitating development of interventions, evaluating health outcomes, appraising population risks, scenario building, planning interventions, and summarizing and presenting health indicators (Garnelo, Brandao, & Levino, 2005). Integration of GIS technology into routine monitoring of health events offers a rapid, quantitative means for identification of unusual disease patterns. GIS is also a useful administrative tool to support decision making. Simple mapping applications can be used to create

maps of health indicators that can be readily used by healthcare providers, public health managers, and policy makers in practice (Sabesan & Raju, 2005). For example, Kyle, Balmes, Buffler, and Lee (2006) outlined how an environmental public tracking tool was developed to improve surveillance of environmental hazards and exposures. The tracking tool, along with associated health outcomes, was used to support policy strategies and interventions for disease prevention at local, state, and federal levels.

Disease modeling extends the disease-mapping application to (a) predict the future spread of disease, (b) identify factors that may foster or inhibit disease transmission, (c) pinpoint high-risk areas for disease prevention or intervention, (d) target control efforts, (e) identify gaps, and (f) increase stimulus for data collection in these areas (Myers et al., 2000; Robinson, 2000). When mapping 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, Shields, Jenkins, Zenilman, & Glass, 2000). Our review found that disease modeling is often one component of risk analysis of 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 suggested 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).

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. Such linkages can be used to develop models that can then be used, by extrapolation, to predict risk of disease over broad geographic areas where data are not available. Here GIS is used to systematically represent the spatial distribution of disease in a way that allows discovery and exploration of relationships between health and place that may not be as readily apparent using traditional techniques (Bavia, Hale, Malone, Braud, & Shane, 1999). From a social determinants of health lens, modeling disease transmission can play a critical role in the geography of human rights and social inequalities. For example, Winch (1998) demonstrated how processes such as climate change interact with human rights to favor disease emergence and related this to health equity of vector-borne diseases.

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. 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 behavior change might be most effective for disease prevention. The public health relevance of this applied utility is evidenced by an increased call for adapting GIS to medicine to facilitate improved medical and ecological applications (Appelrath, Friebe, Grawunder, & Wellman, 2001). Although GIS for disease surveillance is arguably the most established and well-developed application for public health, our review findings suggest that there is still ample opportunity for growth and innovation in this area.

Risk Analysis

Use of GIS for risk analysis is typically linked with 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 healthcare; Bergquist, 2001; Brody, Peck, & Highfield, 2004). An

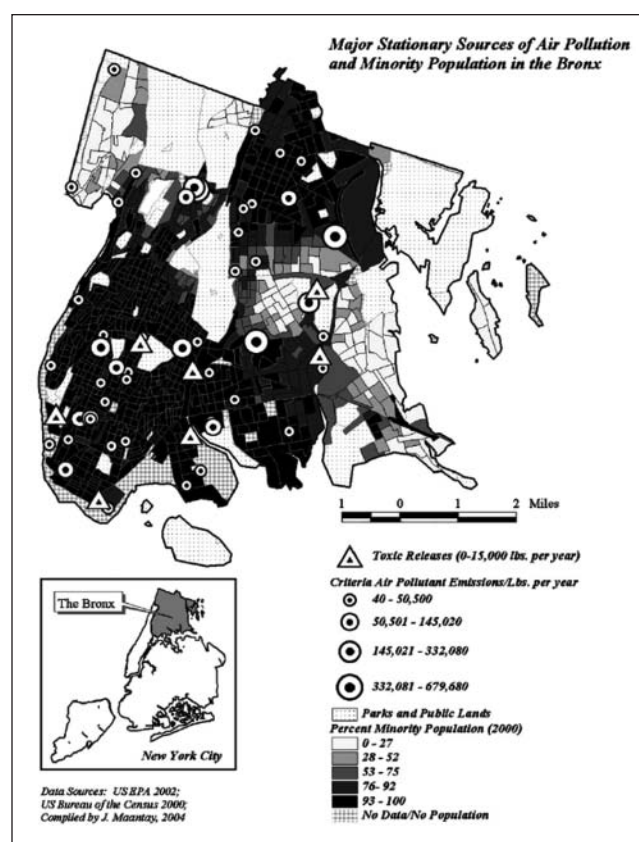


FIGURE 4 Major Stationary Sources of Air Pollution and Minority Population in the Bronx

SOURCE: USEPA (2002); U.S. Bureau of the Census (2000). Reprinted from Maantay, J. (2002). Mapping environmental injustices: Pitfalls and potential of geographic information systems in assessing environmental health and equity. *Environmental Health Perspectives*, 110(Suppl. 2), 161-171. With permission from Elsevier.

example of how a map has been used in risk analysis of pollution sources relative to population exposure is provided in Figure 4.

Risk analysis through GIS allows researchers and practitioners to longitudinally relate many different sources of environmental exposure to the residential locations of people 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; Gupta, 2001). Furthermore, display of environmental risk factors and associated potential health effects via GIS have

been shown to be an effective tool for communication of public health risks (Ali, Emch, Ashley, & Streatfield, 2001; Choi, Afzal, & Sattler, 2006).

Nyerges, Robkin, and Moore's (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 remained opportunity for GIS to enhance future risk research. Recent literature has since 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 various potential impacts of physical environment, landscape ecology, or climate change on human health (McMichael, Martens, Kovats, & Lele, 2000).

Risk analysis applications continue to have potential for situational analysis and policy development. A compelling example is that of the World Health Organization's (WHO's) use of GIS to map environmental health risks in the European region. Their purpose is 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>) (Web site current at the time of writing), has global mapping capability for snail-borne disease epidemics. The HealthMapper Web site facilitates risk management at the county or district level by (a) relating epidemic risk information to population distribution, environmental data, and basic health and social infrastructure and (b) ensuring regular monitoring and updating of the system using national health statistics and survey results (Brooker, Rowlands, Haller, Savioli, & Bundy, 2000; Myers et al., 2000). Our review revealed that the use of GIS for risk analysis also has potential to help policy and decision makers understand the spatial relationships between pollution and health. One example from the United Kingdom reports on the development of appropriate policy interventions emerging from a regression-based method for mapping traffic-related air pollution in four contrasting urban environments (Briggs et al., 2000).

Risk analysis is often information intensive as it encompasses data from secondary, field (primary), and satellite (remote sensing) sources in scenario-building exercises. Data from multiple sources is necessary to facilitate risk modeling and prediction (Cromley & McLafferty, 2002). As such, risk analysis is often combined with disease modeling to estimate and evaluate environmental disease hazards for a given population. For example, Njemanze, Anozie, Ihenacho, Russell, and Uwaeziozi (1999) combined risk analysis (via

probabilistic layer analysis) and GIS mapping 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. This enabled decision makers to apply the results during policy development for water resource management in other developing countries.

Although GIS applications are not the only way to examine variation in disease distributions or environmental exposures, they can effectively demonstrate how humans interact with the environment to create or deter health (Ricketts, 2003). The literature has shown that use of GIS in environmental epidemiology studies is feasible and can lead to policy makers' having a greater understanding of the association between environmental contaminants, disease, and health (Cutchin, 2007; Maantay, 2002). Integration of GIS with environmental and epidemiological research leads to the creation of maps that present complicated relationships in ways that are relatively easy to interpret. These maps can be used to inform development of exposure prevention policy and enhance translation of information back to the community (Miranda & Dolinoy, 2005).

Health Access and Planning

Health access and planning GIS applications 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, that is, it describes relationships between variables associated with service need and the attributes of the service delivery system (Cromley & McLafferty, 2002). Our review noted that 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. Market utilization applications are used to identify and characterize realized access to services within a network or catchment area, that is, to describe patterns of health service

use. Although often interrelated, market segmentation, network analysis, and market utilization GIS applications each have useful properties for independently addressing a variety of health planning questions.

The visual depictions of healthcare provider distributions reported in the health access and planning literature help the general public, healthcare providers, and policy makers to effectively use research data to better target the needs of the community (Nykiforuk & Flaman, 2008). A wide variety of GIS applications for health access and planning have been reported from both developed and developing countries, suggesting that GIS is an accessible and useful global health tool. However when using (or considering) a GIS, care must be taken to ensure that data are collected in a way that is amenable to mapping and that appropriate training and support are provided for users.

Community Health Profiling

Community health profiling is the compilation and mapping of information regarding the health of a population in a community. Profiles can include data on health outcomes as well as direct and indirect factors that influence health. Sociodemographic characteristics, disease morbidity and mortality, health behaviors (e.g., physical activity, tobacco use, sexual practices), and policies (e.g., smoking bans, pesticide legislation) are just a few examples of variables that can be used. In profiling, these variables are linked with the spatial location of community infrastructure such as churches, restaurants, schools, grocery stores, hospitals and clinics, roads, and public utilities. This linkage, when done appropriately, permits examination of the general relationships between health and setting. Data linkage in community profiling must be undertaken with great care and ethical consideration. Often, disparate secondary data sources can be linked in such a way that public users of the data can identify individuals. This must be avoided. One simple approach is to present data at aggregations (or maps at scales) that protect the integrity of the data's intended use and the confidentiality of the individuals it represents.

Community health profiling can be used to better understand the multilevel, ecological links between people and their environments; this helps ensure that the health needs of the target communities are better met (Plescia, Koontz, & Laurent, 2001). Although the volume of literature on profiling is sparse relative to that of disease surveillance, risk analysis, and health access and planning (see Figure 1), this category could be seen as a culmination of them all. Community health profiling treats the community as an overarching context in which all of these health-related variables coexist and interact.

Our review suggests there are many potential but underexplored GIS applications of community health profiling. Profiles could be used (on a limited basis) to (a) develop hypotheses and act as a catalyst for obtaining more information about individuals, families, or neighborhoods; (b) observe general relationships between the environment and health outcomes; (c) track changes in the health of a community over time; and (d) make suggestions for follow-up analysis and research (Pine & Diaz, 2000; Plescia et al., 2001). Community health profiles may 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 to enhance their provision of services to populations (Moss & Schell, 2004). Public health officials and providers could use the data obtained from a GIS-based profile to identify and examine potential environmental or diseases exposures in a community, plan prevention activities and target resources, and to justify screening tests and other interventions, including medical diagnosis and treatment (Pine & Diaz, 2000, 2001).

Similar applications may be important for community development initiatives and valuable to decision makers in the creation of both public health policy and healthy public policy. For example, Hanchette (1999) described how GIS was used to develop health programs and policies for childhood lead poisoning prevention in public health agencies. In a 2006 review article, Scotch, Parmanto, Gadd, and Sharma explore how GIS technology that goes beyond spatial display of data can be better used by public health professionals to play a stronger role in community health assessment problem solving.

We contend that visual presentation of community needs via maps can help ensure that future interventions, projects, and facilities are best aligned with locations in need of services. These maps can help program staff and decision makers to manage and measure community-based public health initiatives and to limit program overlap (Schlundt, Mushi, Larson, & Marrs, 2001). Because of the changing nature of health and disease in different locations and at different times, there is the need for health planners and policy makers to use GIS to more effectively meet the needs of communities (Boulos, 2004).

► DISCUSSION

Our review revealed that health promotion and public health applications of GIS could be generally categorized into four predominant themes: (a) disease

surveillance, (b) risk analysis, (c) health access and planning, and (d) 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 for the purposes of intervention development. 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 ecological context that influences the health of the population within its boundaries.

As apparent in Figure 1, reported research has traditionally focused on disease and risk-based GIS applications. The community health profiling category has the sparsest literature, likely because it is newer relative to disease and risk applications that have historical roots in epidemiology and medical geography. There is an inherent link between spatial analysis and disease spread or exposure risk, in part explaining the prolific reports of traditional GIS applications in these fields. Despite this, GIS applications pertaining to health access and planning and to community profiling have become increasingly prevalent in recent literature. These applications are typically used to increase administrative effectiveness and efficiency in health services—benefits that may have contributed to diffusion and increased use of the application in public health practice and research. GIS also plays an important role in strategic health planning contexts (Higgs, Smith, & Gould, 2003, 2005), where the interdisciplinary information presented in maps can assist in cross-sectoral decision making. Similarly, generation of community health profiles can assist with the development and implementation of population-based interventions. This approach moves the field beyond mere mapping of disease, risk factors, and access to health services to using this information in conjunction with the contextual realities of the populations and communities that health promotion and public health traditionally serve (Caley, 2004).

Although this review focused on exploring how GIS has been used in the health literature, there are additional methods for spatial referencing (e.g., point pattern analysis and traditional “epidemiological” methods) reported elsewhere. When GIS is compared with these other methods, the results complement one another rather than create duplication or overlap in information (Dunn et al., 2001). There is a need for a higher level of understanding on system uses along with increased training in analysis techniques

to increase uptake of GIS in health promotion and public health (Cockings, Dunn, Bhopal, & Walker, 2004). Although GIS holds great potential as a public health tool, there are also many pitfalls to its use. 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 example is one of a variety of challenges potentially encountered when using GIS, suggesting there is a need for experienced users to be attentive to potential biases and errors. There is a parallel 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 equal and caution must be taken when interpreting outputs from maps created by oneself or others (Hurley et al., 2003; Rytönen, 2004). Map interpretation is aided by knowledge of the purpose(s) for which the maps were created and information about the sources that contributed the data therein.

GIS maps can help identify where current information is lacking, solicit feedback from stakeholders, or serve as a stimulus to collect new or additional data at different levels of aggregation. Yet findings from our review suggest that further work addressing a range of critical issues is required if the true potential of this tool is to be fully realized for health-related applications. Future work could investigate problems related to data quality, the impacts and consequences of spatial scale on data relationships, and the development and use of appropriate spatially explicit statistical and modeling techniques in data analysis (Brooker & Michael, 2000). Additional pitfalls are resource-oriented and pertain to training and infrastructure issues such as technical expertise and support as well as the human and fiscal requirements for maintaining currency of software and databases.

Use of GIS technology can help clarify cross-sectoral and interdisciplinary communication by providing powerful tools for storage, linkage (through relational databases), and analysis of spatial, quantitative, and qualitative data from various sources; integration of databases from different sectors in the same format, structure, and map projection; and creation of a *common language* through visual depiction of the data in maps. GIS, then, can be used to integrate, process, analyze, and display digital spatial and nonspatial data to generate and integrate layers of thematic information to provide new insights into health issues (Bernardi, 2001). This sharing of ideas through maps enables communication about the characteristics of people and places over time, thus strengthening issues of *setting* on the

policy-maker agenda and in the priorities of researchers and practitioners. The extent to which a GIS can offer detailed and targeted data manipulation in conjunction with its potential for online, interactive mapping has contributed to its relevance for knowledge exchange. Further to the synthesis provided here, Croner (2003) reviewed how GIS approaches and the Internet can be effectively combined in collaborative public health research. Miller (2007) also suggests ways in which local health departments can more efficiently collaborate by using the Internet and advise on ways to avoid pitfalls with this GIS application.

► CONCLUSION

This systematic literature review synthesized the evidence on the use of GIS as a tool for examining health-related questions. Our findings demonstrate that GIS and spatial analysis can be used as a natural and effective means to approach a variety of program, policy, and planning issues in health promotion and public health. These tools offer unparalleled capabilities for describing, analyzing, modeling, and visualizing *health and place issues* relevant for policy agendas in every jurisdiction. Although this may be appealing to policy makers interested in having the best possible evidence to support their decisions, our findings reveal a paucity of literature providing detailed examples of how GIS has influenced health policy. The current body of literature pertaining to GIS and health emphasizes future implications for policy development only within the focus of the research reported (e.g., see: Moudon et al., 2005; Phillips, Kinman, Schnitzer, Lindbloom, & Ewigman, 2000; Sabesan & Raju, 2005; Scoggins, Kjellstrom, Fisher, Connor, & Gimson, 2004). Although this is not viewed as a weakness of the individual studies discussed, it does point to a significant gap in knowledge about the impacts of examining health and place.

GIS are an innovative technology that can be used to bridge the interface between science and practice by using a spatial aspect to link health outcomes to individual behaviors and ecological (context or setting) factors. GIS can be effectively used to monitor and assess program and policy interventions within a defined environment, while simultaneously tracking changes in the health of a population or community. These applications must be carefully designed and evaluated to ensure validity, reliability, and transparency and to increase accountability for evidence-based policy and practice. We argue that communication with and involvement of stakeholders in the development and display of knowledge (data) in a mapped format is critical to the eventual uptake and utility of the end product.

Interdisciplinary collaboration among methodologists and theorists from the health and social sciences is necessary to advance both the development of GIS applications relevant for health and our conceptualizations of the complex ecological relationships between health and place. Applied research partnerships resting equally on the expertise of (social) scientists and that of practitioners from health, environment, and community sectors are also critical for the evolution of forthcoming (and currently unknown) applications of GIS. The Ottawa Charter for Health Promotion (World Health Organization, 1986) reflects a holistic view of health that accounts for individuals functioning within broader social, environmental, and political contexts. The use of GIS approaches in public health practice and research offer us an opportunity to awaken our interest in the role of the context on health, particularly in relation to *creating supportive environments*.

The potential for GIS applications in the future of health promotion are numerous and limited only by the imagination. To this end, strategic opportunities for its use should be maximized for the mutual benefit of researchers, practitioners, decision makers, and our communities.

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