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Research article

Understanding the use of geographical information systems (GISs) in health informatics research: a review

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ABSTRACT

Background The purpose of this literature review is to understand geographical information systems (GISs) and how they can be applied to public health informatics, medical informatics and epidemiology.

Method Relevant papers that reflected the use of GISs in health research were identified from four academic databases: Academic Search Complete, BioMed Central, PubMed Central and Scholars Portal, as well as Google Scholar. The search strategy used was to identify articles with 'geographic information systems', 'public health', 'medical informatics', 'epidemiology' and 'health geography' as main subject headings or text words in titles and abstracts. Papers published between 1997 and 2014 were considered and a total of 39 articles were included to inform the authors on the use of GIS technologies in health informatics research.

Results The main applications of GIS in health informatics and epidemiology include disease surveillance, health risk analysis, health access and planning and community health profiling. GIS technologies can significantly improve quality and efficiency in health research, as substantial connections can be made between a population's health and their geographical location.

Conclusions Gains in health informatics can be made when GISs are applied through research, and however, improvements need to occur in the quantity and quality of data input for these systems to ensure better geographical health maps are used, so that proper conclusions between public health and environmental factors may be made.

Keywords: environmental health, epidemiology, geographic information systems (GIS), medical informatics, public health

BACKGROUND

For many years, government, community, administrative and political organizations have tried to understand the relationships that exist between geography and health.[1] Epidemiology, in particular the study of determining factors and distribution of health-related states,[2] is a major component of research in health geography, public health and medical informatics. Until the development of geographic information systems (GIS), health and geography were studied using classic maps and health reports, or lack thereof.[3] While GIS can benefit the study of public health and geography, it has its downfalls. The purpose of this literature review is to understand the benefits and drawbacks of GIS and how they can be applied to public health informatics, medical informatics and epidemiology.

A geographical information system (GIS) is defined as 'a computer-based system for collecting, editing, integrating, visualizing and analysing spatially-referenced data'.[4] They contain the spatial dimensions of specific geographic areas.[3] This allows for mapping and analysis of spatial information to occur and be applied in business, market research, government, etc. Health GISs are integrated systems containing tools for managing, inquiring, analysing and presenting spatially-referenced health data.[5]

GIS databases are comprised of both spatial and non-spatial data to allow for a greater understanding of their relationships through a series of thematic features in geography.[6] Non-spatial data (also called attribute or characteristic data) are that information that is independent of geometric considerations. For example, a person's height, mass and age are non-spatial data because they are independent of a person's location. However, weight is spatial data in the sense that weight of something depends on its location. Spatial data define precise geographical locations. Using GIS converts street addresses and coordinates to a specific point on a map.[6] Spatial data include spatial relationships. For example, the arrangement of houses on a street is also spatial data.

Once these systems are ready to use in research, one may use them to assess illness and health care services to treat and prevent the reoccurrence of health issues.[5] Because GIS contain health and illness information for specific regions as well as various forms of environmental data, connections between a population's living area and their state of well-being can be made in a more informed and in-depth manner compared to the use of traditional paper-based maps. As a result, GIS in health studies can improve the quantity and quality of epidemiological research in addition to health care delivery and accessibility as conclusions can be made about a region's care, services, and overall health. Other applications of GIS in public health informatics include efficient planning of health services, better access, logistics and identification of problem areas.[5]

Two examples of GIS in today's society include Google Maps and Google Earth.[7] While they are not necessarily official GIS for research and academics, they can still be useful. Bowman *et al.*[7] reported that Google Maps and Google Earth can help physicians to get a picture of where their patients live, especially when a doctor may be moving to a new community to practice. While these activities may not be health informatics research in and of themselves, they can still be valuable in medicine. For example, there is no point for a doctor in northern rural Canada in relying on the plethora of subspecialties available to them through a major urban centre when the community they are joining are limited to ice roads as the only point of access for much of the year. More examples of GIS used in health have included examining the relationship between health outcomes for people with diabetes and their physicians' use of diabetic medical information.[8] GIS can also be implemented in medical program evaluation to ensure that medical students are experiencing realistic rural and semi-rural placements based on thematic mapping of geographical characteristics of rural communities.[9] Further, one can compare whether or not the same health intervention program is more effective in different geographical areas of the same metropolis. For example, a heart rehab program may be extremely effective in an area where walkability scores are very low and one would expect the opposite to happen. Instead, due to low levels of access to walkable outdoor space, the program is run in an indoor gym and accessible all year round.

While there are improvements that can still be made in GIS, they can still be extremely useful in the study of environmental epidemiology.[10] Mapping through GIS can make substantial gains in the evaluation of environmental health risks.[11] GIS research needs to evolve more although its integration into public health has transitioned beyond its early stages into more efficient and practical uses.[12] For example, specific homes with high rates of lead poisoning or other harmful chemicals can be mapped through GIS and then interventions may be implemented to reduce and/or remove such hazards from those specific homes.[12] In that sense, researchers are not just making observations with GIS anymore, they are taking those observations and integrating them into action plans to make populations healthier. Nykiforuk and Flaman[13] identified the four main uses of GIS in health informatics such as disease surveillance, health risk analysis, health access and planning and community health profiling.

Disease surveillance

Disease surveillance is 'the compilation and tracking of data on the incidence, prevalence and spread of disease'.[14] Its main constituents are disease mapping and disease modelling. This helps us understand where disease and illness spread and how they may be minimized or stopped.[14] As a result, mapping and modelling in disease surveillance are systematic methods linking data on diseases with influencing environmental features.

Risk analysis

Risk analysis is defined as the assessment, management, communication and monitoring of health impacts.[14] This can be seen through studies such as one example which mapped and correlated major stationary sources of air pollution in relation to minority populations in New York City.[15] This

showed that minority populations in Bronx were significantly more likely to be exposed to air pollution and therefore had an increased risk of respiratory diseases.

Health access and planning

One of the most widely practiced applications of GIS in medical informatics is studying a community's access to health care. Access to health care describes a population's capability to use health services when needed.[16] We can identify relationships between different variables associated with the need for health services and how they are implemented.

For example, GIS has been used to assess populations in Central and South America that need access to anti-venom treatment sites for snakebites.[17] Another area for GIS includes the examination of maternity care access.[18] Even though these two topics are very different in the area of medicine that they examine, they both utilize GIS to support decision making regarding the provision of access to vital health care.[19]

Community health profiling

The final health category where GIS is implemented includes community health profiling. This is known as 'the compilation and mapping of information regarding the health of a population in a community'.[13] Profiling can be used to identify the geographical strengths and weaknesses of a specific community to make decisions about their health services to justify the placement of new ones.[20] For example, areas without access to greenspace may require more of an exercise on prescription approach to get patients active and engaged in a local gym as there is no park space safely available to them for walking. As such, community health profiling can help us understand the linkages between people and their environments to ensure that the health needs of different communities are met.[21]

BENEFITS OF GIS IN HEALTH INFORMATICS

There are extensive benefits with GIS in health informatics research. This is because of specific factors that GIS can bring to research including a better availability of geographical health data, more efficient data collection, increased dimensions of health data and a reduced risk of human error due to direct data input from geolocation devices.[3] GIS can enhance researchers' studies of environmental health, assess environmental risks, and help predict future healthcare needs.[22,23,11]

Simultaneously, GIS provides a significantly new approach to old problems in health care.[5] Costs of health services can be improved as those amenities can be planned more efficiently and cost-effectively. Guidance of health practices can also occur. This means that health professionals may be able to gain a better understanding of the people they are serving and major health concerns they should focus more attention on. Such research can lead to significant connections between community health and surrounding environmental factors such as water quality, gas emissions, walkability, health care access and local produce quality.[6,24,25] By identifying these factors in a geographical region, health promotion through multiple dimensions can be planned and implemented.[26]

DRAWBACKS OF GIS

Through review, one can see how greatly those services may increase our knowledge of health care. Just like other tools in research, however, GIS has drawbacks. Those downsides include the fact that GIS is highly dependent on the amount and quality of data for different regions being studied.[3] Moreover, if enough quality data are not conveyed, GIS may not be useful. Accordingly, researchers should not depend completely on them to make informed decisions for health.

Another weakness is the wide variation of GIS software applications.[5] One GIS may not be the same as another used in a similar study leading to discrepancies in research methodologies. Therefore, a goal of researchers in the future may be to design and implement standardized GIS to ensure lower variability.

Lastly, ethical issues are often ignored in the research process, i.e. confidentiality of data collection.[27] This can result in prolonged development of such systems due to the need to reintegrate data into the system in an ethical context. Confidentiality is a significant component of ethical research, and if data do not remain confidential, the credibility of GIS research may be stalled or halted. Unfortunately, loss of confidentiality may be an intrinsic limitation of GIS. It is very difficult to maintain confidentiality when geographic data are presented. For example, displaying information on the number of people with lung cancer in a small village would compromise confidentiality as it may become possible to identify the affected individuals with minimal additional information. A great deal of research is being undertaken in this area of small area geography to identify ways of addressing these concerns.[28] By identifying these faults, we can work to mitigate such factors in further research.[29]

EXAMPLES OF GIS IN HEALTH RESEARCH

A study performed by Dulin *et al.*[30] determined the need for increased access to primary care services in various communities using what they termed a Multiple Attribute Primary Care Targeting Strategy through the implementation of GIS technology. This proved to be extremely valuable in evaluating health services across rural areas as interventions could be applied. A second example determined the walkability of local communities to help encourage physical activity.[26,31] It was identified that various communities do not always contain adequate walking areas. GIS not only identified these problem areas, but the technology was also used to determine how to improve those walking systems. This can be useful for elderly populations as they are in an age group of declining health and many do not have a valid driver's license.[30] Such conclusions may not have been possible without GIS.

A third example of GIS in epidemiology and health informatics includes a study whose goal was to 'determine the

importance of geographic and spatial behavioural factors as predisposing and enabling factors in health care utilization of rural communities'.[32] This is essentially the definition of what GIS in health aims to accomplish. In this study, GIS was used through the completion of questionnaires addressing participants' demographic and socioeconomic characteristics, health status, health insurance coverage, medical care options, location of care providers, personal beliefs about health care, use of health services, health prevention behaviours, locations of daily activities and degree of social isolation from others.[32] It was found that geographic and spatial factors can have significant impacts in the utilization of health care services.

Similarly, the Patient Access Area Model was developed by executing a GIS.[23] This allowed for the evaluation of medical supply and demand to make informed predictions about access to hospitals. Through this, GIS allowed for the conclusion that over 9000 citizens in a southwest area of Japan would not receive proper hospital care and an intervention was planned accordingly.

PROVIDING PERSONALIZED HEALTH CARE THROUGH GIS

McLafferty summarized that the primary uses of GIS for research in environmental health include analysis of the need for health care, measurement of access to care, evaluation of inequalities and understanding geographic variations for service utilization. The final component is to understand the relationships between GIS and health care delivery.[33] While these areas of research in GIS are established, performance and effectiveness still needed significant evolution back in 2003. Later in 2011, Nykiforuk and Flaman[13] concluded that the four predominant themes of GIS used in health studies, as previously stated, were 1) disease surveillance, a) disease mapping and b) disease modeling, 2) risk analysis, 3) health access and planning and 4) community health profiling.

However, this leaves some fundamental issues and gaps that remain need to be addressed. Additionally, we also need research communities to work together and share information so that new, more ethical, research methodologies can be developed that put the privacy of the individual as the highest priority.[13] This will lead to more ethically sound research so that the data can be understood by more people and ultimately lead to better health care.[34]

It was the concept of developing an understanding of his own risks for a heart attack based on the environmental and risk factors associated with the geographical locations at which he had lived all his life that caused Davenhall to conclude that place history can be just as important as a person's lifestyle and genetics when determining current and possible health issues.[34,35] For example, if someone spends most of their life in communities with large amounts of air pollution, their risk of developing lung cancer can be significantly higher than someone who has spent their life in a farming community. This justifies the implementation of GIS in population health.[34] With all of the eclectic forms of research that continue to occur over the last century, one may ask why it has taken so long to determine this?

A major factor is that doctors do not often ask for place history and many electronic health records do not have the ability to record the dozens of geographic locations that patients have often lived at throughout their lifetime, let alone link to a GIS to map their patients life history over the layers of environmental risks from each location. As a result, the knowledge is not properly understood when it is presented in this way.[34] Doctors and researchers focus too much on all factors in health not related to geography. Instead, we need to shift some of our focus to train professionals in biomedicine so that they can better understand GIS-related health data. This would cause doctors to learn about connections between health and geography to make informed conclusions about their patients.[34,35] While the study of lifestyle and family history is still very important, it needs to be realized that they are not the only components to a person's health. This led Jack Lord to quote that 'geography is destiny in medicine'.[34]

This review focused on the use of GIS in epidemiology, medical and public health informatics. It was found that these systems can assist researchers and health professionals in knowledge pursuits. The essential purpose of GIS in informatics is to gain an integrated view of humans within their environments that affect them and in turn affect their environment.[36]

When GIS is used, informed decision making can be applied to public health policy, medical practice and health promotion.[13] Additionally, future predictions about health and illness can be made.[18,37] While GIS can be used for many different applications in society, its main uses in public health include documentation of communities with high rates of disease, examination of environmental characteristics of a region and the analysis of community-clinical linkages.[10]

CONCLUSIONS

Based on this review, it is apparent that GIS in health research is increasing.[38] While GIS has been firmly established in health research, more ethical data collection must occur to ensure accuracy.[27,39] These findings help illustrate how environmental health is using technology to advance our practice of epidemiological studies. Such systems can be of great assistance for any person or organization that is looking to understand how environmental factors can affect health; although, these systems are not without their faults.

There is a discrepancy in published academic information on GIS in health research.[13] Commercial and market research companies have found these tools useful in business to understand their clients; however, the academic world has been hesitant in adopting those practices. A large factor for why this may be is the realization that many GIS tools still require improvement. As a result, increased surveying needs to be accomplished to improve the quality of reporting in health studies.

Significant work still needs to be completed to improve GIS in the study of health geography so that gains in the

comprehension of geographical factors and their influence on population health can continue to be made. This would be more difficult without GIS as they provide more information in research and allow for efficiency and time management. Future directions of GIS research shows promise for increased use over time in health geography as system quality increases. Finally, gains in health informatics can be made when GIS are applied through research. However, improvements need to occur in the quantity and quality of data input for these systems to ensure that better geographical health maps are used so that proper conclusions between public health and environmental factors may be made.

REFERENCES

1. Rytkonen MJP. Not all maps are equal: GIS and spatial analysis in epidemiology. *International Journal of Circumpolar Health* 2004;63(1):9–23. Available from: https://doi.org/10.3402/ijch.v63i1.17642. PMid:15139238.
2. World Health Organization (WHO). *Health Topics: Epidemiology*, 2014. Available from: http://www.who.int/topics/epidemiology/en/. Last accessed 17 March 2017.
3. Boelaert M, Arbyn M and Van der Stuyft P. Geographical information systems (GIS), gimmick or tool for health district management? [Editorial]. *Tropical Medicine and International Health* 1998;3(3):163–65. Available from: https://doi.org/10.1046/j.1365-3156.1998.00221.x. PMid:9593353.
4. Gatrell AC and Elliott SJ. *Geographies of Health: An Introduction*, 2nd edition. Malden, MA: Wiley-Blackwell, 2009.
5. Stevens R, Ahmedzai SH, Ahmed N, et al. *Geographical Information Systems (GIS) in Palliative Care: A Systematic Review* (unpublished literature review). University of Sheffield, Sheffield, UK, 2010.
6. Choi M, Afzal B and Sattler B. Geographic information systems: a new tool for environmental health assessments. *Public Health Nurses* 2006;23(5):381–91. Available from: https://doi.org/10.1111/j.1525-1446.2006.00577.x. PMid:16961558.
7. Bowman MA, Lupo P and Neale AV. Introduction of more editorial board members and Google Maps and Google Earth: the physician's cheap geographic information system (GIS). *Journal of the American Board of Family Medicine* 2010;23(1):4–5. Available from: https://doi.org/10.3122/jabfm.2010.01.090250. PMid:20051535.
8. Orzano JA, Strickland PA, Tallia AF, et al. Improving outcomes for high-risk diabetics using information systems. *Journal of the American Board of Family Medicine* 2007;20(3):245–51. Available from: https://doi.org/10.3122/jabfm.2007.03.060185. PMid:17478656.
9. Booza JC, Bridge PD, Neale AV, et al. Incorporating geographic information systems (GIS) into program evaluation: lessons from a rural medicine initiative. *Journal of the American Board of Family Medicine* 2010;23(1):59–66. Available from: https://doi.org/10.3122/jabfm.2010.01.090167. PMid:20051543.
10. Miranda ML, Casper M, Tootoo J, et al. Putting chronic disease on the map: building GIS capacity in state and local health departments. *Preventing Chronic Disease* 2013;10(120321). doi: http://dx.doi.org/10.5888/pcd10.120321
11. Briggs DJ. *GIS for Emergency Preparedness and Health Risk Reduction*. North Hampton, UK: Springer Science & Business Media, 2002.
12. Cromley EK. GIS and disease. *Annual Review of Public Health* 2003;24(7):7–24. Available from: https://doi.org/10.1146/annurev.publhealth.24.012902.141019 PMid:12668753.
13. Nykiforuk CIJ and Flaman LM. Geographic information systems (GIS) for health promotion and public health: a review. *Health Promotion Practice* 2003;12(1):63–73. Available from: https://doi.org/10.1177/1524839909334624. PMid:19546198.
14. Wall PA and Devine OJ. Interactive analysis of the spatial distribution of disease using a geographic information system. *Journal of Geographical Systems* 2000;2:243–56. Available from: https://doi.org/10.1007/PL00011457.
15. Mantaay J. Mapping environmental injustices: pitfalls and potential of geographic information systems in assessing environmental health and equity. *Environmental Health Perspectives* 2002;110(Suppl. 2):161–71. Available from: https://doi.org/10.1289/ehp.02110s2161.
16. Cromley EK and McLafferty S. *GIS and Public Health.* New York: Guilford, 2002.
17. Hansson E, Sasa M, Mattisson K, et al. Using geographical information systems to identify populations in need of improved accessibility to antivenom treatment for snakebite envenoming in Costa Rica. *PLoS Neglected Tropical Diseases* 2013;7(1):1–13. Available from: https://doi.org/10.1371/journal.pntd.0002009.
18. Gjesfield CD and Jung JK. How far?: Using geographical information systems (GIS) to examine maternity care access for expectant mothers in a rural state. *Social Work in Health Care* 2011;50(9):682–93. Available from: https://doi.org/10.1080/00981389.2011.575537. PMid:21985110.
19. Richard J et al. (Ed). A web-based GIS for health care decision-support. *Proceedings from AMIA 2005*, Paris, France, 2005.
20. Holt JK. Community profiling as part of a health needs assessment. *Nursing Standard* 2008;22(18):51–56. https://doi.org/10.7748/ns2008.01.22.18.51.c6311. PMid:18240806.
21. Plescia M, Koontz S and Laurent S. Community assessment in a vertically integrated health care system. *American Journal of Public Health* 2001:91(5);811–14. Available from: https://doi.org/10.2105/AJPH.91.5.811. PMid:11344895; PMCid:PMC1446692.
22. Sharif R. Environmental health. *NRS* 2013; 509.
23. Doi S, Inoue T, Ide H, et al. Using GIS to simulate inpatient's behavior and visualize healthcare demand. *Procedia Computer Science* 2013;22:1361–68. Available from: https://doi.org/10.1016/j.procs.2013.09.225.
24. Choung R, Locke GR, Schleck CD, et al. A low response rate does not necessarily indicate non-response bias in gastroenterology survey research: a population-based study. *Journal of Public Health* 2013;21:87–95. Available from: https://doi.org/10.1007/s10389-012-0513-z.
25. Cheng CL, Chen YC, Liu TM and Kao Yang YH. Using spatial analysis to demonstrate the heterogeneity of the cardiovascular drug-prescribing pattern in Taiwan. *BMC Public Health* 2011;11:380. https://doi.org/10.1186/1471-2458-11-380. PMid:21609462; PMCid:PMC3125367.
26. Leslie E, Butterworth I and Edwards M. Measuring the walkability of local communities using Geographic Information Systems data. *International Conference on Walking and Liveable Communities* [Conference] (Melbourne, 23–25 Oct.), 2006.
27. Olivingson C, Hallberg J, Timpka T, et al. Ethical issues in public health informatics: implications for system design when sharing geographic information. *Journal of Biomedical Informatics* 2003;35:178–85. Available from: https://doi.org/10.1016/S1532-0464(02)00527-0.
28. Tranmer M, Pickles A, Fieldhouse E, Elliott M, Dale A, Brown M, et al. The case for small area microdata. *Series A: Statistics in Society* 2004;168:129–49.

29. Oppong JR. *Data Problems in GIS and Health*. Denton: Department of Geography, University of North Texas, 2006.
30. Dulin MF, Ludden TM, Tapp H, et al. Using geographic information systems (GIS) to understand a community's primary care needs. *Journal of the American Board of Family Medicine* 2010;23(1):13–21. Available from: https://doi.org/10.3122/jabfm.2010.01.090135. PMid:20051538.
31. Van Holle V, Van Cauwenberg J, Van Dyck D, et al. I. Relationship between neighborhood walkability and older adults' physical activity: results from the Belgian Environmental Physical Activity Study in seniors (BEPAS seniors). *International Journal of Behavioral Nutrition and Physical Activity* 2014;11(1):1–18. Available from: https://doi.org/10.1186/s12966-014-0110-3. PMid:25148845; PMCid:PMC4145228.
32. Arcury TA, Gesler WM, Preisser JS, et al. The effects of geography and spatial behavior on health care utilization among the residents of a rural region. *Health Services Research* 2005;40(1):135–56. Available from: https://doi.org/10.1111/j.1475-6773.2005.00346.x. PMid:15663706; PMCid:PMC1361130.
33. McLafferty SL. GIS and health care. *Annual Review of Public Health* 2003;24:25–42. Available from: https://doi.org/10.1146/annurev.publhealth.24.012902.141012. PMid:12668754.
34. Shaw NT. Geographical information systems and health: current state and future directions. *Healthcare Informatics Research* 2012;18(2):88–96. Available from: https://doi.org/10.4258/hir.2012.18.2.88. PMid:22844644; PMCid:PMC3402560.
35. Davenhall B. Bill Davenhall: your health depends on where you live 2008. *TEDMED* 2008. Available from: http://ted.com/talk/bill_devenhall_your_health_depends_on_where_you_live#+-498970. Last Accessed 17 March 2017.
36. Kohli S, Sahlen K, Lofman O, et al. Individuals living in areas with high background radon: a method to identify populations at risk. *Computer Methods and Programs in Biomedicine* 1997;53:105–12. Available from: https://doi.org/10.1016/S0169-2607(97)01811-7.
37. Geraghty EM, Balsbaugh T, Nuovo J, et al. Using Geographic Information Systems (GIS) to access outcome disparities in patients with type 2 diabetes and hyperlipidemia. *Journal of the American Board of Family Medicine* 2010;23(1):88–96. Available from: https://doi.org/10.3122/jabfm.2010.01.090149. PMid:20051547.
38. Turk, T. Investigating environmental health studies using geographical information systems: cancer case study. *Polish Journal of Environmental Studies* 2013;22(5):1505–17.
39. Lyseen AK, Nohr C, Sorensen EM, et al. A review and framework for categorizing current research and development in health related geographical information systems (GIS) studies. *IMIA Yearbook of Medical Informatics* 2014;110–24.