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Spatial Analysis and Mathematics in Health Research: How

Sifaki-Pistolla Dimitra[1], Pistolla Georgia[2]

[1]Epidemiology researcher, GISanalyst, Faculty of Medicine, University of Crete, Iraklion, Crete
[2]Mathematician, University of Crete, Faculty of Medicine, University of Crete, Iraklion, Crete

Email address:
spdimi11@gmail.com (D. Sifaki-Pistolla), geopist@gmail.com (G. Pistolla)

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Abstract: *Background:* There is an open discussion on how the Geographical Information Systems (GIS) or mathematical models could offer a new perspective on health research and positive health outcomes. The present study is a literature review that aims to explore and identify several GIS and IT applications (spatial or mathematical oriented) in health research, clinical practice, public health and police making. *Methods:* The review was conducted in two different literature database (PubMed, The Cochrane Library and in grey literature via internet (Google). *Results:* Several applications were identified and selected examples are presented in this article. Their positive (current or expected) impact on health outcomes, health research and public health strategies is discussed. *Conclusions:* Such applications could empower positive health outcomes and promote healthy ageing, quality of life and wellbeing, develop networks of active citizens and multi-sector professionals.

Keywords: GIS Applications, Literature Review, Healthcare, Medicine, Epidemiology, Integration, Continuity

1. Introduction

The Geographical Information Systems (GIS) is "a system designed to capture, store, manipulate, analyze, manage, and present all types of spatial/geographical data and other types of information" [1]. A GIS is the combination of the software and hardware, as well as of the analyst and other professionals from several fields (multi-disciplinary team). In fact it refers to a range of processes, methodologies, technologies and operations. It has applications on several fields such as education, engineering, planning, management, transport, insurance, logistics and economics, telecommunications, business, health and other [1,2].

GIS have a long history with Roger Tomlinson to be the first to insert the term "Geographic Information System" in 1968 [2], Tomlinson to be acknowledged as the "father" of GIS and John Snow to be the "father" of spatial epidemiology (Figure 1) [3].

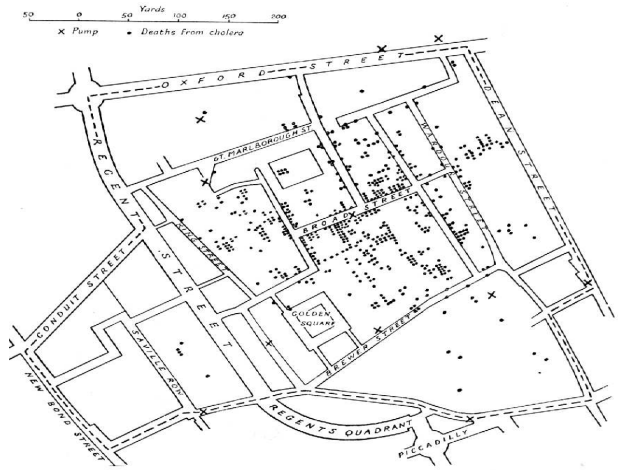

Figure 1. *E. W. Gilbert's version (1958) of John Snow's 1855 map of the Soho cholera outbreak showing the clusters of cholera cases in the London epidemic of 1854.*

Modern GIS have attempted to assess J.Snow's map using digital GIS and 3D analyst (Figure 2).

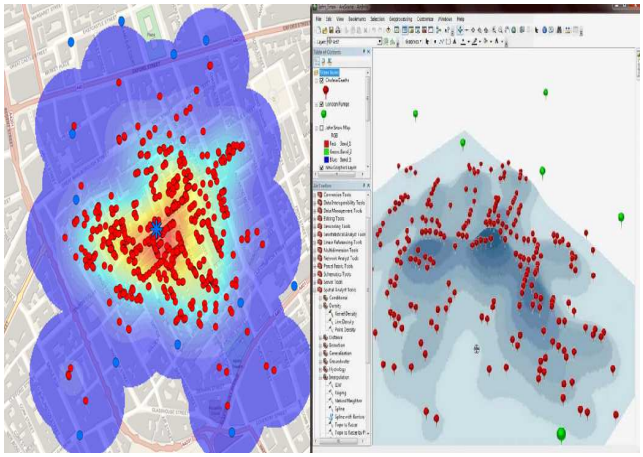

Figure 2. *John Snow's 1855 map of the Soho cholera outbreak using digital GIS technology [(left) Kernel surface and density map, (right) 3D analyst)].*

GIS and other related technologies (eg. Remote Sensing) are increasingly used in health research to analyze spatial or time patterns, distribute diseases and related events, reveal relations of causation, relations between pathogenic and other factors. Understanding the spatial patterns of diseases could shed light on their origins, cause of incidence and control, predict future outbreaks or control them as well as predict spatial dispersion and identify high risk areas or population groups in risk. They contribute to understanding the patterns and trends of a health outcome and design geographically or person-oriented prevention and control strategies [4]. Nowadays, they are used for health research or actions and policy making through a range of applications that could be web-based, ehealth/mhealth apps, digital maps or videos, integrated information systems or databases and other IT applications. These applications are based on mathematical and statistical models (both stochastic and deterministic) that involve a range of tests and algorithms; always considering the spatial and/or time parameter (x;y;z;t dimension) [5].

The present study is a literature review that aims to explore and identify several GIS and IT applications (spatial or mathematical oriented**)** in health research, clinical practice, public health and police making. The methodological approach and the results are described in the following sections.

2. Methods

2.1. Research questions that guided the review

A systematic review was conducted to serve the three research questions, as follows:

a) Are there any researches or practical applications of GIS in health, at a global level?
b) If yes, which are they and how are they applied?
c) What are the benefits or the expected impact?

2.2. Systematic Review

Search Strategy

The systematic review was conducted in two official literature databases and one search web-engine; PubMed and the Cochrane library and Google, while all records were checked by two independent reviewers (DSP, GP).

Several inclusion and exclusion criteria were adopted according to the PICO Framework [P: Populations, I: Interventions, C: Comparison, O: Outcomes] that is used extensively in the Cochrane Collaboration [6]. These basic components (PICO) were examined comprehensively when applying the inclusion criteria. Then exclusion criteria were set with clarity and transparency to justify the reason why some records were excluded the study [7]. The main inclusion and exclusion criteria are presented in the following table.

Table 1. *Inclusion and exclusion criteria of the systematic review.*

Inclusion criteria	Exclusion criteria
Published Material only in English	Other languages if not decided to be included
Published articles must answer the research questions	Papers not clearly answering any of the suggested research questions
Material used is selected from the chosen sources only. Within the chosen period: published in the last 10 years	Any material not within the limited time of the study.
Original research, clinical trials, systematic reviews, article in official websites or e-press, are also included	

Furthermore, several key words were used, with the main ones to be “GIS”, “IT”, “mathematical models”, “health”, “healthcare”, “clinical research”, “public health”, “epidemiology”, “tools”, “questionnaires”, “instruments”, “ehealth”, “mhealth” “GIS applications”, “spatial statistics”, “spatial analysis”, “geo-maths”,

Eligibility Assessment

The eligibility assessment and the whole review process of the records were performed according to the stages demonstrated in figure 3, separately by the two independent reviewers. Potential disagreements were resolved by consensus. The exported records of the two databases were combined and duplicates were removed. Irrelevant records according to the exclusion criteria were also removed at this stage, in case they hadn’t been automatically excluded by filters performance. The remained records were reviewed only by title and those that indicated ineligibility were removed. The included records were reviewed by abstract and those that were relevant for further evaluation were reviewed by full text. Finally, only eligible records were included in the study and were also used for the critical appraisal process.

Data Extraction

All relevant records according to the abstract were extracted in a relevant table during the review process. A final extraction table was developed to accommodate the articles that were finally included in this study (total articles included = 245) while these articles are used in the Results section and

are inserted in the reference list.

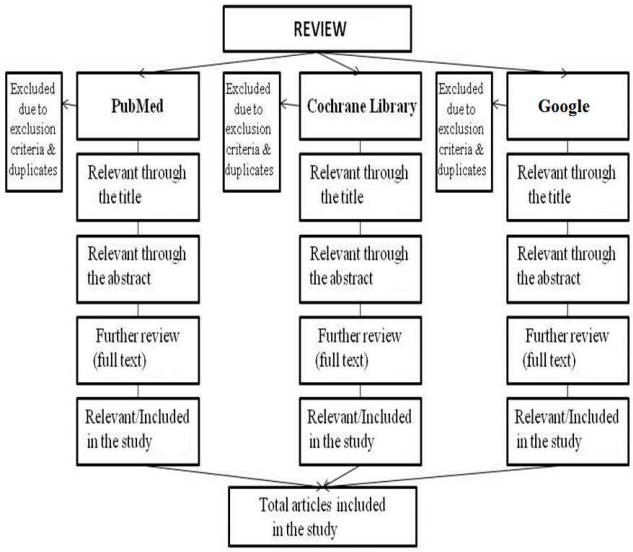

Figure 3. *Flow chart of eligible assessment and review process.*

3. Results

3.1. GIS Applications in Epidemiology and Public Health Research

GIS applications are often applied in the epidemiology and public health sector, especially in the research field. Spatial statistics and geo-epidemiological studies were found to be plenty, mainly in the USA, Southern Europe, Asia and regions of Africa. Most of them deal with disease spread or mapping, spatial clusters and hot spots of the disease, correlation of several environmental and other factors, location of healthcare facilities (relocation etc) and hospital management (building, workforce, supplies, workflows etc) [8-12]. Additionally, there are GIS applications that use IT technology in order to develop a commercial or non-commercial product that offers a range of services and would be used by healthcare professionals, authorities and the general public.

The Canadian government in collaboration with the New Brunswick Lung Association, GeoConnections and the Natural Resources of Canada, started an initiative for building the Canadian Geospatial Data Infrastructure (CGDI) [13]. This was an effort towards the expansion of these data into the public health sector in order to "develop effective intervention strategies for chronic and infectious diseases, address shortcomings in population health monitoring, improve healthcare services and respond to health safety emergencies". The new form of the CGDI is a big database that consists of various smaller nested databases that connect all authorities and units involved in the health sector. It offers a range of applications (from digital mapping to IT and web-based applications and services). This GIS-based technology was a challenge for all partners involved and managed to standardize processes and become a type of integrated health atlas. The GIS mapping tools enabled health professionals and officers to analyze population health parameters, access disease information timely, develop healthcare policy initiatives, coordinate medical response measures, monitor environmental determinants of health, focus on different types of diseases (integrate-coordinate their management) [14], identify exposure risk and associations among various parameters and other. Their main focus was on asthma, chronic obstructive pulmonary disease, myocardial infarction, bronchitis, pneumonia, influenza, severe acute respiratory syndrome, hantavirus and avian flu. Furthermore, they scheduled training and workshops for potential users and information campaigns for government officials and decision-makers, health agencies and other unit [13].

Additionally, the Indian government and the Public health foundation in India has also developed a comprehensive geospatial database that aims to link health status of rural populations along with their social, cultural and environmental characteristics. This database will be used by professionals and offer them the chance to predict the health outcome of communities for a given set of physical and social factors. Big epidemiological studies would be conducted and major health needs and dynamics would be captured. These outcomes would be reported to community representatives as well as state policy makers. Final goal is the development of targeted policy measures and the assessment of their effectiveness at a peripheral level [15]. A similar example was followed by researcher in Iran who tried to propose a decision making support system GIS can be used as a decision support system in order to help the mangers of public health. This tool focused on major health needs, general welfare and quality of life [16].

Other types of GIS services have been identified by the literature review and focus on community health services. Such applications are more frequently developed by the ESRI. For instance, a group of GIS health maps that offer human services by locating clients, patients, incidents or alerting the public health interest. One of these services is the GIS platform "Helping hearts". This was developed in collaboration with the Center for Disease Control and Prevention (CDC). Its goals are to flex, integrate and map health data for cardiovascular diseases and disease-related parameters and alert interest and arise awareness for screening tests (Give your neighborhood a health check). Interactive maps and time-series models are some of the methods that are used to assess the platform's goals [17].

Another service that has been developed the same enterprise is the "New Mexico Community data collaborative leverages" which is and ArcGIS Online creative laboratory that collects health data and provides a range of apps that could be developed inside this GIS system by different users. It also promotes multi-disciplinary collaboration and people networking, data requests and sharing and state support with the involvement of the authorities. Some examples of public map galleries are presented in the figure below (Figure 4) [17].

Figure 4. *(Left) A gallery of maps on a variety of issues-nativity demographics, chronic disease and obesity prevention. (Right) Customized gallery for early childhood advocacy organizations – focus on teen birth, child nutrition, poverty and early development.*

3.2. GIS Applications in Clinical Practice

The role of "place" in patient care and in clinical practice is vital for an effective treatment and patient-centered health care. There are several GIS applications that focus on specific type of patients or Primary Health Care. Two more rare examples are presented here; one for patient care [18] and on for the role of GIS in the surgery [19].

One of the most significant breakthroughs of GIS technology is when it is combined with clinical data. These types of services are offered by the Loma Linda University Medical Center (LLUMC) for EHRs [18]. The LLUMC has an integrated GIS system that aims to better patient service before, during and after the arrival. This system connects geography with clinical and other information of the patients (doctors can locate a patient's address) and help in determining a personalized medical care (treatment, medication etc) by highlighting each patient's special characteristics, environmental, occupational and other exposures and risks. Concluding it minimizes costs and health expenditures while it busts hospital effectiveness in terms of quality and integration in care [18].

An interesting study was the one of J.L.Garb et al., who used GIS to examine the findings of transanal endoscopic microsurgery (TEM) and test whether anatomic features of the rectum and other clinical information collected at the time of surgery could be combined in the GIS and export clinical outcomes. Topographic techniques, 2D and 3D mapping and choropleth map of operative failure rates were used. The authors supported that other imaging modalities (eg.CT, MRI) are less detailed than the GIS approach and they don't detect rectal lesions, the exact location of polyps and the distance from the anus or their relationships with the sphincter apparatus, prostate, vagina and the peritoneal reflection [19].

3.3. Other Applications: Geomedicine, Ehealth/Mhealth Apps

Geo-medicine and GIS-based ehealth/mhealth apps are increasing rapidly and are acklowledged as the new frontier inmedical informatics [20]. These applications are usually used by phsicians at the point of care or by patients either for preventive and health literacy reasons or as a replacement of the waiting rooms and the convensional patient cards. These are applications accessed by computers, mobile phones, tablets etc., using text messages, sms, alerts, or personal accounts and online integrated plaforms [21]. These GIS-apps could work as health-support systems that empower self management and double the seld-reported quit rate in the short term. Australia, UK, USA, Canada, France and other rehions of the world have developed such apps and have managed to increase the number of users and patient's engagement. These apps are also integrated with hospitals, healthcare authorites and researchers and support the evaluation of healthcare services and interventions [22-32].

4. Discussion

The present review studied extensively 245 articles on GIS applications and technology in the health sector and presented selected applications in the results' section. More than a 50% of the reviewed articles focused on the use of spatial statistics and analysis in selected chronic or communicative diseases. Cancer statistics and mapping were the most frequent topics in the literature [33]. Apps of GIS technology were the next more frequent in the literature with themes relevant to disease surveillance, health support systems, health promotion, disease prevention, communication and networking among patients, caregivers, families, health care providers and/or relevant authorities.

The majority of the reviewed studies presented positive results and successful interventions with limited barriers or product limitations; which still provided at least equal results with those of traditional approaches [20, 34-36]. All these applications managed to add to the existing knowledge, scientific community or the general benefit, while most of them proved to be cost-effective and quality-driven.

Such applications could empower positive health outcomes and promote healthy ageing, quality of life and wellbeing, develop networks of active citizens and multi-sector professionals; by inserting and maintaining quality, continuity, accessibility, equity and efficiency in health processes and actions.

5. Conclusions

A range of GIS applications was revealed and their positive impact on health research and management was highlighted. Apart from these applications or any other efforts towards GIS in health, a systematic and stable strategic framework has to be adapted by each country in order to approach health aspects, drastically and effectively.

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