OPEN ACCESS

ISAR Journal of Science and Technology

Volume 3, Issue 3, 2025, Page: 1-12

Abbriviate Title- ISAR J Sci Tech

ISSN *(Online)*- 2584-2056

https://isarpublisher.com/journal/isarjst

The Role of GIS in Public Health: Mapping and Analyzing Spatial Epidemiology

Rasha Flayyih Hasan[1*], Hasan Shakir Majdi[2]

Training and Workshop Center, University of Technology- Iraq, 10066 Baghdad, Iraq.

Department of Chemical Engineering and Petroleum Industries, Al-Mustaqbal University College, 51001 Hillah, Babylon, Iraq.

***Corresponding Author**

Rasha Flayyih Hasan

Training and Workshop Center, University of Technology- Iraq, 10066 Baghdad, Iraq.

Article History

Received: 11.01.2025
Accepted: 02.02.2025
Published: 05.03.2025

Abstract: The use of GIS technology has had a big impact in improving the ways in which health related information is acquired, processed, and presented in public health. GIS is used in spatial epidemiology as an important tool to address queries related to distributions and determinants of health and illness in space and time. When multiple data sets are superimposed on each other, GIS helps the public health workers to see the spatial variation, recognize the hotspots and develop appropriate prevention strategies. In its modern form, GIS was applied to public health beginning with cholera map drawn by John Snow in 1854. Today there are numerous GIS applications ranging from disease mapping, resource allocation, to the assessment of environmental health. Directions in GIS include remote sensing, mobile data collection, and the use of artificial intelligent to provide real time analysis and predictive analysis. The above developments help in response to diseases outbreaks that include COVID-19 where GIS was useful in mapping the virus spread and response measures. However, there are challenges to the extensive use of GIS in public health such as data quality, ethical issues in the use of privacy and the problem of the digital divide in restricted access to GIS technologies in low resource settings. Nonetheless, GIS remains evidence of its applicability to the current emerging public health issues such as monitoring and spread of communicable diseases, as well as the effect of hazardous environmental factors. Clearly, with steady improvements in technological growth and interprofessional cooperation, GIS will continue to be a valuable resource in the fight toward establishing health equity as well as in the improvement of decisions made within the realm of public health.

Keywords: Geographic Information Systems (GIS), Spatial Epidemiology, Public Health, Disease Mapping, Health Equity, Environmental Health, Remote Sensing, Predictive Modeling, Health Surveillance, Data Privacy.

Cite this article:

Hasan, R. F., Majdi, H. S., (2025). The Role of GIS in Public Health: Mapping and Analyzing Spatial Epidemiology. *ISAR Journal of Science and Technology*, *3*(3), 1-12.

1. Introduction

One of the greatest developments in public health has been the incorporation of Geographic Information Systems (GIS) for the field has been greatly enhanced by GIS as a means of comprehending and addressing prevalent health issues. And as public health comes across more and more multifaceted tasks, GIS has become a basic tool with which epidemiologists can add spatial component to the data to reveal patterns and tendencies that are not apparent in tabular and graphic displays. The use of GIS in public health started from the late twentieth century as a result of enhanced computers and data collection tools. Its first version was primarily used for the purpose of disease surveillance and mapping of outbreak, thereby helping the epidemiologists to keep track of the trends of infectious diseases spreading in various communities and to identify the relative risks in such a community. With time, usage of GIS has stretched across the numerous areas of health having to do with the environment, social and economical status and health facility accessibility.

Most important is the capacity of GIS to support evidence-based decision making. Epidemiologists use GIS data or maps to locate areas of high risk for disease transmission, to prioritize and distribute resources and control measures and to assess the impact of such measures. Information derived from spatial analyses enhance understanding of the interrelated factors that normally affect health of populations. With new and impending problems like infectious diseases, chronic diseases attributable to environmental factors, there is likelihood that application of GIS will expand greatly in public health. Thus, the use of real-time data

feeds from the wearable technology and mobile applications that are integrated into GIS have the potential of enabling timely response to public health disasters.

However, there are some factors which limit the uptake of GIS in practice of public health as explained below. This is because data quality always presents a major problem due to variations in approaches used in data collection hence leading to poor understanding of needs of the community. Furthermore, the issues of privacy and informed consent are also ethical considerations which should be properly addressed when working with sensitive geographical data. In this regard, a list of present and future GIS applications in public health has been presented in the following table As for the future developments, further technological developments will continue to improve GIS capabilities in public health. There are innovations like the incorporation of artificial intelligence (AI) could enhance the aspect of the prediction model for health; the aspect of remote sensing of environment may also enhance the capability to track the effects of environment on health. Since its inception, GIS has provided value in linking large datasets to other applications that influence public health policy and practice. Its continuous expansion is a result of a growing awareness, by the practicing professionals, that contemporary health issues cut across the traditional medical paradigm and necessitate understanding of space's impact on population health, [5], [1], [7] & [6].

2. History of GIS in Public Health

2.1. Early Developments and Milestones

The development of Geographic Information Systems (GIS) in the context of public health has advanced over a long period of time which started in the mid 19th century with a number of landmark developments and advancements made throughout the years. An important stage was reached during the cholera epidemic of 1854 in London, when John Snow made a manual geographic mapping of cholera. His work attributed the outbreak to contaminated water, demonstrating the ability of spatial analysis in disease pattern determination and paving way for the next GIS investigations. Moving into the twentieth century further progress was made with the use of computer based GIS systems. Change in the advancement of GIS occurred in the 1960s when Roger Tomlinson developed this type of GIS, which added data processing and spatial analyzing features that could not have been offered by traditional techniques. The expansion of GIS with satellite imagery in remote sensing expanded the uses of GIS to provide public health workers tools for analyzing environmental health factors at larger scales.

Public health research of the 1990es brought much attention to the use of spatial analysis. This period focused on the geographical consideration of disease epidemiology making interpretations of health related data even more meaningful. It became possible for the researchers to define the clusters and connections between diseases and the surroundings, which enriched the epidemiological works. In addition, the application of GPS in addressing health issues enhanced the process of real-time data collection that enabled early responses to disease outbreaks, and right resource mapping. As a perfect example, GIS has established its relevance within the public health by constantly evolving its application for new difficulties and ideas. Due to the availability of a variety of datasets – from socio economic indicators to environmental – public health specialists have adopted GIS for more holistic studies that can be applied in policy and intervention formulation.

In view of this, the importance of GIS is being appreciated globally in the attainment of many of the Sustainable Development Goals (SDGs), most especially, those that affect human health. As GIS makes understand spatial factor affecting population health, it assists the local health departments, ministries of health, or even the World Health Organization in improving their approaches to addressing health crises. However, some issues related to the application of geographic information in public health are still questionable such as quality of data, availability of data and ethical uses of geographic information. Nevertheless, cases in history like Snow's map of cholera, show how GIS and spatial analysis can be beneficial to the cause of disease prevention and control across the globe. While this historical perspective shows how GIS has contributed to positive change in public health it also reminds the reader of today's health issues that can be solved by using GIS in decision making and ways of intervention, [9], [4] and [1].

2.2. Evolution of Technology and Methods

The advances in Geographic Information Systems (GIS) have affected public health by moving from simple cartography to advanced analysis. The beginning of GIS practices was initiated from the cholera map developed by John Snow in the 19th century to document the geographical distribution of diseases and their associated environments that form the basis of modern GIS spatial analysis. a turning point occurred in the 1960s when Roger Tomlinson oversaw the evolution of the Geographic Information System from a paper based system to one that operated on a computer and in doing so offered public health workers better data analysis and data visualization tools. The advancement of remote sensing technology improved the GIS applications resulting to real time control of environmental factors that impact health of people. Remote sensing data from satellites was required for the analysis of various aspects of land use, vegetation, and climate, which are influential in the epidemic patterns.

There was a focus on spatial analysis in the 1990s within the public health literature. Scientists started using large data sources and the new methods to analyze complicated patterns of diseases. GPS technology came handy to change the outlook of data collection process, as it provided accurate geographical location that was crucial in conducting epidemiological studies. A new wave of GIS evolution was observed as we moved into the 21st century with emergence of AI and machine learning. These technologies made it possible to process data automatically and use production analytics that improved the GIS systems. Mobile applications with location identification became more popular among the public health workers to monitor clients' daily behaviors and risks in real-time fashion.

Furthermore, these technological advancements have encouraged integration of GIS with other fields such as urban planning and transport and environmental science that go beyond the domain of public health. The most important attribute, which is the integration of multiple sources of data, is essential for designing interventions in order to address multifaceted public health challenges. Transition from traditional mapping to advanced GIS techniques is a shift from rudimentary methodological advances of GIS to more complex methodological frameworks that can solve

current public health issues. Innovative technologies' gradual incorporation is expected to improve disease surveillance while increasing knowledge of how spatial characteristics influence population health trends, [4] and [1].

3. Fundamentals of Spatial Epidemiology

3.1. Definition and Importance

Spatial epidemiology occupies a significant place in modern theories of public health as an area of study focusing on the spatial distribution of events related to health and possible factors that caused that distribution. Location based information technologies such as Geographic Information Systems (GIS) are very useful in this area, and they assist in the identification, analysis and explanation of spatial patterns associated with different health related occurrences. With disease occurrences, GIS enables the health department to pick out certain trends and patterns that could otherwise be unnoticed when using data analysis. This approach is also more comprehensive than simple case-specific approaches and provides insight at the population level how different factors including environmental influence and status of socioeconomic factors influences health status.

If used appropriately, GIS in public health is not just a tool for visualization, but also has the following functions. Firstly, GIS facilitates fast and better disease monitoring due to collection and combining of existing data. For example, in an epidemic, health organizations can be able to study the patterns of spread of diseases to particular geographical regions. This information is useful at the right time in decision making on the use of resources and the specific action to be taken. Additionally, GIS is used for syndromic surveillance, whereby public health agencies are able to identify variations in the health related factors before they transform into major epidemics. To sustain such necessary epidemic early warning systems, evaluating spatial relations of health event is crucial.

Technologically, GIS responds to the type of epidemiological investigations that concerns "where" and "why" diseases are prevalent. This fosters the interlinkage of multiple data types such as demographics, environment, and accessibility to healthcare, and feed into innovative models to understand the contribution of these factors in the disparities of health within a community. Furthermore, GIS is indispensable in equity assessment in spatial epidemiology this integration is important for identifying complex interactions between variables which affect public health. When socio-economic factors are depicted along with health status, researchers can easily locate out areas preferred by diseases or conditions. This evidence is very helpful in developing specific strategies for the promotion of fair and equal access to care in public health.

However, the practitioners need to be informed of the limitation related to GIS application in public health research. The nature of data plays an important role in spatial analysis and the quality and consistency of these data can pose problems. However, issues to do with ethics, particularly on privacy should be given some thought before embracing the handling of geospatial data that are associated with individual's identity. Spatial epidemiology constitutes a major shift in the way public health is studied and analyzed by incorporating geographic location of population and incorporating principles of GIS. Appreciation of GIS in disease dynamics increases ability in the formulation of public policies that should foster the welfare of a specific geographical area [4], [13], [5], [20], [1] and [6].

3.2. Key Concepts and Theories

Spatial epidemiology is essential in determining the correlation between spatial attributes and population health. It concerns itself with the prevalence of a disease and its relation with demographic/environmental/behavioral/other indices. This is why knowing these connections is critical when looking for patterns in one disease's incidence in different areas. One of the fundamental principles in this field is spatial autocorrelation claiming that observations similar in some aspect will be geographically proximate to each other, which reflects the impact of geographic context on health. Another important principle is the modifiable areal unit problem (MAUP) which is another problem of geographic data analysis stating that statistical outcomes depend on the chosen geographic units. Various levels of data aggregation can lead to misinterpretation of disease occurrence or risk in certain areas, therefore the focus needs to be made on selected spatial units.

Syndromic surveillance is an important use of GIS technologies and focuses on constant monitoring of health status in an effort to identify and prevent emerging epidemics. Using GIS platforms, consolidated data can be obtained that are used to assess the trends in health from time to time and space to space, and in the process; interventions can be made to occur apace. A number of models improve the understanding of the individual's behaviours concerning the public health initiatives using GIS. The Health Belief Model shows that people's beliefs relevant to diseases and the benefits of preventing them greatly influence their participation in health programs. This model assist researcher when studying the reaction of the community as well as their engagement with GIS application in enhancing public health.

Ecological Systems Theory also depicts a range of contexts in which individuals are embedded, going from close to distant environments. This perspective is helpful in throwing light on how different levels of impact influence the uptake and success of GIS technologies in public health interventions. Thus, understanding these dynamics allows researchers to develop unique strategies for managing certain contextual issues. In spatial epidemiology, the quality of capabilities is regularly improving through technological development of the methods for analyzing complicated data sets. Bayesian statistics are now useful to improve the measure of uncertainty in small-area disease rates and to maintain accuracy in detecting high risk areas. These core concepts and theories are crucial in harnessing GIS for public health application researches and interventions to enhance populace health decision-making, [2], [1], [31] and [27].

4. Key Applications of GIS in Public Health

4.1. Disease Mapping and Surveillance

Use of Geographic Information Systems (GIS) in disease mapping and surveillance has proved to be very relevant and has boosted the achievement of most initiatives in the field of public health. Through assembling a wide variety of data with spatial analysis, GIS offers a broad perspective on the occurrence and diffusion of diseases. One of them is to serve in disease surveillance; using

maps to present data is inconvenient because such data veil short-term trends, while GIS makes it possible to analyze occurrences of diseases on the map, find "hot spots," and potentially prevent an outbreak.

This flexibility make GIS suitable for real time monitoring which was a big plus during the outbreak of diseases such as COVID 19. This was possible where the authorities needed to monitor the growth of cases over time, in order to assign appropriate resources and interventions. It would be much easier to identify areas that are most affected and need urgent attention when we use maps. Also, GPS technology integration improves real time surveillance of activities in areas of location since GPS give accurate location details. Environmental information is therefore also useful in the analysis of public health using GIS. It can help researchers look at how one environmental exposure can relate to another—the air or the water and health aspects, for instance. Through these mappings, it is possible for public health workers to establish that certain populations are suffering from the effects of risk factors in their environment, so as to design methods or standards of prevention regarding specific community needs.

Moreover, GIS plays a role in assessing the degree of accessibility of health care in one or another region. When demographic data is mapped on the locations of healthcare facilities, policy makers can discuss the existing gaps and deficits in healthcare provision. This insight is particularly useful for proper planning of resources for the targeted provision of services. In cancer epidemiology, GIS has been particularly applied to display incidence rates and identify differences between different population groups. Despite the fact that differences in descriptive statistics may not be reflective of the true variation in cancer incidence rates across space, public health researchers utilize various statistical techniques within GIS environments to answer essential questions regarding the distribution and relationships of cancer risks to geographic features. All these applications do not only assist to determine where the intercessions are essential but also facilitate the restructuring of these intercessions to conform to the conditions of the area in question.

However, some difficulties are still encountered in the application of GIS for disease mapping and surveillance. It is thus important that data quality related problems such as accuracy or inconsistency interfere with the analyses and result in the generation of wrong conclusions. In addition, issues of privacy and confidentiality concerning health information must be well addressed in order to foster public acceptance and utilization of such superior technologies. With the progression of such technology in the future, the integration of such technologies like the artificial intelligence and machine learning in the GIS platforms open new doors for complex analyses that can revolutionize disease surveillance all over the world . Since the information can be predicted far more accurately, it will be possible for public health officials to act in order to stop the outbreak before it becomes a problem. For future practice, the stakeholders of public health should focus on training of the practitioners and encourage the integration of GIS in the different fields to enhance its utilization in the public health surveillance practice to overcome existing challenges, [4], [20], [2] and [13].

4.2. Resource Allocation and Planning

Institute for Geographic Information Systems has played a key role in distribution and management of resources especially in public health through strategic planning. Another large role of GIS is to process spatial information concerning health care and disease distribution. When the geographical distribution of medical facilities is overlaid with demographic data and indicators of health status, the resulting pattern reveals districts where access to medical care is low or diseases frequent. This serve to increase efficiency in the allocation of resources since the targeting increase the intervention odds of reaching the appropriate people.

Using geographic information and demographic data on maps, it becomes easy to determine the healthcare provider gaps in a region. For example, it is possible to identify areas with high population density and poor clinic availability to decide where more services are required. With restrictive funding available in the Sub-Saharan Africa for instance, GIS is an important asset in positioning of health facilities, filling gaps in the provision of services, and improving health in the communities. Moreover, GIS also improves situational analysis of various public health activities including immunization and cleanup of risky areas. Through analysing geospatial data in the periods before and after interventions, the effectiveness can be evaluated, and modifications can be made as soon as possible. Ongoing assessment is important in order to improve programs to address the needs of the community as much as possible.

GIS integration also helps in handling emergencies in the existing public health plans as well. In emergencies such as an epidemic or disaster, information on geographical space helps to make instant and effective decisions. For instance during an outbreak of an infectious disease, GIS can be used to monitor the geographical location of cases, thus allowing the health department to direct resources like vaccines, and medical personnel to regions that need them most. Also, GIS has its significance as a tool in environmental health assessments. Population density data can also be used by public health agencies to determine those groups of people most likely to be affected by pollution or other ecological issues. This information helps stakeholders to put in place measures of preventing or dealing with consequences of dangerous exposures.

Information sharing with stakeholders is also made easier through GIS tools since policy makers as well as the public can easily understand information that may otherwise be complicated. The utilization of interactive mapping enhances the communication of complexities in the distribution of resources and or difficulties facing population needs and health. Additionally, application of GIS allows for an integration with social determinants of health as socioeconomic status such as income and education are incorporated with geographic data. This integrated perspective does not only reveal which areas require attention of health care providers but also the likely increased morbidity propensity of some groups of people.

As new technologies are developed and implemented in the near future such as AI, remote sensing, the role of GIS will increase in defining resource distribution patterns within different health related intervention programs. The dynamic advancement in GIS application reveals its potential of improving its efficiency to address existing and future public health issues in order to promote health and wellbeing of populations. This paper will demonstrate that GIS has become a critical asset in the field of public health by

showing how resource allocation as well as interventions have been impacted by its application. Because it helps with spatial analysis, real-time assessment, emergency response, evaluation of environmental health risks, and stakeholder involvement and response to social determinants of health, it plays a critical role in the enhancement of public health agendas. When advanced in the future, integration of new technologies will advance the significance of GIS in the delivery of healthcare and the welfare of the society [2], [7] & [3].

4.3. Environmental Health Studies

Geographic Information Systems (GIS) can be considered as valuable assets in Environmental Health that explain the relationship between the environment and health. A major area of utilizing GIS is the mapping and analysis of data on pollution and health consequences. Pollution patterns of air, water, emissions, and changes in land use are other environmental parameters important to health officials because they show where health problems related to these factors may be more likely to occur. For example, GIS links high concentrations of certain pollutants with growing incidences of respiratory illnesses, thus guiding efforts to address the problem in the right locations.

Furthermore, GIS is used in evaluating the level of population exposure to environmental risks through combining population characteristics, demographics, socioeconomic status, health indices, and spatial data. It is crucial to analyse adverse effects of environmental hazards on various populations, including communities that are most vulnerable as identified by this encapsulating evaluation. Knowledge of these risks is beneficial in the construction of particular public health measures to minimize contacts and improve community readiness. The application of GIS transcends pollution source specific analysis to include even environmental evaluations. Studies conducted using GIS have found that there are strong linkages between the impacts of global warming including things like hurricanes and the health issues like malaria, heat stress and the rest. When historical information is integrated with predictive models in GIS environments, the researchers will be able to predict the adverse conditions that may affect specific populations in the future.

Moreover, GIS plays a critical role in reaction to natural catastrophes or other epidemics through monitoring of dangerous materials and their effects on population in real-time. This capability is most valuable during occurrence such as toxic spills or disease outbreaks in which fast decisions of resource allocation are crucial. With rising concern of climate change and its impact on health, the application of GIS enhances the formulation of policies meant to reduce health effects in relation to environmental depletion. Visualising the relationship and environmental variables such as demographics, diseases prevalence on geographical maps, make it easier for stakeholders such as local governments to the global organizations to make informed decisions on these crucial issues.

Moreover, most forms of GIS technologies promotes interdisciplinary research between fields for instance epidemiology, urban planning, environmental science among others. This makes the approach useful in establishing the impact of urban characteristics such as green space equity or the density proximity to hazardous waste facilities on public health. Combining such high-tech tools as remote sensing technologies with essentially low-tech GIS analysis greatly improves the capacity to detect temporal changes with reference to environmental factors as well as health behaviors. With the increasing amount of data available to support GIS because of technological advances such as satellite imagery or sensor networks, GIS is therefore poised to become an even more useful tool in the development of solutions to the multifaceted issues related to environmental and public health. [23], [18], [2], [8], [1] and [3].

5. Methodologies in GIS and Spatial Epidemiology

5.1. Data Collection Techniques

Methods of data collection in GIS and public health are important in assessing the health needs of various populations on the society. These methodologies include a number of methods that enable them to obtain, process, and analyze spatial data – crucial components in research into epidemiology. According to surveys, one of the most significant ways to gather primary data from communities involves telephone interviews, online questionnaires, or direct, face-to-face conversations. These tools enable the identification of demographic data, health behavior and disease incidence in target populations by the public health professionals from those populations in geographical areas of interest. If integrated with GIS technology the survey results can be geocoded to display spatial distribution associated with specific health results.

Another considerable approach for obtaining environment information associated with public health is remote sensing. The satellite or aerial images provide a vast database of the land use, vegetation cover as well as climatic information. This data is important for purposes of identifying the correlation between environmental characteristics and health status. For instance, it could reveal possible vector-borne diseases outbreak by studying shifts of land use that may change the habitats of vectors. Geographic Information Systems (GIS) form instrumental databases that facilitate the convergence and visualization of multiple sources of information. As a digital tool, GIS enables the superposition of many data elements and, specifically, several types of attributes, whether demographic, environmental, and so on, which makes it easier to find relations between them. Furthermore, GIS applications allow displaying the geographic distribution of the availability of healthcare and diseases, which is essential in decision-making on distribution of resources and healthcare policy.

Besides direct observation and aerial photography, GPS (Global Positioning System) technology has revolutionized spatial data acquisition by offering spatial location data during field appraisals. Fieldworkers using GPS for their research can geo-code the observations on the field, for example, reporting the position of disease incidences or health facilities, which is valuable in improving accuracy of spatial data base used in epidemiological assessment. Mobile technology has also emerged as essential equipment for collecting data in the areas of public health. The interventions involve the use of mobile applications through which fieldworkers or community members can report any emerging health complication or environmental state in real-time. This immediacy helps in responding to new public health situation as

they occur and also engage the public in the monitoring of health determinants in their neighbourhood.

In addition, new strategies such as social media analysis are being embraced to track perceptions and trends of certain health related matters in certain societies. Scientists employ crawl- and scrape-technology to process geotagged social media data to gain insights into community perceptions on disease epidemic or prevention. Another dimension of data gathering in community HIM is that participatory mapping methods extend data gathering processes in a way that engages community stakeholders in mapping their experiences regarding the geography of health. However, this engagement also goes a long way in empowering local people as well as ensuring that indigenous information on health also forms part of the strategies to be implemented. Surveys, remote sensing technologies, GIS integration, GPS tracking using mobile applications, social media analytics, and participatory maps may greatly improve the current knowledge of public health professions regarding the geographical factors influencing the health related issues of a population, [23], [13], [10], [26], [18], [29], [1] and [25].

5.2. Analytical Tools and Software

Specialized equipment and applications are pivotary to the use of Geographic Information Systems (GIS) in public health. Software like ArcGIS and QGIS lets the users to visualize, analyze and interpret data and create enriched maps that render the health trends that are affected by various conditions including the environment, socio-economic status, and demographics. In public health, these tools are used in disease mapping and surveillance, which cannot be done without them. The disease incidence maps allow public health to pinpoint areas of high infection and potential outbreaks in a given population densities. Network analysis and geostatistical modeling are other analytical procedures that GIS software provides in enhancing understanding of the influence of transport road networks and distance to health facilities in disease transmission.

Remote sensing technology is therefore an improvement on traditional GIS in that it offers key data on environmental conditions as obtained from aerial and satellite images. This information is important in explaining ecological drivers of health for example in relation to land-use changes and vectors. Remote sensing data enhances spatial and temporal scales of health research when integrated with GIS namely for environmental changes, which are critical for decision making processes at a given time. Global Positioning Systems (GPS) enhance the accuracy of data collection on the physical location of a phenomenon during field research. Good geolocation is essential in epidemiological studies because the precise locations of health events or resources determine the response measures. The use of GPS-enabled instruments in the projects helps the fieldworkers and other personnel to geo-reference data in the best way possible thereby making the databases of public health more credible.

New technologies also extend GIS uses in public health. Technologies such as artificial intelligence, machine learning are incorporated in GIS to perform the analysis autonomously, to predict the projection of the diseases on the backdrop of big data sets, and to allocate the resources according to the real-time evaluation. Furthermore, mHealth application that integrates GPS tracking make it possible to monitor the health behaviour of individuals on a daily basis making it easy to detect risks early. As for public health agencies, the cloud storage solutions connected to the GIS applications are being implemented. This shift enhances the flow and dissemination of information across organizations and organizations and makes information up to date for fast decisions. Such enhancements enable the leadership in the domain of public health to capacitate themselves in countering new risks by offering broad access to updated visual and analytic tools. The integration of state-of-the-art analytical techniques with innovative technologies while addressing the spatial relations of determinants to community health outcome prepares public health professions to intervene effectively when necessary, [4], [7], [15], [19], [5], [1] and [16].

6. Case Studies

6.1. Successful GIS Interventions in Epidemic Control

GIS solutions have become indispensable in the study of public health, especially during epidemics. One most illustrative example is the use of GIS in combating the Ebola outbreak in West Africa where GIS was used to map disease incidence and response. Thus, using such data, the Department of Health was able to find out the areas with the most intensiveness of the disease, distribution rates, and the correct distribution of resources to the regions affected. This made the spatial analysis not only to support the suppression and isolation measures in the near future but also to give indications about the areas and factors that might lead to the future spread of the virus.

Likewise, in the course of the COVID-19 outbreak, different health organizations used GIS in creating dynamic maps that illustrated the infection rates within the different areas. These maps helped risk communication among public health authorities to reveal that they could respond to the identified risks with well-timed interventions. Some high-risk areas needed enhanced testing and vaccination campaigns, officials used demographic data complementary to the infection rates to develop targeted health messages in relevant groups of the virus-susceptible population. GIS applications are also beneficial while addressing the challenge of opioid epidemic in North America. Therefore, through consideration of the geographical distribution of opioid prescriptions in relation to overdose cases, the agencies were able to design targeted prevention measures such as community-based campaigns and law enforcement actions against the violators of the appropriate use of the beneficial drugs. This data was enlightening visually to help reveal geographic distributions of opioid use and identify areas that are more deserving of resources for prevention and treatment services.

During calamities for instance hurricanes or floods, GIS is essential in disaster management by revealing population distribution and physical facilities characteristics. After hurricane Katrina hit GIS was used in providing quick estimates of the extent of damage as well as the provision of information on the location of affected areas, hospitals, shelters and other critical resources. This capability improved the provision of near-end immediate responses and played a role in the identification of areas that needed continued support in the post-disaster phase. In addition, community-centered GIS activities have enhanced epidemic control measures as people participated in them. In projects earmarking vector borne diseases such as malaria or dengue fever,

local bodies contributed information on environmental risks in the area through mapping by public health workers. This partnership enabled communities and created local data that would lead to appropriate vector control strategies in different settings. The success of the integration of GIS in the management of epidemical diseases is a reminder of the need to balance an increased use of technology and a focus on community interventions and multisectoral approaches within public health systems. These examples show that spatial analysis not only supports timely response during a crisis but also builds the foundational work for continuously improving community resistance to future epidemics, [4], [24], [2], [17] and [6].

Figure 1: GIS in Public Health, [24].

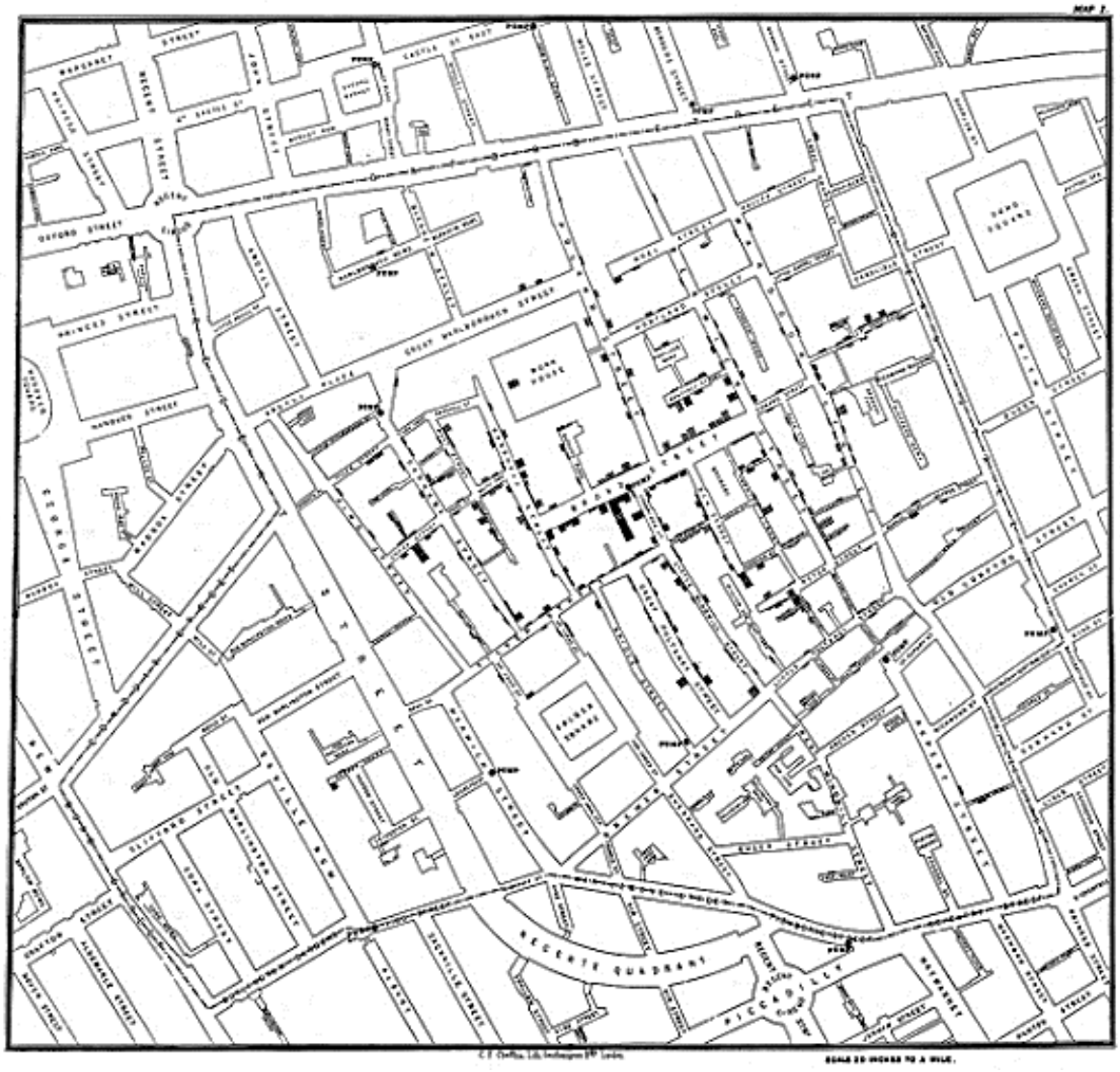

Figure 2: Snow Cholera Map, [24].

6.2. Evaluating Public Health Outcomes through GIS Applications

The use of Geographic Information Systems (GIS) is vital in the public health because GIS helps to display, analyze and support decisions concerning health issues. The role of GIS in public health practice is to make it easier for the health professionals to notice a disease differential, an outbreak of a disease, or notice where resources are required. The quantitative analysis of the epidemiological data unveils spatial distribution of diseases in various areas give the authorities tools to identify areas where diseases are more prevalent. Hence, it is important for designing and deploying timely and efficient interventions that employ resource allocations.

One of the most important functions of GIS is to evaluate the accessibility of health care services. When maps of healthcare facilities are placed on top of demographical information, researchers are able to identify areas that do not have adequate access to basic healthcare facilities. The details gathered in the research become relevant for policymakers on where to invest funds or open new clinics to address the deficit in service provision. Also, the case involves integrating on one side several datasets, for example, socioeconomic status, the environment, and health, on the other side in order to have a complete picture of how these factors impact the health of a community. GIS is also used effectively during disease outbreaks, disasters and other calamities. For example, in the period of COVID-19, GIS technologies provided ways for tracking and mapping of infection rates, and of vaccination campaigns, at the regional level. Spatial analyses were used by public health authorities to properly contain the virus and direct resources to specific areas that required them. This application supports increasing of situational awareness and improving the rates of response during the public health threats.

In addition to outbreak management, GIS enables the health programs to be evaluated for the long term since trends can be easily followed. Thus, updates of the population health in terms of of chronic diseases and vaccination status allow for evaluation of interventions geared at enhancing the community's health. This long-standing view is important for deciding whether public health interventions work as intended. Furthermore, environmental health is beneficial by helping in visualizing and analyzing exposure risks based on geographic information system. For instance, when one overlays pollution sites with population density, it identifies people living in tribes who are most affected by pollution. Such facts help to carry out specific measures: alterations of policy, focus on individuals more vulnerable because of the geographical factor within the community programs. The use of GIS in public health decision making helps the officials to have better knowledge base making the population health interventions much more effective. With the development of technology especially AI and big data analysis, the prospects of GIS will expand as time goes on, providing sharper assessments of the undercurrents of public health concerns, [2], [24], and [1].

7. Challenges and Limitations

7.1. Data Quality and Accessibility Issues

The paper focuses on the challenges in the adoption of Geographic Information Systems (GIS) in public health which is mainly attributed to data issues. One of the biggest challenges is the credibility of the health information which can present errors, stale information or no geospatial reference. These can distort analyses and harm public health interventions that rely on good data sets among the population. To expand GIS applications, researchers should use valid and dependable methods for checking the accuracy as well as the appropriateness of data to particular research questions.

Another issue pertains to data integration where data are collected from different organizations and these datasets are developed based from different standards. This lack of interoperability makes working with data an issue and requires special precautions to ensure the data's integrity when merging it. If integration is not done carefully, then there will be an introduction of error which will again make the analysis more difficult. Measurement errors as a constituent of spatial epidemiology are therefore not without technical challenges. Such errors can occur due to contamination by noise factors or due to constraints or challenges that are likely to be faced while accumulating the data or running the analysis. For example, constraints in GPS are that it is sometimes inaccurate and some categorical variables are misclassified. If these errors are not described and corrected, they can introduce artifacts into analysis, raising questions for studies that rely on geographical characteristics.

Privacy issues also limit access to as well as use of public health datasets in GIS frameworks. The difficulty is then to find the most appropriate ways to protect the privacy of those individuals while leveraging the health information at the same time. It is therefore important that ethical standards and legal requirements and regulation been adhered to. For a GIS to be as effective as it should be while keeping individuals' identities a secret, other ways like pooling the data into higher zones, or performing some mathematical operations that will ensure that their identity cannot be discovered can be employed. Furthermore, the modifiable areal unit problem makes GIS-based public health analyses more cumbersome in terms of interpretation. The decision-makers who use statistical analysis in their research are likely to fall into either of these pitfalls: find the wrong correlation because they are looking at aggregated data and fail to observe any trends because they are limited by artificial geographical segments, such as ZIP codes or census tracts, which may not reflect the true nature of the disease. Finally, the distributions of technology to researchers mean that effectiveness of using the GIS in different contexts can vary at a phenomenal rate. In low resource environments, access to good quality geospatial tools and sufficient training can be challenging among the SMEs. It is crucial to address those gaps to bring out the best in GIS in enhancing the launch of public health, [7], [28], [5], [1] and [3].

7.2. Ethical Considerations in Spatial Data Use

The issues of ethical nature in the context of GIS applications in public health are significant and connected with privacy and information security. While collecting data for GIS, time and again, personal health information is involved in the process and that is a huge concern when it comes to protecting the identity of the individuals while at the same time obtaining useful information that can be used to help with the improvement of health related issues. Collecting such spatial data also raises concerns about compromising privacy due to the high level of detail making it mandatory to follow privacy policies that restrict access to, and use

of sensitive information.

One of the main ways of handling these ethical issues is to make certain that all information that is fed into GIS is anonymised and aggregated as necessary. Due to the complex nature of exposing people through spatial data, preventive measures should be taken, for example, present the results at more generalized geographic levels or eliminate the identifiable features from the maps. However, this summary can sometimes hide real relations between values in the data or distort trends concerning the so-called modifiable areal unit problem. Justification of aggregated datasets is not unusual among public health practitioners as they can obscure specific trends or results in confusing generalisations about diseases or health inequality rates. If not properly managed, these statistical depictions may be used to stereotype or discriminant against one or the other group which explains why it is always important to explain to the society that no GIS analysis is complete and that there is always some element of bias that one cannot escape because it is embedded in the statistical models.

However, the distribution of GIS technologies still varies in the community, and it increases the inequality in work in the public health sector. Lack of technological infrastructure and human resource training remains other barriers to the utilization of GIS tools in resource-constrained environments. This digital divide brings about ethical issues of fairness and justice in accessing this effective technology important for studying health in various groups. The nature of GIS methodology make ethical issues even more challenging because information made available by such techniques may be misleading to those with no understanding of the complex spatial analysis involved. For this reason, it becomes essential that public health professionals get sufficient practice not only in the utilization of these technologies but also in the reporting of results as well as the dissemination of such information appropriately.

To optimize these tasks successfully, the development of sound guidelines for ethical data use is essential. Training of standard procedures in data collection, provision of security for sensitive information and constant training in ethical issues will enhance sound use of GIS in public health. Multiple sectors need to engage in discussion of current questions and potential developments for the future, including public health officials, policymakers, ethicists, and technologists. Although the increased application of GIS technology can improve population health outcomes, it is crucial to consider the ethical factors that can complement GIS use and protect people's rights at the same time.

8. Future Trends and Opportunities

8.1. Advancements in Technology (AI, Remote Sensing)

The innovations in communication technology and outdoor applications such as AI and remote sensing are enhancing GIS's utility in public health at a very fast pace. Advanced Information Technologies complement spatial modeling by enabling fast processing of big data sets and providing predictions that would be impossible to provide otherwise. Unlike manual methods which involve a lot of work to gather data and time-consuming in analyzing the results before informing public health interventions—thus jeopardising the lives of many—AI algorithms can sift through a vast amount of data to find trends in health outcome. For instance, the machine learning algorithms can use satellite image analysis to forecast an occurrence of diseases based on physical characteristics such as topological and climatic status of a specific country.

Integrating GIS with AI enhances disease mapping and offers capabilities of real time outbreak tracking. Modern public health organizations are now ready with new systems that incorporate various data type such as EHRs and social media data and sensor data to help the organizations in identifying early symptoms of new health threats. These elements let for the fast detection of a possible outbreak, as it define an increase in the rate of disease incidence, or an unusual situation in different geographic areas. Technological developments in geophysical and geochemical measurements are key instruments for studying the environmental determinants of health. The technology of using satellites and drones helps explore the modifications In land usage, air quality, and water conditions in some regions. These technologies help in establishing relationship between the environmental factors and health effects, for example, determining the effects of residence near an industrial area on respiratory diseases among community residents.

Moreover, the increased use of mobile technologies and 'wearables' with position registering elements has also very much enhanced information gathering in public health. Such devices are constantly collecting information about individual actions and displacements, which makes the health management process more focused. Such a real-time feedback allows for risk assessment and enables the person to make some choices based on the data about his or her health. GeoAI has received increasing attention as a novel trend at the interface of AI and GIS in public health studies. They include different techniques, which deploy geographic context within the concept of modeling with the purpose of improving community health. GeoAI can help researchers extract meaningful information from large datasets and use spatial perspectives to consider and overcome social factors that influence health.

Data handling and analysis capabilities have advanced to produce remarkably complex models within GIS frameworks that correlate with both personal and population level susceptibilities and disease risks. They help so much in placing the public health challenges on a proactive platform by allowing the roll out of intervention measures based on analyses of all aspects. They further explained that, given the exponential advancement in technology, the application of sophisticated GIS tools would soon redefine approaches to both surveillance and distribution of resources, as well as methods of intervention in public health. Since it will influence local communities, global processes, and initiatives, this transformation will affect the functioning and response of public health entities to health challenges, [12], [30], [21], [14], [1] and [22].

8.2. Integration with Other Public Health Initiatives

Geographic Information Systems (GIS) when integrated with public health increases the efficiency of health programs since it brings a geographical dimension which is usually left out in other models. GIS technologies allow the public health officers to display and process different datasets with demographic, environmental, and health factors in order to improve the understanding of the inequality between health and growth and in order to make more accurate prediction of risks and threats to

populations.

Multisectoral interventions are one of the most important areas for the use of GIS in addressing public health crises. Housing, transportation, and social welfare data become fed into the GIS system that enables it to pinpoint sectors that need attention. It is also useful in the approach to the social factors that define health, most of which require the integration of other sectors to develop effective solutions. Furthermore, GIS enhances the process of monitoring and evaluating the program while enhancing the designing and implementation process. It's advantageous to integrate data continually in public health when interventions occur because adjustments can be made more quickly based on new conditions or the identification of a new health threat. The capacity of mapping the data allows the stakeholders to easily understand the consequences of new discoveries and prepare for the changes.

This paper has shown that in most of the developed effective GIS in public health requires the involvement of stakeholders. This way, the local communities are involved in the mapping exercises hence the data collected represents them and their experiences. Community engagement provides the needed information and also ensures that the community fully supports the initiatives in question. Official collaboration with NGOs is also important in order to leverage the use of GIS applications in governmental institutions. It can strengthen the delivery of goal-oriented public health initiatives by ensuring concordance of objectives of multiple programs as in disease prevention, including malaria, or mother and child health care.

This means that as technology grows, incorporating GIS with other features like artificial intelligence (AI) is expected to take a further step in the enhancement of public health. AI can quickly assess a significant amount of spatial information and detect trends that are not recognizable by regular assessment. This integration will enhance the use of epidemiological data for the optimization of the resource and modeling predictability. Mobile technology presents further possibilities of GIS to be incorporated into mobile platforms specifically for the convenient availability of geographic information for frontline clinical workers in healthcare facilities. Such capability will eventually improve decisions made during epidemics or disasters where actions are needed promptly.

Last but not the least, standardisation of the health information exchange at the national and international levels of operation is critical. The adoption of standard procedures will enhance international collaboration in combating cross-border communicable diseases, prevalent diseases and environmentally induced diseases. As GIS is integrated with other cross-sectional public health activities, there is much potential to improve community preparedness for future health calamities, [1], [4], [7], [1] and [6].

9. Conclusions

Map integration as a component of Geographic Information Systems (GIS) in public health is a major development for data analysis and utilization in health. GIS is critical in the analysis of various public health problems since it can be used to display spatial relations in view of the nature of disease distribution and their temporal variations in relation to social factors. More importantly, this geographic perspective aids in improving the knowledge of the epidemiological trends and guides efforts at targeting the right areas.

In matters relating to public health crises, GIS becomes a precious tool because its real time features enable quick collection and sharing of information. This functionality is important to monitor an outbreak of infectious disease well to ensure that incidents are tracked as they happen to give health authorities better view of the situation and fine-tune their responses.

Equity is also well supported by GIS in the context of public health. On this aspect, it offers information on the existing areas with few health facilities making it important in assessing the geographical mapping of the available health facilities in relation to the population. As such the above analyses assist policymakers in decision making especially relating to resource deployment especially for the marginalized groups. This aspect of GIS is important in helping to minimize such differences and make sure that all the required services get to all the populations.

Though GIS offers numerous advantages to its users, there are still some problems that have to be solved. Data quality is one of the crucial factors of intervention strategies because incomplete or erroneous information is likely to provide misleading results in decision-making processes. Further, the privacy and ownership of the data need to be solved for the general public to trust and embrace the application of geospatial information for improved health status.

The future of GIS in public health is bright as technological advancement goes on such as artificial intelligence and remote sensing that brings more opportunities to the application of GIS. Such developments are thought to improve the information analysis and provide an opportunity to produce broader surveys of a given health situation within a larger region. Moreover, incorporating GIS practicing to other public health programs can enable a systems approach to addressing multifaceted barriers and enablers such as climate change effects on health.

Therefore, as the world moves towards a more challenging environment with emerging public health issues, GIS is going to be one of the core tools. Its ability to offer spatial intelligence does not only enhance research processes but also assists decision-makers at different levels to implement positive interventions for enhancing the global population health results, [1], [4], [7], [14], [11], [2], [3].

References

[1] Biu, P. W., Nwasike, C. N., Tula, O. A., Ezeigweneme, C. A., & Gidiagba, J. O. (2024). A review of GIS applications in public health surveillance. *World Journal of Advanced Research and Reviews*, *21*(1), 030-039. [Online]. Available: https://wjarr.com/sites/default/files/WJARR-2023-2684.pdf

[2] Jones, S. E. (2023). The applications of geographic information systems (GIS) in public health. *Journal of Applied Geographical Studies*, *3*(1), 1-14. [Online]. Available: https://www.researchgate.net/publication/377432606_The_Applications_of_Geographic_Information_Systems_GIS_in_Public_Health

[3] F. Abiala. (2023). "Applications of GIS in the Health Sector". [Online]. Available:

https://www.spatialnode.net/articles/applications-of-gis-in-the-health-sector30b829

[4] Biu, P. W., Nwasike, C. N., Tula, O. A., Ezeigweneme, C. A., & Gidiagba, J. O. (2024). A review of GIS applications in public health surveillance. *World Journal of Advanced Research and Reviews*, *21*(1), 030-039. [Online]. Available: https://www.researchgate.net/publication/377265989_A_review_of_GIS_applications_in_public_health_surveillance

[5] "GIS and public health". Dec 2023. [Online]. Available: https://en.wikipedia.org/wiki/GIS_and_public_health

[6] Davenhall, W. F., & Kinabrew, C. (2012). GIS in health and human services. In *Springer handbook of geographic information* (pp. 557-578). Berlin, Heidelberg: Springer Berlin Heidelberg. [Online]. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC7121355/

[7] Yasobant, S., Vora, K. S., & Upadhyay, A. (2019). Geographic information system applications in public health: Advancing health research. In *Healthcare Policy and Reform: Concepts, Methodologies, Tools, and Applications* (pp. 538-561). IGI Global. [Online]. Available: https://www.researchgate.net/publication/330481467_Geographic_Information_System_Applications_in_Public_Health_Advancing_Health_Research

[8] Charlotte D. Smith. (2024). "Charlotte Smith | Berkeley Public Health".. [Online]. Available: https://publichealth.berkeley.edu/people/charlotte-smith

[9] Wang, F. (2019). Why Public Health Needs GIS?. [Online]. Available: https://www.tandfonline.com/doi/full/10.1080/19475683.2019.1702099

[10] "Course Descriptions". Jan 2024. [Online]. Available: https://cosspp.fsu.edu/publichealth/course-descriptions/

[11] Wang, F. (2019). Why Public Health Needs GIS?. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7297184/

[12] Geoffrey Jacquez, Ph.D.. "GIS and Public Health: 8 Trends for 2024". Dec 2023. [Online]. Available: https://biomedware.com/gis-and-public-health-8-trends-for-2024/

[13] Sifaki-Pistolla, D., Chatzea, V. E., Frouzi, E., Mechili, E. A., Pistolla, G., Nikiforidis, G., ... & Tzanakis, N. (2022). Evidence-based conceptual collection of methods for spatial epidemiology and analysis to enhance cancer surveillance and public health. *International Journal of Environmental Research and Public Health*, *19*(19), 12765. [Online]. Available: https://www.mdpi.com/1660-4601/19/19/12765

[14] Musa, G. J., Chiang, P. H., Sylk, T., Bavley, R., Keating, W., Lakew, B., ... & Hoven, C. W. (2013). Use of GIS mapping as a public health tool–-from cholera to cancer. *Health services insights*, *6*, HSI-S10471. [Online]. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC4089751/

[15] J. D. Berman. (2018). "GIS and Spatial Analysis for Public Health". [Online]. Available: https://www.sph.umn.edu/sph/wp-content/uploads/syllabi/2018/fall/pubh-6100.pdf

[16] Beale, L., Abellan, J. J., Hodgson, S., & Jarup, L. (2008). Methodologic issues and approaches to spatial epidemiology. *Environmental health perspectives*, *116*(8), 1105-1110. [Online]. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC2516558/

[17] S. M. Christopher Thomas. "Mapping Community Health: GIS for Health and Human Services | Esri Press". (accessed Nov 16, 2024). [Online]. Available: https://www.esri.com/en-us/esri-press/browse/mapping-community-health-gis-for-health-and-human-services

[18] "Public Health (PB HLTH)". (accessed Nov 16, 2024). [Online]. Available: https://guide.berkeley.edu/courses/pb_hlth/

[19] B. D'Arcy. "14 Ways Health Departments Can Use GIS in 2023". Nov 2024. [Online]. Available: https://www.govpilot.com/blog/health-department-gis-map

[20] CDC. "What is GIS?". May 2024. [Online]. Available: https://www.cdc.gov/gis/php/what-is-gis/index.html

[21] Olawade, D. B., Wada, O. J., David-Olawade, A. C., Kunonga, E., Abaire, O., & Ling, J. (2023). Using artificial intelligence to improve public health: a narrative review. *Frontiers in Public Health*, *11*, 1196397. [Online]. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC10637620/

[22] Jerrett, M., Gale, S., & Kontgis, C. (2010). Spatial modeling in environmental and public health research. *International journal of environmental research and public health*, *7*(4), 1302-1329. [Online]. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC2872363/

[23] Joe C. Wen and C. Dunlop. (2024). "Public Health (PUBHLTH) 2024-25 Edition". [Online]. Available: https://catalogue.uci.edu/allcourses/pubhlth/

[24] IPS. "The Role of GIS in Public Health". Jun 2020. [Online]. Available: https://publicstrategies.org/the-role-of-gis-in-public-health/

[25] Auchincloss, A. H., Gebreab, S. Y., Mair, C., & Diez Roux, A. V. (2012). A review of spatial methods in epidemiology, 2000–2010. *Annual review of public health*, *33*(1), 107-122. [Online]. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC3638991/

[26] "Andrew Curtis | Department of Population and Quantitative Health Sciences | Case Western Reserve University". Mar 2024. [Online]. Available: https://case.edu/medicine/pqhs/about/people/primary-faculty/andrew-curtis

[27] Elliott, P., & Wartenberg, D. (2004). Spatial epidemiology: current approaches and future challenges. *Environmental health perspectives*, *112*(9), 998-1006. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/15198920/

[28] Zhang, Z., Manjourides, J., Cohen, T., Hu, Y., & Jiang, Q.

(2016). Spatial measurement errors in the field of spatial epidemiology. *International Journal of Health Geographics*, *15*, 1-12. [Online]. Available: https://ij-healthgeographics.biomedcentral.com/articles/10.1186/s12942-016-0049-5

[29] "Public Health (MPHP) < Case Western Reserve University". Sep 2024. [Online]. Available: https://bulletin.case.edu/course-descriptions/mphp/

[30] Kamel Boulos, M. N., Peng, G., & VoPham, T. (2019). An overview of GeoAI applications in health and healthcare. *International journal of health geographics*, *18*(1), 7. [Online]. Available: https://ij-healthgeographics.biomedcentral.com/articles/10.1186/s12942-019-0171-2

[31] Osei, F. (2014). Current statistical methods for spatial epidemiology: a review. *Austin Biometrics Biostat*, *1*(2), 1-7. [Online]. Available: https://austinpublishinggroup.com/biometrics/fulltext/biometrics-v1-id1009.php