Advancements in Disease Surveillance: The Role of GIS in Global Health Preparedness

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Abstract
This systematic review explores the application of Geographic Information Systems (GIS) in disease surveillance, a critical tool for managing emerging health threats in the 21st century. By enabling real-time monitoring, spatial analysis, and data integration, GIS has become essential for tracking disease outbreaks, optimizing healthcare resources, and informing public health interventions. The study highlights how GIS technology enhances preparedness and response during crises, with a particular emphasis on the COVID-19 pandemic, where GIS facilitated rapid data dissemination and visualization. Moreover, the integration of artificial intelligence and data analytics with GIS systems promises to advance predictive capabilities, improve decision-making, and foster global collaboration. Despite its transformative impact, challenges such as data quality, ethical considerations, and infrastructure limitations are noted. Addressing these obstacles through stakeholder engagement and equitable access is crucial for maximizing GIS's potential to build resilient health systems capable of confronting future public health crises.

Keywords: Disease Surveillance, Geospatial Health, GIS, Health GIS, Health Preparedness, Public health

1. Introduction

Using Geographic Information Systems (GIS) for disease surveillance in the 21st century represents a transformative approach to public health, enabling real-time monitoring, integration of diverse data sets, and spatial analysis. GIS is crucial for tracking disease outbreaks, optimizing resource allocation, and enhancing public health decision-making through advanced mapping and analytics. During the COVID-19 pandemic, GIS proved essential for disseminating accurate, timely health information, allowing public health authorities to respond quickly to evolving threats [1]. This technology also facilitates collaboration across regions, comprehensively understanding disease patterns and enabling coordinated responses. Furthermore, GIS aids in identifying vulnerable populations, predicting outbreak hotspots, and informing preventive measures, thus enhancing preparedness and resilience in the face of emerging global health challenges [2] and [3]. Integrating geographic and demographic data helps public health systems monitor trends and allocate resources effectively, ultimately improving outcomes and saving lives. As the global landscape of infectious diseases continues to evolve, GIS will play an increasingly critical role in managing health threats, making it an indispensable tool in modern public health efforts. In this dynamic and complex field, the continued development and application of GIS technologies are vital for building more resilient and responsive health systems capable of mitigating future pandemics and other public health crises [4]. By fostering global collaboration and ensuring equitable access to these technologies, GIS can significantly contribute to advancing health security and preparedness worldwide [5] and [6].

The review emphasizes the potential of Geographic Information Systems (GIS) in disease surveillance, but it also acknowledges several challenges. These include issues with data quality, infrastructure limitations, and ethical concerns surrounding privacy and data sharing. Effective implementation of GIS also requires robust training and stakeholder engagement to prevent misinterpretation and ensure the proper use of these tools.

Additionally, continuous evaluation and adaptation of GIS technologies are crucial as public health agencies respond to emerging health threats, ensuring systems remain reliable and equitable across diverse settings. Global collaboration and equitable access to technology are critical for building resilient health systems that can address pandemics and public health challenges effectively [7] and [8].

The future of Geographic Information Systems (GIS) in disease surveillance is projected to evolve significantly with the integration of artificial intelligence (AI) and real-time data aggregation. AI will enable the automation of data analysis, enhancing the accuracy and speed of outbreak predictions. Real-time aggregation of data from various sources will further improve the precision of public health interventions, facilitating better situational awareness. Additionally, global cooperation and equitable access to technology are paramount to developing resilient health systems capable of efficiently responding to pandemics and addressing health disparities. Such advancements will help public health authorities detect, monitor, and mitigate health crises more effectively, reducing the response time during outbreaks and enhancing global preparedness. [9] and [10]. The systematic review highlights the critical importance of Geographic Information Systems (GIS) in modern health surveillance, especially in the face of evolving public health threats. As the field continues to change, GIS must incorporate advanced technologies such as artificial intelligence (AI) and data analytics to improve the accuracy and efficiency of disease detection and monitoring [11] [12] and [13].

These technologies also offer enhanced decision-making capabilities for health professionals, enabling faster and more targeted responses to health crises. Global collaboration is emphasized as essential, particularly in ensuring equitable access to GIS technology. Many regions, especially low-resource settings, face significant barriers in accessing and utilizing these advanced tools [14]. Bridging this gap is vital for strengthening global health systems and reducing disparities, making sure that all regions can effectively combat disease outbreaks.

Moreover, the review stresses the need for continuous research and innovation in GIS methodologies. This includes developing systems that can integrate real-time data from diverse sources, enabling more predictive and dynamic approaches to disease surveillance. By improving situational awareness, health systems can implement interventions more rapidly and efficiently. Ethical concerns, especially related to privacy and data sharing, remain key challenges in expanding GIS use. As more data is collected and integrated, safeguarding patient privacy while ensuring the responsible use of information becomes increasingly important. Addressing these concerns is crucial to maintaining public trust and enhancing the overall effectiveness of GIS in public health. Through ongoing research, innovation, and global cooperation, GIS will continue to be a transformative tool in public health, helping professionals better manage current and future health challenges [15] and [16].

2. Historical Context

The integration of Geographic Information Systems (GIS) into public health has significantly evolved over centuries, with its origins traced back to the earliest documented use of maps in 1694 during efforts to contain the plague in Italy. This period marked the beginning of spatial visualization as a valuable tool for linking place and health [17]. Over the next 225 years, maps played a crucial role in tracking and controlling infectious diseases, including yellow fever [18], cholera [19] and [20], and the 1918 influenza pandemic [21]. These historical applications highlighted the importance of mapping in public health, particularly in visualizing the spread of diseases and understanding patterns of transmission. As the understanding of the relationship between geography and disease developed, GIS technologies advanced, allowing for more sophisticated analyses. During outbreaks, such as cholera in the 19th century, maps were used to pinpoint sources of infection and inform public health interventions [19] and [20], a famous example being John Snow’s cholera map in 1854, which traced the outbreak to a contaminated water pump in London [22] and [23]. These early efforts laid the foundation for the modern use of GIS in public health. Today, GIS has evolved into a powerful tool for disease surveillance, outbreak response, and health resource management [24]. By integrating real-time data, GIS allows public health professionals to track disease spread, analyze risk factors, and allocate resources effectively. This technology is now indispensable in modern public health, offering valuable insights for responding to both infectious and non-infectious disease challenges globally [25] and [26].

The advent of computerized Geographic Information Systems (GIS) in the 1960s marked a transformative shift in public health, enhancing the ability to analyze, visualize, and detect disease patterns rapidly and accurately [27]. This breakthrough allowed for real-time spatial data integration, leading to more informed decision-making during outbreaks.

A 2014 systematic review revealed that 28.7% of health-related GIS studies were focused on infectious disease mapping, highlighting its vital role in this area [28]. GIS has become essential for identifying high-risk areas [29], predicting outbreaks [30], and planning interventions, contributing significantly to global health surveillance and response [31]. Moreover, GIS's influence extends beyond infectious diseases to include mapping non-communicable diseases, analyzing environmental risks, and assessing disparities in healthcare access. Its integration with technologies like artificial intelligence further enhances predictive capabilities, allowing health agencies to anticipate and respond to health challenges more efficiently. GIS now serves as a cornerstone in modern public health, providing crucial insights that improve both short-term crisis management and long-term healthcare planning [32]. The SARS outbreak in 2003 catalyzed the rise of web-based tools for applied geography [33] and [34], leading to an increase in the accessibility and utilization of GIS in real-time disease tracking. This development proved crucial during the COVID-19 pandemic, where various maps and charts were employed to illustrate the rapid spread of the virus and the subsequent strain on health infrastructures worldwide [6] [35] and [36].

Additionally, the World Health Organization (WHO) established the Global Outbreak Alert and Response Network (GOARN) to enhance international cooperation in managing outbreaks of epidemic-prone diseases. GOARN brings together technical expertise, health resources, and coordination from a global network of organizations, enabling a rapid, well-coordinated response to emerging health threats. This initiative has been pivotal in strengthening global preparedness by consolidating the necessary skills and resources to control outbreaks, improve surveillance, and ensure a timely response. GOARN is key in addressing global health challenges like pandemics, and ensuring stronger international collaboration in public health management [37].

3. Methodology of the Systematic Review

3.1 Systematic Review Framework

A systematic review was conducted following the guidelines provided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist. The PRISMA framework ensures that systematic reviews are comprehensive, transparent, and methodologically sound by following structured steps, including identification, screening, eligibility, and inclusion of relevant studies [38]. Using PRISMA helps maintain the rigor and quality of reviews, ensuring reproducibility and providing clear insights into the evidence base on a particular topic, making it essential for systematic health research and reviews. The review aimed to evaluate web-based infectious disease surveillance systems by implementing a comprehensive search, screening, and analysis process across various databases, including PubMed, Web of Science, and Embase, covering literature published between 2000 and 2015. Eleven surveillance systems were selected for evaluation due to their frequent use and relevance in the field. These systems were chosen based on their widespread application in public health surveillance and their ability to provide valuable insights into monitoring disease trends, assessing health threats, and facilitating timely responses. The selection criteria likely focused on the systems' effectiveness, data quality, and overall impact on public health outcomes, ensuring that the evaluation covered the most pertinent and impactful surveillance tools in use today.

3.2 Study Selection Process

The study selection employed a systematic framework for identifying, retrieving, and summarizing relevant literature. The inclusion criteria focused on full-text citations published in English between 1993 and 2023. This approach ensured a comprehensive review of relevant materials within the defined timeframe, allowing for a thorough evaluation of the selected literature. The systematic method adhered to established guidelines, ensuring transparency, consistency, and quality in the selection and review process. This robust framework facilitated a detailed and accurate synthesis of the findings within the scope of the study. The selection process was conducted in three phases: title screening, abstract screening, and full-text review. Two independent reviewers facilitated this process, ensuring a rigorous and unbiased approach. Duplicates were removed, and manuscripts were screened based on predefined inclusion criteria, with a particular emphasis on health facility-based disease surveillance systems. This multi-phase approach ensured that only the most relevant and high-quality studies were included in the final review, adhering to the systematic framework established for this evaluation.

3.3 Data Quality Assessment

To ensure a robust analysis, three data quality categories were defined: conformance, completeness, and plausibility. These categories assessed various aspects of data quality. Conformance measured the internal and external consistency of the data, ensuring alignment with established standards.

Completeness evaluated the presence and coverage of necessary data elements, ensuring no critical information was missing. Plausibility examined the temporal consistency among values, verifying that the data followed expected patterns over time [39]. This structured approach helped ensure data reliability and accuracy in the evaluation process. The assessment differentiated between verification and validation processes. Verification focused on ensuring consistency within the dataset itself, examining whether the data adhered to internal standards and maintained logical coherence. Validation, on the other hand, assessed how well the data conformed to external datasets, ensuring that it aligned with other credible sources. This distinction ensured that both the internal integrity of the data and its reliability when compared to external references were thoroughly evaluated, providing a more comprehensive analysis of data quality [40].

3.4 Search Strategy

A comprehensive search was conducted using a combination of Medical Subject Headings (MeSH) terms and related keywords. The search focused on domains such as surveillance, evaluation, framework, and health to capture relevant literature. This approach ensured that a wide array of sources was considered, facilitating a thorough exploration of the topic. Utilizing MeSH terms enhanced the precision of the search, as it allowed for the identification of relevant studies across various databases by categorizing medical concepts systematically [41]. Specific search strategies employed various algorithms to retrieve articles published between January 2010 and November 2022. This approach ensured broad coverage of relevant literature across multiple domains, capturing studies that aligned with the review's focus areas. By combining tailored search algorithms with Medical Subject Headings (MeSH) terms and relevant keywords, the search process was optimized to identify key articles and data sources related to surveillance, evaluation frameworks, and public health, ensuring a comprehensive and systematic review of the available literature [42].

3.5 Data Presentation and Analysis

Data analysis techniques, including artificial intelligence and data mining, were applied to identify trends and patterns over time. Various analysis types were utilized, including geographic-level comparisons and evaluations of key performance indicators (KPIs) [43]. The features for effective data presentation included clarity, organization, minimal distractions, aesthetic design, and consistency, aimed at facilitating user understanding and engagement.

3.6 Limitations and Future Directions

The review acknowledged several limitations, including the need for better communication with public health officials during the development phase of surveillance systems. This would ensure that systems are tailored to meet actual public health needs. Additionally, it highlighted the importance of ongoing training for public health staff, ensuring they are equipped to use the systems effectively. Implementation planning was also noted as a crucial aspect, requiring careful coordination to ensure surveillance systems are not only developed but also integrated smoothly into public health practice [44]. The findings of the review aim to guide the design and improvement of emerging disease surveillance systems by focusing on key elements such as stakeholder engagement and data validation methodologies. Effective collaboration with stakeholders ensures that the systems are practical and aligned with real-world public health needs. Additionally, robust data validation methodologies are critical to ensuring that the data collected is accurate, reliable, and useful for decision-making, enhancing the overall effectiveness and responsiveness of surveillance systems in detecting and managing emerging health threats [45].

3.7 Applications of GIS in Emerging Disease Surveillance

Geographic Information Systems (GIS) have become crucial in emerging disease surveillance, transforming public health management by offering powerful tools for monitoring and decision-making. GIS enables health authorities to integrate spatial and temporal data, providing a comprehensive, dynamic view of disease patterns. This real-time analysis is invaluable for visualizing the spread of infectious diseases, identifying high-risk areas [46], and predicting future outbreaks [47], which facilitates timely interventions and resource mobilization. Moreover, GIS aids in understanding the influence of environmental factors, population density, and human mobility on disease transmission, particularly in regions with high population concentrations or migration levels. The ability of GIS to enhance surveillance is complemented by its role in optimizing resource allocation. By mapping health infrastructure and population distribution, GIS ensures efficient and equitable deployment of healthcare services, especially in response to outbreaks or pandemics [48].

GIS also enables the identification of vulnerable populations who may be disproportionately impacted by diseases, allowing for targeted health interventions in those areas. As GIS technology continues to evolve, its integration with artificial intelligence and machine learning enhances its predictive capabilities, enabling more accurate disease forecasting. However, the full potential of GIS is sometimes limited by infrastructure and data quality challenges, particularly in low-resource settings. Addressing these issues through enhanced stakeholder engagement, capacity-building, and improvements in data validation are essential to maximize the effectiveness of GIS in global public health surveillance [49].

In addition to enhancing disease surveillance, Geographic Information Systems (GIS) are crucial for optimizing the allocation of healthcare resources. GIS helps map health infrastructure, such as hospitals and vaccination centers, enabling public health authorities to distribute resources efficiently, especially during health crises like pandemics. By identifying vulnerable populations at greater risk, GIS ensures targeted interventions reach those most in need. The integration of GIS with artificial intelligence (AI) and machine learning has further improved predictive capabilities, allowing for more accurate forecasts of disease spread and resource requirements [50] and [51]. Despite these advancements, implementing GIS in low-resource settings faces challenges, particularly in terms of infrastructure and data quality. Addressing these issues through enhanced data validation, stakeholder engagement, and capacity-building is essential to fully leverage the potential of GIS in global disease surveillance. GIS also facilitates the strategic planning of health interventions by providing critical insights into geographic disparities [52]. For example, during an outbreak, GIS can identify areas with insufficient healthcare access or vulnerable populations that may be disproportionately affected, ensuring a more equitable response. By mapping healthcare facilities and tracking population movements, GIS can anticipate where resources will be needed most and predict areas that may experience future outbreaks. This functionality is especially useful during pandemics like COVID-19 [53], where efficient resource allocation can significantly impact response effectiveness. The integration of AI and machine learning has also boosted GIS capabilities, enhancing its ability to process large datasets and create predictive models for disease transmission [54]. However, to fully utilize these advancements, low-resource settings must overcome challenges related to infrastructure limitations, data availability, and technological capacity. Collaborative efforts to improve these conditions, alongside better data validation and training, are essential for maximizing the global impact of GIS on disease surveillance [55].

3.8 Disease Mapping and Analysis

Geographic Information Systems (GIS) have become an integral tool in modern public health, revolutionizing how diseases are monitored, managed, and responded to in both global and local contexts. With the ability to integrate vast amounts of spatial and temporal data, GIS enables health professionals to visualize the geographical distribution and variations of diseases, offering invaluable insights into trends during outbreaks. This real-time visualization is crucial for identifying disease hotspots and tracking the spread of infectious diseases across different regions. By generating detailed thematic maps, GIS helps identify at-risk populations and stratify various risk factors, allowing health authorities to assess community healthcare needs effectively. Through the integration of demographic, environmental, and epidemiological data, public health officials can obtain a comprehensive picture of how diseases are spreading, which areas are most vulnerable, and where resources need to be deployed most urgently [56].

The application of GIS goes beyond basic disease mapping by enhancing the capacity of health systems to predict future outbreaks and optimize resource allocation. By analyzing spatial and temporal trends, GIS enables health over time. This predictive capability is invaluable in anticipating where and when future outbreaks might occur, administrators to forecast potential epidemics, identifying patterns in disease transmission and hotspots allowing for proactive interventions that can prevent large-scale epidemics. During pandemics like COVID-19, for instance, GIS played a crucial role in tracking cases, visualizing the spread in real-time, and informing decision-making on lockdowns, vaccination rollouts, and resource distribution [53]. Furthermore, the integration of GIS with advanced technologies such as artificial intelligence (AI) and machine learning has further enhanced its predictive capabilities, allowing for even more accurate forecasts of disease spread and the allocation of medical resources. Despite these advancements, challenges remain in implementing GIS in low-resource settings, where infrastructure limitations and data quality issues can hinder its full potential. Ongoing efforts to improve data validation, capacity-building, and stakeholder engagement are essential to maximizing the benefits of GIS in global health surveillance systems [56] and [57].

3.9 Data Integration and Management

One of the significant advantages of Geographic Information Systems (GIS) in public health is its capability to manage and integrate diverse data sources, including epidemiological surveillance, demographic statistics, and environmental data. This multi-source integration enables a more comprehensive approach to disease monitoring, allowing health professionals to analyze a broad spectrum of data within a spatial context [58] and [59]. The ability to combine epidemiological data with demographic and environmental factors enhances the understanding of how diseases spread and which populations are most at risk. This holistic perspective is invaluable in addressing the complexities of modern public health challenges. Furthermore, the integration of these data types eliminates redundancy and improves data accuracy by reducing duplication, which can often plague traditional data collection methods. By streamlining the data management process, GIS significantly reduces the operational costs associated with gathering and analyzing health-related information [60].

GIS not only reduces costs but also enhances the precision of disease surveillance through standardized geo-referencing of epidemiological data. This structured framework provides a consistent approach to managing large datasets, ensuring that data from various sources can be easily compared and analyzed within a unified system. Standardizing data formats and referencing improves interoperability between different health systems, enabling smoother coordination between local, national, and international health authorities. This is particularly important in managing global health crises, where the rapid exchange of accurate, geo-referenced data is crucial for effective decision-making and resource allocation. The standardized management of data in GIS facilitates real-time updates, allowing health professionals to monitor the evolution of outbreaks and adjust their strategies accordingly. Consequently, GIS provides a structured, cost-effective, and highly efficient framework for managing the complex data needs of modern public health systems, particularly in the context of emerging disease surveillance [61] and [62].

3.10 Real-time Monitoring and Decision Support

Web-based GIS technologies have revolutionized how health data is accessed and shared. By storing health data on central servers, public health professionals can access real-time information from various terminals. This advancement allows for dynamic mapping and immediate dissemination of health information [63], empowering patients to locate nearby health services easily. GIS also supports interactive queries that help in answering questions related to location, trends, and spatial patterns of diseases [64][65][66] and [67].

3.11 Collaborative Surveillance Efforts

GIS fosters collaborative efforts in disease surveillance by enabling cross-border data sharing and visualization. For instance, case studies have demonstrated the effectiveness of GIS in mapping infectious diseases across regions, allowing for interactive analysis and sharing among multiple partners. Such collaborative capabilities are essential for understanding the global spread of diseases and implementing timely interventions.

3.12 Health Resource Allocation

GIS is a powerful tool for monitoring healthcare resources and their utilization. By mapping health facilities and patient care environments, public health officials can optimize resource allocation and logistics. This includes routing health workers and supplies to service locations, thereby improving the efficiency of health interventions [53].

3.13 Benefits of Using GIS in Disease Surveillance

Geographical Information Systems (GIS) offer numerous advantages for enhancing disease surveillance and public health management. By enabling the capture, storage, and analysis of large volumes of geographically referenced data, GIS facilitates more efficient health planning and management compared to conventional methods [68].

3.14 Enhanced Data Management

GIS serves as a robust platform for the integration of diverse data sources, including epidemiological surveillance, demographic statistics, and environmental data. This capability reduces duplication in data collection efforts, thereby lowering costs associated with surveillance activities. The standardized geo-referencing of epidemiological data supports structured approaches to data management, which is essential for continuous and systematic analysis [69].

3.15 Rapid Mapping and Analysis

One of the key benefits of GIS is its ability to provide quick access to extensive data sets, enabling health professionals to conduct faster and more thorough analyses of disease patterns and trends. GIS tools offer dynamic analysis features that are vital for monitoring and managing epidemic situations. The flexibility of GIS allows for both precomputed and real-time statistical analyses, which are crucial for timely decision-making during disease outbreaks [70].

3.16 Comprehensive Applications

GIS applications in public health include identifying geographical distributions of diseases, analyzing spatial and temporal trends, and forecasting potential epidemics. By mapping populations at risk and identifying gaps in immunization, health administrators can better allocate resources and plan targeted interventions [71]. Furthermore, GIS aids in monitoring the utilization of health services and facilitates the routing of health workers and supplies, thereby optimizing healthcare deliver [72].

3.17 Support for Policy and Resource Allocation

GIS enhances communication regarding the burden of diseases, thereby informing decisions about resource allocation and prioritization of communities that require intervention. The ability to visualize complex data can help develop culturally competent programs and assist with program planning, monitoring, and evaluation [73].

3.18 Continuous Monitoring and Real-time Data Use

The importance of real-time data monitoring has been underscored by recent global health crises, such as the COVID-19 pandemic [74] and [75], which highlighted the need for effective public health dashboards. GIS not only supports continuous health status monitoring but also plays a pivotal role in disease outbreak prediction and management by integrating real-time data from various sources. This capability underscores the necessity of dashboard design principles that enhance usability and facilitate quick comprehension of critical information [76].

4. Challenges and Limitations

4.1 Data Quality and Evaluation

One of the primary challenges in utilizing Geographic Information Systems (GIS) for emerging disease surveillance lies in ensuring data quality [77]. Data quality evaluation encompasses several dimensions, including completeness, validity, accuracy, consistency, and precision, all of which are crucial for the data's intended use in public health contexts. Poor data quality can lead to significant issues, including type 1 (false positive) and type 2 (false negative) errors, which may undermine the effectiveness of disease surveillance efforts. Furthermore, existing frameworks for evaluating secondary data often lack practical tools for implementation, providing generic recommendations without sufficient detail, which complicates the evaluation process for practitioners in the field.

4.2 Infrastructure Limitations

The successful implementation of GIS-based disease surveillance systems also heavily depends on robust infrastructural arrangements. Inadequate information and communication technology infrastructure can hinder effective data collection and analysis. Specifically, challenges related to transportation and communication facilities impede the ability of health workers to perform their roles effectively in the data collection process [78] and [79], further exacerbating data representativeness and reliability. Additionally, the need for proper data warehousing and web service architecture highlights the necessity for an integrated approach to data management, which remains a significant challenge in many settings.

4.3 Human Resource Constraints

Human resource limitations further complicate the effectiveness of disease surveillance systems. Inadequately trained personnel, high patient demand, and multiple reporting requirements create a burden that can detract from data collection and reporting efforts. As noted in various studies, the attitudes of health workers towards data reporting can also be influenced by the existing operational challenges, including insufficient training and support, leading to a lack of engagement with the surveillance system [73].

4.4 Ethical and Privacy Concerns

Ethical considerations surrounding data release and confidentiality represent another layer of complexity in the deployment of GIS for disease surveillance. While measures are taken to remove personal identifiers from datasets, there is still a risk of indirect identification of individuals, particularly in small data sets with rich demographic information. This poses a dilemma for public health entities aiming to balance the utility of shared data with the imperative to protect individual privacy. As frameworks for data sharing evolve, ongoing evaluation and revision of policies, such as those negotiated by the Centers for Disease Control and Prevention (CDC) and the Council of State and Territorial Epidemiologists (CSTE), are necessary to enhance the protection of sensitive health data [80].

4.5 Evaluation of Effectiveness

The evaluation of Geographic Information Systems (GIS) for disease surveillance involves a comprehensive framework designed to assess the effectiveness and utility of these systems in public health contexts [81]. This framework integrates established evaluation principles and methodologies tailored to healthcare data and resources, providing a set of steps and tools applicable to large healthcare datasets, including an Electronic Health Records (HER)-based data, insurance claims, and survey data [43].

4.6 Key Evaluation Constructs

An essential aspect of the evaluation framework includes identifying the suitability of data for observational studies. A systematic literature review has revealed 16 measures and 33 sub-measures organized into five domains: explicitness of policy and data governance, relevance, availability of descriptive metadata, usability, and quality [9]. These constructs go beyond conventional data quality measures, such as completeness and accuracy, and focus on the broader implications of data governance and usability for effective disease surveillance.

4.7 Engaging Stakeholders

Engaging with stakeholders throughout the evaluation process is crucial for ensuring that findings are relevant and actionable. This engagement aids in defining the context and objectives of the evaluation, ultimately supporting the use of evaluation findings [9]. The literature indicates that the effectiveness of GIS projects often hinges on quality, geo-referenced data; hence, establishing clear communication with partners regarding data requirements is imperative.

4.8 Evaluation Steps and Practical Elements

A successful evaluation process generally includes four common steps: (1) context description, (2) evaluation process description, (3) implementation, and (4) formulation of recommendations. Evaluators are encouraged to adapt these steps to their specific contexts and needs, taking into consideration the unique attributes of the systems being assessed, such as usability and representativeness [45]. Moreover, practical elements like case studies and graphical representations of data outputs enhance the clarity and impact of evaluation results [10].

4.9 Assessing System Attributes

The effectiveness of GIS in disease surveillance can also be evaluated through specific attributes such as timeliness, acceptability, flexibility, and stability. The frequent inclusion of these attributes in evaluation approaches indicates their significance in assessing the functionality and reliability of GIS systems in public health applications. Attributes aimed at economic evaluation, however, are less commonly addressed, suggesting a potential area for further investigation and emphasis in future evaluations [10].

5. Conclusion

Geographic Information Systems (GIS) play an indispensable role in modern public health surveillance, offering comprehensive tools to monitor and manage emerging disease threats. As evidenced in this review, GIS not only enhances the precision and speed of disease tracking but also supports targeted interventions and resource allocation. The integration of AI and machine learning further amplifies its capacity for predictive modeling, improving global health preparedness. Nevertheless, the full potential of GIS in disease surveillance is contingent on addressing infrastructural and ethical challenges, particularly in resource-limited settings. Moving forward, global collaboration and continuous innovation in GIS technology are essential to bridge these gaps, ensuring that all regions can effectively leverage GIS for improved health outcomes. As the landscape of public health evolves, GIS will remain a cornerstone of disease surveillance, fostering resilient health systems prepared to address both current and future global health challenges.

6. Future Directions

Integrating Geographic Information Systems (GIS) into emerging disease surveillance is poised for significant advancement as public health agencies adapt to new challenges and opportunities. Future systems must prioritize the seamless access and integration of diverse data sources, which is crucial for enhancing the effectiveness of surveillance methodologies [42] and [45]. For instance, integrating GIS-based assessments, as shown in studies on COVID-19 vaccination coverage and case prevalence, underscores how geographic and epidemiologic data can guide targeted interventions and resource allocation in real time [53]. Incorporating user-centered design principles can further improve these systems, ensuring that they are tailored to the tasks and needs of end users, thereby fostering a more efficient and user-friendly interface [42]. Moreover, the ongoing development of digital disease surveillance systems, such as HealthMap, highlights the importance of aggregating online data sources, social media, and news reports to provide real-time situational awareness during disease outbreaks [42] and [61]. Leveraging GIS for real-time data visualization enhances situational awareness, as demonstrated by the structured approach to COVID-19 crisis management at district and sub-district levels in Thailand, where integrated data frameworks have streamlined response efforts [83].

The application of Artificial Intelligence (AI) and data mining techniques is expected to refine these surveillance efforts, enabling the prediction of trends and patterns in disease propagation through advanced algorithms applied to social media data [61]. Legal and regulatory frameworks will also play a vital role in shaping future directions, as strategies like Integrated Disease Surveillance and Response (IDSR) aim to strengthen the coordination between various health systems, enhance laboratory capacities, and promote community involvement in public health [44]. Ethical considerations are crucial, especially as advanced surveillance systems increasingly rely on personal data [82]. For example, studies examining public perception and preventive behaviors emphasize the importance of balancing data utility with privacy [84].

As we navigate post-pandemic realities, the ethical use of data, particularly concerning individual privacy, must be carefully considered, especially with the growing reliance on mobile and digital technologies for disease tracking. Furthermore, the need for global collaboration is critical, as pandemics transcend national borders. Countries must focus on sharing information and technologies in an integrated and interoperable manner to facilitate a coordinated global response to public health challenges [61]. Lastly, addressing the digital divide between developed and developing nations remains essential, ensuring that technological advancements are accessible and beneficial for all. Initiatives such as self-care programs, which leverage simple technology and community engagement to promote public health, underscore the potential for equitable solutions in public health surveillance [85].

References

[1] Ahasan, R., Alam, M. S., Chakraborty, T. and Hossain, M. M., (2020). Applications of GIS and Geospatial Analyses in COVID-19 Research: A Systematic Review. *F1000Research*, Vol. 27(9). https://doi.org/10.12688/f1000 research.27544.2.

[2] Carbajales-Dale, P., Annan-Coultas, D., Joseph, A., Thompson, M., Jafarifiroozabadi, R., Limber, S., P., Holaday, B. and Mihandoust, S., (2023). Using GIS to Improve Public Health Emergency Response in Rural Areas During the COVID-19 Crisis: A Case Study of South Carolina, US. *Transaction in GIS*, Vol. 27(4), 975-995. https://doi.org/10.1111/tgis.13069.

[3] Johari, N. S., Abdullah, N. M. and Bukari, B. M., (2022). GIS Communicate Emergency Preparedness Mapping: The Usability for Rural Area. *IOP Conference Series: Earth and Environmental Science*. https://doi.org/10.1088/1755-1315/1022/1/012031.

[4] Behl, A., Nair, A., Mohagaonkar, S., Yadav, P., Gambhir, K., Tyagi, N., Sharma, R., K., Butola, B., S. and Sharma, N., (2022). Threat, Challenges, and Preparedness for Future Pandemics: A Descriptive Review of Phylogenetic Analysis Based Predictions. *Infection, Genetics and Evolution*. Vol. 98. https://doi.org/10.1016/j.meegid.2022.105217.

[5] Geospatial World. (n.d.). How Geospatial Data and Technologies Can Help in Disease Prevention and Control. Geospatial World. [Online]. Available: https://www.geospatialworld.net/article/how-geospatial-data-and-technologies-can-help-in-disease-prevention-and-control/. [Accessed: Sept. 19, 2024].

[6] Kamel Boulos, M. N. and Geraghty, E. M., (2020). Geographical Tracking and Mapping of Coronavirus Disease COVID-19/Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-Cov-2) Epidemic and Associated Events Around the World: How 21st Century GIS Technologies are Supporting the Global Fight Against Outbreaks and Epidemics. *International Journal of Health Geographics*, Vol. 19(8). https://doi.org/10.1186/s12942-020-00202-8:contentReference[oaicite:0]{index=0}.

[7] Choi, J., Cho, Y., Shim, E. and Woo, H., (2016). Web-Based Infectious Disease Surveillance Systems and Public Health Perspectives: A Systematic Review. *BMC Public Health*, Vol. 16(1238). https://doi.org/10.1186/s12889-016-3893-0.

[8] Kroll, M., Phalkey, R. K. and Kraas, F. (2015). Challenges to the Surveillance of Non-Communicable Diseases – A Review of Selected Approaches. *BMC Public Health*, Vol. 15(1243). https://doi.org/10.1186/s12889-015-2570-z.

[9] Felix, S. E. B., Yusuf, H., Ritchey, M., Romano, S., Namulanda, G., Wilkins, N. and Boehmer, T. K., (2024). A Standard Framework for Evaluating Large Health Care Data and Related Resources. *Morbidity and Mortality Weekly Report (MMWR)*, Vol. 73(3), 1–13. https://www.cdc.gov/mmwr/volumes/73/su/su7303a1.htm.

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[10] Calba, C., Goutard, F. L., Hoinville, L., Hendrikx, P., Lindberg, A., Saegerman, C. and Peyre, M., (2015). Surveillance Systems Evaluation: A Systematic Review of the Existing Approaches. *BMC Public Health*, 15(448). https://doi.org/10.1186/s12889-015-1791-5.

[11] Kamel Boulos, M. N., Peng, G. and VoPham, T., (2019). An Overview of GeoAI Applications in Health and Healthcare. *International Journal of Health Geographics*. Vol. 18(7). https://doi.org/10.1186/s12942-019-0171-2.

[12] Zhao, A., P., Li, S., Cao, Z., Hu, P., J., H., Wang, J., Xiang, Y., Xie, D. and Lu., X., (2024). AI for Science: Predicting Infectious Diseases. *Journal of Safety Science and Resilience*, Vol. 5(2), 130-146. https://doi.org/10.1016/j.jnlssr.2024.02.002.

[13] Goovaerts, P., (2023). GEO AI and its Impact on Public Health. *BioMedWare Geospatial Software and Research*. [Online]. Available: https://biomedware.com/geo-ai-and-its-impact-on-public-health/. [Accessed: Sep. 19, 2024].

[14] Khashoggi, B. F. and Murad, A., (2020). Review Issues of Healthcare Planning and GIS: A Review. *ISPRS International Journal of Geo-Information*. Vol. 9(6). https://doi.org/10.3390/ijgi9060352.

[15] ESRI, (2023). Transforming Healthcare with GIS: A Strategic Blueprint for FutureReady Hospitals. *An ESRI Technical Paper*. New York. [Online]. Available: https://www.esri.com/content/dam/esrisites/en-us/media/technical-papers/strategic-health-care-planning.pdf. [Accessed: Sep. 19, 2024].

[16] Kumar, H., (2024). Using GIS in Healthcare: Mapping Public Health Trends. *MicroGenesis*. [Online]. Available: https://mgtechsoft.com/blog/using-gis-in-healthcare-mapping-public-health-trends/. [Accessed: Sep. 19, 2024].

[17] Alfani, G., (2013). Plague in Seventeenth-Century Europe and the Decline of Italy: An Epidemiological Hypothesis. *European Review of Economic History*, Vol. 17(4), 408-430. https://doi.org/10.1093/ereh/het013.

[18] Fijman, N. S. and Yee, D. A., (2022). Mapping Yellow Fever Epidemics as a Potential Indicator of the Historical Range of Aedes Aegypti in the United States. *Memórias do Instituto Oswaldo Cruz,* Vol. 6(117). https://doi.org/10.1590/0074-02760220306.

[19] Mukhopadhyay, A. K., (2015). Mapping of Cholera Cases using Satellite Based Recording Systems to Investigate the Outbreak. *Indian Journal of Medical Research*, Vol. 42(5), 509-511. https://doi.org/10.4103/0971-5916.171269.

[20] Nkeki, F. N. and Osirike, A. B., (2013). GIS-Based Local Spatial Statistical Model of Cholera Occurrence: Using Geographically Weighted Regression. *Journal of Geographic Information System,* Vol. 5(6). https://doi.org/10.4236/jgis.2013.56050.

[21] Peterson, W., (2023). Spatial Comparison of London's Three Waves of Spanish Flu. *Geospatial Health*. https://doi.org/10.4081/gh.2023.1235.

[22] Tulchinsky, T. H., (2018). John Snow, Cholera, the Broad Street Pump; Waterborne Diseases then and Now. *Case Studies in Public Health*, Vol. 30, 77–99. https://doi.org/10.1016/B978-0-12-804571-8.00017-2.

[23] Ruths, M. B., (2009). The Lesson of John Snow and the Broad Street Pump. *AMA Journal of Ethics*, Vol. 11(6), 470-472. https://doi.org/10.1001/virtualmentor.2009.11.6.mhst1-0906.

[24] Zhan, F. B., Lu, Y., Giordano, A. and Hanford, E. J., (2005). Geographic Information System (GIS) as a Tool for Disease Surveillance and Environmental Health Research. *IEEE Xplore*, Vol. 2. https://doi.org/10.1109/ICSSSM.2005.1500242.

[25] Texilia American University Zambia, (2024). How GIS in Public Health is Shaping the Future of Healthcare? [Online]. Available: https://tau.edu.zm/blog/gis-in-public-health-the-future-of-healthcare/. [Accessed: Sep. 15, 2024].

[26] Abiala, F., (2023). Applications of GIS in the Health Sector, the Numerous Capabilities of GIS in Health. [Online]. Available: https://www.spatialnode.net/articles/applications-of-gis-in-the-health-sector30b829. [Accessed: Sep. 15, 2024].

[27] Olamide, O., (2021). Evolution of GIS. Geoinfotech Blog | Geospatial Technology. [Online]. Available: https://geoinfotech.ng/evolution-of-gis/. [Accessed: Sep. 15, 2024].

[28] Bertazzon, S., (2014). GIS and Public Health. *Geo-Information*, Vol. 3(3), 868-870. https://doi.org/10.3390/ijgi3030868.

[29] Murad, A. and Khashoggi, B. F., (2020). Using GIS for Disease Mapping and Clustering in Jeddah, Saudi Arabia. *ISPRS International Journal of Geo-Information*, Vol. 9(5). https://doi.org/10.3390/ijgi9050328.

[30] Karras, A., Karras, C., Sioutas, S., Makris, C., Katselis, G., Hatzilygeroudis, I., Theodorou, J., A. and Tsolis, D., (2023). An Integrated GIS-Based Reinforcement Learning Approach for Efficient Prediction of Disease Transmission in Aquaculture. *Information*. Vol. 14(11). https://doi.org/10.3390/info14110583.

[31] Biu, P. W., Nwasike, C. N., Tula, O. A., Ezeigweneme, C. A. and Gidiagba, J. O., (2024). A Review of GIS Applications in Public Health Surveillance. *World Journal of Advanced Research and Reviews*. Vol 24(1). https://doi.org/10.30574/wjarr.2024.21.1.2684.

[32] Biu, P. W., Nwasike, C. N., Nwaobia, N. K. and Ezeigweneme, C. A., (2024). GIS in Healthcare Facility Planning and Management: A Review. *World Journal of Advanced Research and Reviews*, Vol. 21(1), 012-019. https://doi.org/10.30574/wjarr.2024.21.1.2682.

[33] Boulos, M. N. K., (2004). Descriptive Review of Geographic Mapping of Severe Acute Respiratory Syndrome (SARS) on the Internet. *International Journal of Health Geographics*, Vol. 3(1). https://doi.org/10.1186/1476-072X-3-2.

[34] Lai, P. C., Wong, C. M., Hedley, A. J. and Lo, S. V., (2004). Understanding the Spatial Clustering of Severe Acute Respiratory Syndrome (SARS) in Hong Kong. *Environmental Health Perspectives*, Vol. 112(15), 1550-1556. https://doi.org/10.1289/ehp.7117.

[35] Pardo, I. F., Napoletano, B. M., Verges, F. R. and Billa, L., (2020). Spatial Analysis and GIS in the Study of COVID-19. A Review. *Science of the Total Environment*, Vol. 739. https://doi.org/10.1016/j.scitotenv.2020.140033.

[36] Thammaboribal, P., Tripathi, N., Junpha, J., Lipiloet, S. and Wongpituk, K., (2024). Examining the Correlation between COVID-19 Prevalence and Patient Behaviors, Healthcare, and Socioeconomic Determinants: A Geospatial Analysis of ASEAN Countries. *International Journal of Geoinformatics*, Vol. 20(3), 95–112. https://doi.org/10.52939/ijg.v20i3.3159.

[37] World Health Organization, (2024). *Global Outbreak Alert and Response Network*. [Online]. Available: https://goarn.who.int/. [Accessed: Sep., 22, 2024].

[38] PRISMA, (2024). *Welcome to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Website*. [Online]. Available: https://www.prisma-statement.org/. [Accessed: Sep., 22, 2024].

[39] Kahn, M. G., Callahan, T. J., Barnard, J. and Bauck, A., (2016). A Harmonized Data Quality Assessment Terminology and Framework for the Secondary Use of Electronic Health Record Data. *EDM Forum*, Vol. 4(1). https://doi.org/10.13063/2327-9214.1244.

[40] Chen, H., Hailey, D., Wang, N. and Yu, P., (2014). A Review of Data Quality Assessment Methods for Public Health Information Systems. *International Journal of Environmental Research and Public Health*, Vol. 11(5), 5170-5207. https://doi.org/10.3390/ijerph110505170.

[41] National Library of Medicine, (2024). *Introduction to MeSH*. [Online]. Available: https://www.nlm.nih.gov/mesh/introduction.html. [Accessed: Sept. 25, 2024].

[42] Beard, R., Wentz, E. and Scotch, M., (2018). A Systematic Review of Spatial Decision Support Systems in Public Health Informatics Supporting the Identification of High-Risk Areas for Zoonotic Disease Outbreaks. *International Journal of Health Geographics*, Vol. 17(38). https://doi.org/10.1186/s12942-018-0157-5.

[43] Rabiei, R., Bastani, P., Ahmadi, H., Dehghan, S. and Almasi, S., (2024). Developing Public Health Surveillance Dashboards: A Scoping Review on the Design Principles. *BMC Public Health*, Vol. 24(392). https://doi.org/10.1186/s12889-024-17841-2.

[44] Mandyata, C. B., Olowski, L. K. and Mutale, W., (2017). Challenges of Implementing the Integrated Disease Surveillance and Response Strategy in Zambia: A Health Worker Perspective. *BMC Public Health*, Vol. 17(746). https://doi.org/10.1186/s12889-017-4791-9.

[45] Centers for Disease Control and Prevention (CDC), (2001). Updated guidelines for evaluating public health surveillance systems: Recommendations from the Guidelines Working Group. *Morbidity and Mortality Weekly Report (MMWR)*, Vol. 50(RR-13), 1-35. https://www.cdc.gov/mmwr/preview/mmwrhtml/rr5013a1.htm.

[46] Bouchard, C., Dumas, A., Baron, G., Bowser, N., Leighton, P., A., Lindsay, L., R, Milord, F., Ogden, N., H. and Aenishaenslin, C., (2023). Integrated Human Behavior and Tick Risk Maps to Prioritize Lyme Disease Interventions Using a 'One Health' Approach. *Ticks and Tick-borne Diseases*, Vol. 14(2). https://doi.org/10.1016/j.ttbdis.2022.102083.

[47] Bag, R., Ghosh, M., Biswas, B. and Chatterjee, M., (2020). Understanding the Apatio-Temporal Pattern of COVID-19 Outbreak in India Using GIS and India's Response in Managing the Pandemic. *Regional Science Policy & Practice*, Vol. 12(6), 1063-1104. https://doi.org/10.1111/rsp3.12359.

[48] Chen, L., Chen, T., Lan, T., Chen, C. and Pan, J., (2023). The Contributions of Population Distribution, Healthcare Resourcing, and Transportation Infrastructure to Spatial Accessibility of Health Care. *Inquiry*, Vol. 60, 1-16. https://doi.org/10.1177/00469580221146041.

[49] Luan, H. and Law, J., (2014). Web GIS-Based Public Health Surveillance Systems: A Systematic Review. *ISPRS International Journal of Geo-Information*, Vol. 3(2), 481-506. https://doi.org/10.3390/ijgi3020481.

[50] Fadiel, A., Eichenbaum, K. D., Abbasi, M., Lee, N., K. and Odunsi, K., (2024). Utilizing Geospatial Artificial Intelligence to Map Cancer Disparities Across Health Regions. *Scientific Reports*, Vol. 14. https://doi.org/10.1038/s41598-024-57604-y.

[51] Shabanpour, N., Razavi-Termeh, S. V., Sadeghi-Niaraki, A., Choi, S., M. and Abuhmed, T., (2022). Integration of Machine Learning Algorithms and GIS-Based Approaches to Cutaneous Leishmaniasis Prevalence Risk Mapping. *Observation and Geoinformation*, Vol. 112. https://doi.org/10.1016/j.jag.2022.102854.

[52] Mandadi, R., Tripathi, N., Pal, I., Mozumder, C. and Gonzales, A., (2023). Geostatistical Exploratory Analysis on Child Malnutrition and its Determinants in India. *International Journal of Geoinformatics*, Vol. 19(6), 77–90. https://doi.org/10.52939/ijg.v19i6.2699.

[53] Polin, S., Lokavee, S., Sukdee, S., Junpha, J., Harnwunggmoung, A., Samngamdee, M., Ampant, P., Thammaboribal, P. and Wongpituk, K., (2024). Assessment of COVID-19 Vaccination Services During the 5th Wave of the Outbreak in Thailand. *International Journal of Geoinformatics*, Vol. 20(3), 28–36. https://doi.org/10.52939/ijg.v20i3.3125.

[54] Choi, Y., (2023). GeoAI: Integration of Artificial Intelligence, Machine Learning, and Deep Learning with GIS. *Applied Sciences*, Vol. 13(6). https://doi.org/10.3390/app13063895.

[55] Olawade, D., B., Wada, O., J., David-Olawade, A., C., Kunonga, E., Abaire, O. and Ling, J., (2023). Using Artificial Intelligence to Improve Public Health: A Narrative Review. *Front Public Health*, Vol. 11. https://doi.org/10.3389/fpubh.2023.1196397.

[56] Geospatial World. (n.d.). GIS: A Tool for Monitoring and Management of Epidemics. Geospatial World. [Online]. Available: https://www.geospatialworld.net/article/gis-a-tool-for-monitoring-and-management-of-epidemics/. [Accessed: Sept. 19, 2024].

[57] Gao, S., Mioc, D., Anton, F., Yi, X. and Coleman, D. J., (2008). Online GIS Services for Mapping and Sharing Disease Information. *International Journal of Health Geographics*, Vol. 7(8). https://doi.org/10.1186/1476-072X-7-8.

[58] Liberatore, M. J. and Nydick, R. L., (2008). The Analytic Hierarchy Process in Medical and Health Care Decision Making: A Literature Review. *European Journal of Operational Research*, Vol. 189(1). https://doi.org/10.1016/j.ejor.2007.05.001.

[59] Schmidt, K., Aumann, I., Hollander, I., Damm, K. and Schulenburg, J. M. G., (2015). Applying the Analytic Hierarchy Process in Healthcare Research: A Systematic Literature Review and Evaluation of Reporting. *BMC Medical Informatics and Decision Making*, Vol. 15. https://doi.org/10.1186/s12911-015-0234-7.

[60] Mesgari, S. M. and Masoumi, Z., (2008). GIS Applications in Public Health as a Decision Making Support System and it's Limitation in Iran. *World Applied Sciences Journal*, Vol. 3(1), 73-77.

[61] Jia, P., Liu, S. and Yang, S., (2023). Innovations in Public Health Surveillance for Emerging Infections. *Annual Review of Public Health*, Vol. 44, 55-74. https://doi.org/10.1146/annurev-publhealth-051920-093141.

[62] Zhang, L., Guo, W. and Lv, C., (2024). Modern Technologies and Solutions to Enhance Surveillance and Response Systems for Emerging Zoonotic Diseases. *Science in One Health*, Vol. 2. https://doi.org/10.1016/j.soh.2023.100061.

[63] Homhuan, S., Suwanprasit, S., Namwong, C., Khamnoi, P., Boonma, R., Mate, T. and Wanginkhom, N., (2021). #Safe Mapping Platform: A GIS Mobile Crowd Sensing Platform for COVID-19 Self-Tracking and Self-Risk Managing. *International Journal of Geoinformatics*, Vol. 17(5), 55–60. https://doi.org/10.52939/ijg.v17i5.2009.

[64] Földváry, L., (2021). Geostatistical Investigations on the Spread of COVID-19. *International Journal of Geoinformatics*, Vol. 17(1), 75–84. https://doi.org/10.52939/ijg.v17i1.1713.

[65] Farhan Ul Moazzam, M., Paracha, T., Rahman, G., Lee, B. and Farid, N., (2021). Spatial and Temporal Mapping of COVID-19 Pandemic Using GIS Technique: A Case Study of Italy. *International Journal of Geoinformatics*, Vol. 17(5), 100–108. https://doi.org/10.52939/ijg.v17i5.2019.

[66] Kanav, A., Yadav, B., Sharma, R. and Kumar, J., (2024). Spatio-temporal Analysis of COVID-19 Hotspots in India Using Geographic Information Systems. *International Journal of Geoinformatics*, Vol. 20(1), 72–87. https://doi.org/10.52939/ijg.v20i1.3027.

[67] Yotha, N., Phimha, S., Prasit, N., Senahad, N., Sirikarn, P. and Nonthamat, A., (2023). Spatial Association Patterns with Cultural and Behaviour with the Situations of COVID-19. *International Journal of Geoinformatics*, Vol. 19(4), 51–63. https://doi.org/10.52939/ijg.v19i4.2637.

[68] Saran, S., Singh, P., Kumar, V. and Chauhan, P. (2020). Review of Geospatial Technology for Infectious Disease Surveillance: Use Case on COVID-19. *Journal of the Indian Society of Remote Sensing*. Vol. 48(8), 1121–1138. https://doi.org/10.1007/s12524-020-01140-5.

[69] Harris, D. R., (2023). Geographic Information Systems as Data Sharing Infrastructure for Clinical Data Warehouses. *Journal of the Society for Clinical Data Management*, Vol. 3(S1). https://doi.org/10.47912/jscdm.240.

[70] Mekruksavanich, S. and Jitpattanakul, A., (2021). Forecasting Mobility Trends in Southeast Asia during the Coronavirus (Covid-19) Pandemic by Machine Learning Approaches. *International Journal of Geoinformatics*, Vol. 17(5), 45–53. https://doi.org/10.52939/ijg.v17i5.2007.

[71] Brissette, I., Casper, M., Huston, S. L., Jordan, M., Karns, B., Kippes, C. and Vaughan, A. S., (2019). Application of Geographic Information Systems to Address Chronic Disease Priorities: Experiences in State and Local Health Departments. *Preventing Chronic Disease*, Vol. 16. https://doi.org/10.5888/pcd16.180674.

[72] Sharma, A. K., (2015). Role of GIS in Health Management Information System and Medical Plan: A Case Study of Gangtok Area, Sikkim, India. *International Journal of Environment and Geoinformatics*, Vol. 2(1), 16-24.

[73] Robin, T. A., Khan, M. A., Kabir, N., Rahaman, S. T., Karim, A., Mannan, I. I., George, J. and Rashid, I., (2019). Using Spatial Analysis and GIS to Improve Planning and Resource Allocation in a Rural District of Bangladesh. *BMJ Global Health*, Vol. 4. https://doi.org/10.1136/bmjgh-2018-000832.

[74] Siladlao, S., Rojanabenjakun, P., Songsin, N., Panrinsaen, R., Jummaree, T., Chusuton, S., Sawetsenee, K., Khonraengdee, P. and Mekwimon, W., (2024). Factors Related to Health Literacy in the Prevention of COVID-19 Disease in the Elderly in Lad Yai Subdistrict, Mueang District, and Samut Songkhram Province. *International Journal of Geoinformatics*, Vol. 20(3), 74–80. https://doi.org/10.52939/ijg.v20i3.3137.

[75] Klanreungsang, B. and Suppawimut, W., (2022). Bayesian Network Integration with GIS for the Analysis of Areas Vulnerable to the Outbreak of COVID-19 in Bangkok, Thailand. *International Journal of Geoinformatics*, Vol. 18(5), 53–69. https://doi.org/10.52939/ijg.v18i5.2373.

[76] Opiyo, S. O., Nalunkuma, R., Nanyonga, S. M. and Nathan, M., (2024). Empowering Global AMR Research Community: Interactive GIS Dashboards for AMR Data Analysis and Informed Decision-Making. *Wellcome Open Research*, Vol. 9. https://doi.org/10.12688/wellcomeopenres.21010.1.

[77] Han, X., (2020). On Statistical Measures for Data Quality Evaluation. *Journal of Geographic Information System*, Vol.12(3). https://doi.org/10.4236/jgis.2020.12301.

[78] Davenhall, W. F. and Kinabrew, C., (2012). GIS in Health and Human Services. *Springer Handbook of Geographic Information*, 557–578. https://doi.org/10.1007/978-3-540-72680-7_29.

[79] Ike, F. and Esther, N., (2022). Health-Care Facilities Accessibility Analysis Using GIS: A Case Study of Uyo Municipal South –Eastern Nigeria. *European Journal of Applied Sciences*, Vol. 10(1), 313–323. https://doi.org/10.14738/aivp.101.11621.

[80] Haddad, L. M. and Geiger, R. A., (2024). Nursing Ethical Considerations. *StatPearls Publishing*. [Online]. Available: https://www.ncbi.nlm.nih.gov/books/NBK526054/. [Accessed: Sept., 25, 2024].

[81] Lu, X., (2005). A Framework of Web GIS Based Unified Public Health Information Visualization Platform. Computational Science and Its Applications. *ICCSA 2005: International Conference, Singapore, May 9-*

12, 2005, Proceedings, Part III, 3482, 256–265. https://doi.org/10.1007/11424857_28.

[82] Suherningtyas, I., Pitoyo, A. and Widayani, P., (2024). Spatial Analysis of the Economic Resilience Index during COVID-19 in the Marginal Land of the Gunungsewu Karst Area, Gunungkidul, Indonesia. *International Journal of Geoinformatics*, Vol. 20(8), 72–87. https://doi.org/10.52939/ijg.v20i8.3457.

[83] Laosupap, K., Boonsang, A., Butsorn, A., Tubtimhin, S., Semrum, W., Kamuttachat, K., Chaaumphan, A. and Wongpituk, K., (2024). Development of Systems and Mechanisms for Managing the Coronavirus Disease 2019 Crisis in Det Udom District, Ubon Ratchathani Province, Thailand. *International Journal of Geoinformatics*, Vol. 20(3), 81-85. https://doi.org/10.52939/ijg.v20i3.3139.

[84] Wongpituk, K., Tanthanapanyakorn, P., Sanguanchue, A., Saykaew, T. and Chankong, W., (2021). Perception of Risk, Severity of Disease and Preventive Behaviors of COVID-19 in a New Epidemic Situation among People in Samut Songkhram Province, Thailand. *International Journal of Geoinformatics*, Vol. 17(5), 90-92. https://doi.org/10.52939/ijg.v17i5.2017.

[85] Tanthanapanyakorn, P., Sanguanchue, A., Khuntikulanon, N., Chanmalee, S. and Cetthakrikul, S., (2021). Effectiveness of the Self-Care Sandbag Exercise Program for the Osteoarthritis of Knee Patients in the Secondary Care in Thailand: Randomized Control Trial. *International Journal of Geoinformatics*, Vol. 17(5), 195-198. https://doi.org/10.52939/ijg.v17i5.2051.