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Review Article

Geographic information systems applications in India's public health-are we moving towards the right direction?

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ABSTRACT

Governments worldwide focus particularly on digital healthcare sensors for leveraging data and technology like Geographic Information Systems (GIS) to improve governance and service delivery. Geoinformatics technology can help with epidemiological research and outbreak response, minimizing the health consequences in communities beforehand, during, and then after epidemic episodes. We can all agree that location and time play a crucial role in carrying out an efficient public health response. Since location information is essential for every stage of planning, response, and recovery, GIS helps the location-based support of public health preparedness programmes like support for decisions, resource allocation, communication and collaboration, and civic participation. GIS scales to situations ranging from adverse weather to pandemics. Public health professionals can coordinate their efforts with those of other organizations and external stakeholders due to maps and apps. The public health preparedness community may achieve significant strides by incorporating GIS data, models, communication and engagement centres, and location-centric apps. GIS technology can help with this efficient method for gathering data, performing analysis, where they are most needed, interacting with decision-makers, and finally achieving health equity can be created with the aid of a location-based strategy. During COVID-19, this reality was disseminated more extensively through the news media and the national, state, and local governments. This paper evaluates the application of GIS in the Indian public health system and the various aspects of public health where GIS may emerge as a game-changer for future policy decisions.

Keywords: Geographic information system, Public health, Risk mapping

INTRODUCTION

The cornerstone of health system planning is defining the location of health services in relation to the communities they are intended to serve, ensuring that the appropriate services are accessible to the population and that no one is geographically deprived of essential services. However, in its most fundamental meaning, access to health care refers to geographic accessibility.[1] Healthcare is a complicated and multidimensional concept with many differing ideas.[2] A basic understanding of the location of service providers in relation to populations is required for improved data metrics on health access.[3] In the 1970s and earlier, provider-to-population ratios were used to estimate availability. Later, with the development of geographic information system (GIS) in the 1980s and 1990s, distance as a metric emerged.[4,5] More recent methods include network analyses, floating catchment area methods, and cost-distance analyses.[6,7] Estimating precise access to emergency treatment and procedures is now possible by identifying top-tier hospitals and lower-tier facilities. Other additions include applications for defining access to Basic emergency Obstetric Care/ Emergency Obstetric and Newborn Care (BEmOC/EmONC) services, assessing the implementation of public health sector services, and community-based interventions.[1]

GIS are computer-based applications that integrate and map geographic data for the study observations with clear spatial locations.[8] A GIS may map any phenomenon that can be linked to its precise position on the surface of the earth.[2] Compared to statistics tables that contain the same information, maps can convey a lot of information in a way that is simpler to understand. GIS facilitates analyzing spatial and temporal trends, determining the geographic distribution of diseases, mapping at-risk populations identifying risk factors, evaluating the use of resources, planning and directing interventions, and monitoring of diseases and interventions throughout time.[7,9,10] The purpose of this study is to explore the numerous areas of healthcare where GIS can be applied and to predict features that will improve the country's healthcare system.

USES OF GIS IN PUBLIC HEALTH STUDIES

GIS is used in public health for a wide range of purposes, such as identifying hotspots for a particular disease, pinpointing vulnerable populations, identifying the causes of diseases, tracking disease incidences, pinpointing medical facilities, calculating mortality and morbidity rates, locating water pollution sources, mapping disease zones, and planning and implementing corrective actions.[11,12] GIS makes health mapping and analysis more rapid and precise than conventional methods. Large amounts of data are quickly and easily accessible to health professionals. For tracking and managing epidemics, it provides a variety of dynamic analysis tools and visual analytics.[13,14] Figure 1 illustrates a number of studies that have been published in the past 12 years that were carried out in the field of public health in India utilizing GIS technology.

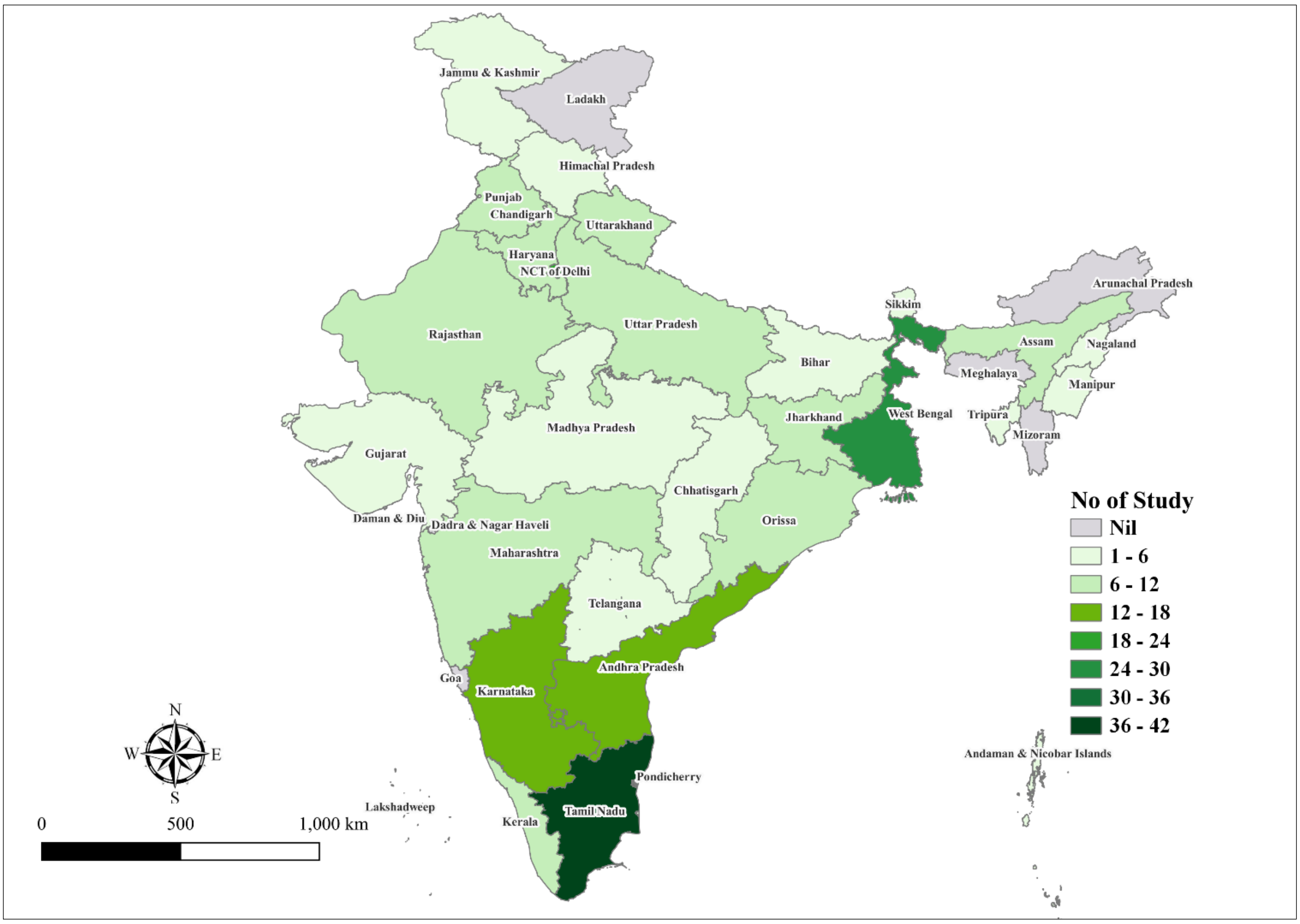

Figure 1: GIS and public health studies in India (2010-2022).

HISTORY OF GIS

GIS is a computer-based tool that analyses spatial relationships, patterns, and trends in geography, data for geographic positions on the surface of the Earth is stored, analyzed, and visualized using GIS. It has transformed over the past 50 years from an idea to a study field. A number of significant pivotal moments helped GIS transform from a rudimentary tool to a cutting-edge, powerful platform for comprehending and organizing our world.

John Snow's cholera outbreak map in 1854, in the city of London was a significant development that linked geography and public health safety. This marked the beginning of not only spatial analysis but also of an entire field of research called epidemiology, which is the study of the transmission of disease. This is John Snow's cholera map, which he created using paper maps and spatial analysis to bring an end to the outbreak in London, England.[15] Prior to 1960, transparent layers on light tables were employed in sieve mapping to find overlapped areas.[16] However, there were difficulties with this: calculating areas was practically impossible, data was sparse and frequently inaccurate, and measuring distances was time-consuming. This was historically the primary driver of the switch from paper to computer mapping.

Roger Tomlinson created, designed, and led the construction of the Canadian Geographic System (CGIS) while working for the Canadian government in the 1960s. Because many people view CGIS as the foundation of GIS, this was a significant period in the development of GIS. The soil, drainage, and climate characteristics were utilized by the Canadian land inventory to assess the land's suitability for different crop varieties and forested areas. It realized straight away the importance of precise and relevant data for land planning and decision-making.[17] GIS pioneering - The US Census Bureau was a pioneer in adopting some of the fundamental concepts of GIS. Its efforts resulted in the digital input of the 1970 census utilizing the GBF-DIME data format (Geographic Base File – Dual Independent Map Encoding).[18] This format was used by the US Census Bureau to start digitizing urban areas and census borders. The UK's ordnance survey also began creating its standard topographic maps. Every house, every fence, and every stream in every region of Great Britain are among the several GIS data packages that the ordnance survey continues to produce to this day.

The initial vector GIS, termed ODYSSEY GIS, was created by the Harvard Laboratory for Computer Graphics. Esri's ARC/INFO utilized the ODYSSEY GIS technical framework, and this effort paved the way for the commercialization of GIS software, the following stage of development.[19] Memory capacity and graphical capabilities were expanding in the late 1970s. Geographic Information Making And Management Systems (GIMMS), MAPICS, SURFACE, GRID, IMGRID, GEOMAP, and MAP were among the new computer cartography products. In this period of GIS history, there were an expanding number of GIS software vendors in the late 1980s. Esri, the current world's leading provider of GIS software, has introduced ARC/INFO for minicomputers in 1982. Then, for the Intel microcomputer, it published PC ARC/INFO in 1986. Esri has contributed significantly to the development of GIS software and is currently regarded as the world's foremost expert in this field. Decision-makers were gradually learning to understand the value of spatial analysis. GIS was gradually introduced in a variety of industries. The software can handle both vector and raster data. GIS systems can use this data that is gathered from space if there are more satellites in orbit. GIS data is becoming more widely available. Free downloads are available for TIGER data, Landsat satellite imagery, and even LiDAR data. Huge quantities of spatial data are stored in online repositories like ArcGIS online.[20] It comes down to quality control and customizing it to meet your demands. Today, open source is gaining popularity. A new era of open-source GIS software is slowly emerging. QGIS is getting lighter than ever before.[21] However, there will always be a need for highly specialized GIS software. Almost any spatial issue that exists today can be solved by software companies like Esri.

Map densities

Patterns and clusters of diseases maps were created showing the spatial distribution of incidence and burden across two time periods. For many years, efforts in spatial epidemiology focused on developing tools, such as point pattern analysis or space-time scan statistics, for detecting significant disease clustering in time and space.[22]

Hotspot locations are frequently considered to be high-risk zones and priority locations for epidemic control intervention activities. The study's inclusion of the viewpoint of individual-level transmission potential contributes to disease risk mapping.[23] When intervention resources are focused on epidemic clusters, it is easy to overlook the fact that people with high transmission potential are frequently found on the outskirts of rising illness clusters.

MAP PATTERNS

Employed spatial techniques to help establish the presence of an outbreak. Through formal statistical tests of clustering or visual analysis, techniques were utilized to find uncommon patterns of cases. to explain the nature of the outbreak and to formulate a theory, Fitzpatrick and colleagues presented the use of dot mapping to support an epidemic in real time while looking into an increase in measles cases in Dublin, Ireland.[24] They were able to spot case clustering as it emerged by constantly updating their maps throughout the break, which ultimately helped them target control strategies.

In actuality, people might be exposed to infectious agents wherever they go, and conventional census denominators that capture populations at night aren't always representative of population distributions during the day. Studies made an effort to track case movements, none took into consideration population shifts during the day. To increase the accuracy of estimations of spatial risk, this geographical uncertainty should ideally be taken into account during the data collecting, processing, and visualization stages. To do this, new analytical techniques may be needed.[22]

MAP PREDICTION

A set of guidelines known as a "spatial weighting function" is useful for assessing the correlation variables since it assigns values or "weights" to each pair of places within a study region. Using certain new neighbour patterns based on spatial weighting functions, the model may tightly associate cells with geographical phenomena. Thus, it is easier and more direct to incorporate features relating to a particular location, such as different attributes for different geographic regions and spatial weighting functions.[23]

DECISION SUPPORT SYSTEMS

The Athiyannur Sree Chitra (ASA) initiative, based in Kerala, makes use of female health workers to pinpoint the epicenter of disease transmission, the direction and scale of disease transmission, and—most importantly—it pertains geospatial epidemiological analysis of variables like proximity, similarity, geometry, and cognition to accurately identify the incidence of disease as well as ecological and socioeconomic factors. In addition to mapping the geographic distribution of disease prevalence, it was used for disease surveillance, epidemiological investigation, health monitoring, ongoing disease control programmes, intervention measures, health information systems, site selection of health services, and providing a datum of guidelines for decision-making toward the achievement of filariasis health-care management in India.[25] Simulations can be used to alter the availability of the resources in order to examine the consequences on public health by expanding the capacity of local healthcare services. The number of deaths during a pandemic may be successfully reduced by adding more hospital beds or mechanical ventilators, for example, when governments are thinking about resource prioritization, prospective investments, or resource re-allocation between regions. This analysis could aid in guiding these decisions if there is sufficient information on resource efficacy. The production of graphical maps that indicate where resource shortages and surpluses are concentrated throughout districts and provinces is made possible by the data's simple exportation to GIS software. Using this data, as well as simulated exercises, plans can be created at the municipal, state, and federal levels. In general, the technology may assist decision-makers in better understanding and awareness of increases in resource demand during pandemics. The model can support decision-making for the prevention and control of infectious illnesses by visualizing and analyzing efforts of various sorts of interventions.

MODERN HEALTH SYSTEM AND GIS

The aim of current healthcare planners is to develop health programmes and regulations that take socioeconomic and geographic health inequities into account. In order to analyze geographical dimensions of health policy and practice and evaluate geographic equity (or inequity) in the provision of health services, they should make use of evidence-based methods. Sentinel cases can be found using spatial grids, and outbreak boundaries can be determined. By combining POCT with GIS and ring vaccination, it will be possible to promptly detect sentinel cases, follow them spatially, and contain outbreaks.[26]

Community profiling

It shows that in order to identify and screen persons who are at mental health risk due to geographic distance, psychiatrists and public health professionals should take precautions when applying either hypothesis alone.[27] Community networks can be represented using GIS to assist public health nurses in developing and implementing population-based treatments at the local level, either individually or in transdisciplinary groups.[28]

Healthcare access and planning

Studies showed GIS to look into illness patterns spatiotemporal variations in health outcomes, and possible causes for mapped trends (e.g., the relationship between cancer incidence and various environmental factors). These often include combining health information with socioeconomic and environmental data. GIS can be used to target resources for disease prevention by emphasizing areas with noticeably high rates. It can also be used to forecast which regions may be at future risk and which may benefit most from local population screening in the future.[29]

GIS would introduce a spatial analysis tool for interactive mapping, allowing the relevant agencies to redistrict and relocate health jurisdictions for efficient use of the healthcare infrastructure There wasn't a system in place to generate suggestions automatically at the district level and review them at the state level.[30]

The traditional approach is expensive and time-consuming, and it cannot manage PHC centres dynamically. The outcome demonstrated that health decision-makers and planners can use ongoing advancements in fields of knowledge like remote sensing, GIS, and computer science to research, monitor, map, plan, and follow up on supply and demand in PHCCs to manage various HC facilities in accordance with Ministry of Health and Population (MoHP) standards. The study discovered that because of the rapid population growth, the population is regarded as an active criterion. Theoretically, PHC facilities cover the covered region, however by the standards of the Egyptian MOHP, they do not cover the serviced population. In addition, the study looked at how many alternative public and private health services were utilized by certain patients instead of PHC facilities.

Diseases surveillance

This study may help educate people about the risk factors for malaria and helping to concentrate control efforts solely on susceptible populations, allowing for the best possible use of the available resources—which is crucial for developing nations with weak socioeconomic indicators. Malaria mapping makes it simple to update data and easily accessible for decision-makers to create cost-effective malaria management strategies in endemic areas. The successful implementation of such control measures largely depends on the accurate localization and spatial mapping of malarial hotspots. Malaria risk maps are a useful resource for bringing up focused, effective control strategies with government officials. GIS makes it possible to produce updated maps as soon as new data becomes available. A focus area for malaria monitoring and surveillance could be GIS mapping.[31,32] A databank of malaria incidence, demographics, socioeconomic status, and access to medical services should be established for the nation's malaria-endemic regions. These elements can be included in a malaria database to help pinpoint areas where resources can be used most effectively for effective malaria control.

Risk mapping and predictions

GIS has expanded the number and variety of technologies available for use in the epidemic analysis. The analysis of infectious disease outbreaks necessitates the synthesis of knowledge and experience from a variety of domains. Simple maps alone can reveal important insights about the distribution of cases, which is only one of the many beneficial contributions that spatial studies can make. However, improvements in GIS technology and the availability of high-quality spatial data are creating a chance for the creation and use of increasingly advanced tools. Infectious disease outbreaks could have less of an adverse influence on public health if these novel techniques were adopted and old strategies were used more widely.[33]

Better neighbourhood planning

An address is the most widely used type of georeferencing when describing a location inside a city to others. When urban GIS applications receive data directly from inhabitants or via outdated information systems, they must be able to swiftly and accurately derive a spatial position from addresses.[34] In this essay, we use a broad definition of addresses that includes not only the conventional elements of postal addresses but also additional direct or indirect contacts to locations, such as building names, postal codes, or phone area codes, which are equally helpful for locating urban locations. The most popular method of connecting information in a spatial database to information gathered for other purposes, such as health, safety, and taxation, is through street addresses. Addresses are another crucial link to older systems that have vital data for both updated and historical uses. According to estimates, addresses are connected to 80% of the data utilized in local governments. A crucial component of a successful urban GIS project is the creation and maintenance of an address base. We developed the geocoding certainty indicator as a result of the address geocoding process (GCI). Four particular goals were established to test whether community networks can be visualized using GIS to create community-level interventions to help prevent low birth weight (LBW) newborns.[35]

Crisis management (outbreak/pandemic situations)

The characteristics and spatial-temporal distribution of human H7N9 cases, show that the strongest cluster was in Shanghai and Zhejiang provinces from March 2013 to April 2013 and that these two regions have not had a major cluster since that time throughout the whole study period. In addition, a rather small cluster near Guangzhou and Shenzhen occurs in February 2014.[36] This shows that disease prevention measures may have successfully stopped the H7N9 virus from spreading. Point-of-care technology has advanced well beyond mobile diagnostics to become a way to optimize preparedness, emergency management, and outbreak control in terms of both space and time. During emergencies, disasters, and outbreaks, using GISs to deploy POCT close to where patients live and work makes triage and quick therapeutic turnaround times possible.[37] They can speed up urgent primary care and help access-required isolated population clusters. By categorizing several spreader types, we significantly improve our understanding of outbreak expansion in this study. When an outbreak is in its exponential growth phase, early spreaders with high transmission potential may start additional sources of infection towards the borders of the primary cluster, leading to geographic extension. To restrict the outbreak in terms of both range and magnitude, spatial targeting should therefore prioritize the outbreak's edge. It is still crucial to count successful spreaders when calculating morbidity and mortality. However, due to the great density of their clustering, they are more vulnerable to the dwindling of nearby susceptible populations and declining transmission potential. The core of contemporary GIS technologies is the use of web-based tools, enhanced data sharing, and real-time data to support important decision-making. Dashboards are a great example of these ideas and have become quite popular for communicating and comprehending the SARS-CoV-2 coronavirus's spread.[38] People all over the world who want to safeguard themselves and their communities can communicate using map-based dashboards to access information. This kind of tool facilitates information dissemination for authorities and increases data transparency.

RESOURCES OF GIS

It is admirable that Google and MSN, or Microsoft Network, are disseminating "free" geospatial tools, imagery, maps, and eventually analysis skills through a worldwide distribution network.[39] Building on the potent and universal visual language of geography, they were successful in making their adaptable, multipurpose maps and imagery of the globe recognizable and approachable to millions of regular Internet users throughout the world from outside the domain of highly specialized geosciences.

Now accessible on Indian Cloud is Indo ArcGIS, the most reputable GIS platform in India. Cloud Infrastructure, Esri India's GIS Infrastructure Managed Services, and ArcGIS Software (Enterprise, Pro, and Extensions).[40] Utilization will increase at a cheaper total cost of ownership which is deployed and managed by Esri India professionals. With a more dependable, secure, flexible, and affordable Cloud Infrastructure for GIS applications, it provides ready-to-use solution products, base maps, and datasets.

The Director General of Health Service (DGHS), Ministry of Health and Family Welfare, Remote Sensing Center, and Indian Space Research Organization (ISRO) launched the Bhuvan National Health Resource Repository (NHRR) in 2017 after realizing the need for timely and accurate health resource data from both the public and private sectors.[41] By building a solid, consistent, and secure IT-enabled repository of India's healthcare resources, we can increase evidence-based decision-making and create a platform for citizen- and provider-centric services.

The Ayushman Bharat Digital Mission, the National Health Authority's flagship programme, has announced the expansion of the digital health ecosystem with the successful integration of 52 digital health applications (ABDM). A total of 12 additional health services are offered, including the Hospital Management Information System (HMIS) for the Central Government Hospital Scheme (CGHS), the Hospital Management System by NICE-HMS, the Equal app by Infinity Identity Technologies Pvt Ltd, the IHX Claim Management Platform by IHX, the Karkinos Application Suite by Karkinos Healthcare Private Limited, the Meraadhikar app by Fingoole Technologies Pvt Ltd, the Paperplane WhatsApp Clinic by Paperplane Communications Pvt Ltd, nPe Bills and Services app by NICT and HISP-EMR by Society for Health Information System Program (HISP).[42]

Some well-known government solutions are eSanjeevani AB-HWC by C-DAC Mohali, UK Telemedicine Service for Uttarakhand Government by Dhanush Infotech Pvt Ltd, and Anmol Application of the National Health Mission by National Informatics Center (NIC). The ABDM sandbox environment's applications just completed integrating across several milestones. There are now 20 applications from the government and 32 from the private sector.[42]

BARRIERS TO USING GIS IN HEALTH SYSTEMS

There are still many instances when these worries are valid and where it is necessary to protect data subjects (e.g., from identity theft). Study assert that any study utilizing secondary data sources must address the moral issues brought on by the conflict between upholding individual privacy and satisfying society's information demands.[43] Most programmes utilizing earlier databases posed little danger of harm owing to individual identification or treatment. Not so with GIS-based investigations. By mapping specific places to individual case information, GIS can be used to identify people.

While most administrators of huge databases and census data have tight guidelines on the level of geography at which they will distribute information, rules differ between states, localities, and organizations. Maintaining privacy is one of the biggest issues in health mapping because GIS may be connected to constructing profiles.[8]

SUMMARY

In recent times healthcare sector starting to appreciate the enormous potential of GIS. Innovative strategies are being developed by the public and corporate sectors to utilize the data integration and spatial visualization capabilities of GIS. It is a potent tool that has been effectively used to solve several important health challenges, from improved services to disease management. The number of benefits is anticipated to keep growing as more healthcare professionals adopt and incorporate the programme, including the connectivity between hospitals and the communities they serve, which is maybe the most crucial connection to be created. The integration of GIS and Global Positioning System (GPS) improves the accuracy of spatial and non-spatial data for analysis and decision-making by providing an integrated strategy for disease prevention and monitoring at local, regional, and national levels. A major investment in preparation, risk mitigation, prevention and control, as well as rapid financial support, are necessary for effective responsiveness. In this context, GIS can be a vital tool for successful early planning in terms of health education, warning and evacuation, provision of emergency medical treatment, and protection of infrastructure.

CONCLUSION

To achieve the objective of Universal health coverage focusing on four conditions must be met: availability, access, quality and utilization. The GIS-based solution is especially useful in this situation since it can measure accessibility to PHCs, hospitals, and other medical facilities. It can do this by mapping out each healthcare provider's point data and its distance from the district's residents. To protect data privacy, appropriate anonymization techniques must be used to aggregate the data, revealing details on its usage and quality. The use of GIS in combination with anonymized and aggregated personal health records could be very effective. It can be concluded that the role of GIS will be more significant in the increasingly information-intensive environment of future health care because of its capabilities to integrate various data sources, from legacy systems to picture data and make complex data more promptly and easily comprehended.

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REFERENCES

1. Maina J, Ouma PO, Macharia PM, Alegana VA, Mitto B, Fall IS, et al. A spatial database of health facilities managed by the public health sector in sub Saharan Africa. Sci Data. 2019;6(1):134.
2. Mansour S. Spatial analysis of public health facilities in Riyadh Governorate, Saudi Arabia: A GIS-based study to assess geographic variations of service provision and accessibility. Geo-spatial Inf Sci. 2016;19:26-38.
3. Comber AJ, Brunsdon C, Radburn R. A spatial analysis of variations in health access: linking geography, socio-economic status and access perceptions. Int J Health Geogr. 2011;10:1-11.
4. Caley LM. Using geographic information systems to design population-based interventions. Public Health Nurs. 2004;21:547-54.
5. Delamater PL, Messina JP, Shortridge AM, Grady SC. Measuring geographic access to health care: raster and network-based methods. Int J Health Geogr. 2012;11:1-18.
6. Vadrevu L, Kanjilal B. Measuring spatial equity and access to maternal health services using enhanced two step floating catchment area method (E2SFCA)– a case study of the Indian Sundarbans. Int J Equity Health. 2016;15:1-12.
7. Weiss DJ, Lucas TCD, Nguyen M, Nandi AK, Bisanzio D, Battle KE, et al. Mapping the global prevalence, incidence, and mortality of Plasmodium falciparum, 2000-17: a spatial and temporal modelling study. Lancet. 2019;394(10195):322-31.
8. Cromley EK, McLafferty SL. GIS and public health. Guilford Press. 2011.
9. Ouma P, Macharia PM, Okiro E, Alegana V. Methods of measuring spatial accessibility to health care in Uganda. In: Practicing Health Geography. Springer. 2021;77-90.
10. Al-Kindi KM, Alkharusi A, Alshukaili D, Al Nasiri N, Al-Awadhi T, Charabi Y, El Kenawy AM. Spatiotemporal Assessment of COVID-19 Spread over Oman Using GIS Techniques. Earth Syst Environ. 2020;4(4):797-811.
11. Qayum A, Arya R, Kumar P, Lynn AM. Socio-economic, epidemiological and geographic features based on GIS-integrated mapping to identify malarial hotspots. Malar J. 2015;14:1-20.
12. Cordes J, Castro MC. Spatial analysis of COVID-19 clusters and contextual factors in New York City. Spat Spatiotemporal Epidemiol. 2020;34:100355.
13. Zipf L, Primack RB, Rothendler M. Citizen scientists and university students monitor noise pollution in cities and protected areas with smartphones. PLoS One. 2020;15:e0236785.
14. Saran S, Singh P, Kumar V, Chauhan P. Review of geospatial technology for infectious disease surveillance: use case on COVID-19. J Indian Soc Remote Sens. 2020;48:1121-38.
15. Snow J. On the mode of communication of cholera. Edinb Med J. 1856;1:668.
16. Carver SJ. Integrating multi-criteria evaluation with geographical information systems. Int J Geogr Inf Syst. 1991;5:321-39.
17. Tomlinson RF. The impact of the transition from analogue to digital cartographic representation. Am Cartogr. 1988;15:249-62.
18. Marx RW. The TIGER system: automating the geographic structure of the United States census. Gov Publ Rev. 1986;13:181-201.
19. Ali E. Geographic Information System (GIS): Definition, Development, Applications & Components. Dep Geogr Ananda Chandra Coll India. 2020.
20. Johnston K, Ver Hoef JM, Krivoruchko K, Lucas N. Using ArcGIS geostatistical analyst. Esri Redlands. 2001.
21. Steiniger S, Bocher E. An overview on current free and open source desktop GIS developments. Int J Geogr Inf Sci. 2009;23:1345-70.
22. Pfeiffer DU, Robinson TP, Stevenson M, Stevens KB, Rogers DJ, Clements ACA. Spatial analysis in epidemiology. OUP Oxford. 2008.
23. Ng T-C, Wen T-H. Spatially adjusted time-varying reproductive numbers: understanding the geographical expansion of urban dengue outbreaks. Sci Rep. 2019;9:1-12.
24. Fitzpatrick G, Ward M, Ennis O, Johnson H, Cotter S, Carr MJ, O Riordan B, Waters A, Hassan J, Connell J, Hall W, Clarke A, Murphy H, Fitzgerald M. Use of a geographic information system to map cases of measles in real-time during an outbreak in Dublin, Ireland, 2011. Euro Surveill. 2012;17(49):20330.
25. Soman B. Participatory GIS in action, a public health initiative from Kerala, India. Int Arch Photogramm Remote Sens Spat Inf Sci. 2014;40:233.
26. Padilla CM, Kihal-Talantikit W, Perez S, Deguen S. Use of geographic indicators of healthcare, environment and socioeconomic factors to characterize environmental health disparities. Environ Heal. 2016;15:1-11.
27. Solomou I, Constantinidou F. Prevalence and predictors of anxiety and depression symptoms during the COVID-19 pandemic and compliance with precautionary measures: age and sex matter. Int J Environ Res Public Health. 2020;17:4924.
28. Zha P. Social epidemiology. In: Social pathways to health vulnerability. Springer. 2019;159-80.
29. Musa GJ, Chiang PH, Sylk T, Bavley R, Keating W, Lakew B, Tsou HC, Hoven CW. Use of GIS Mapping as a Public Health Tool-From Cholera to Cancer. Health Serv Insights. 2013;6:111-6.
30. Patel M, Patel M. An integrated GIS/GPS based e-governance approach for different agencies to fight against COVID-19. In: Understanding COVID-19: The Role of Computational Intelligence. Springer. 2022;447-69.
31. Ceccato P, Connor SJ, Jeanne I, Thomson MC. Application of geographical information systems and remote sensing technologies for assessing and

monitoring malaria risk. Parassitologia. 2005;47:81-96.
32. Ahmad F, Goparaju L, Qayum A. Studying malaria epidemic for vulnerability zones: Multi-criteria approach of geospatial tools. J Geosci Environ Prot. 2017;5:30-53.
33. Carroll LN, Au AP, Detwiler LT, Fu T, Painter IS, Abernethy NF. Visualization and analytics tools for infectious disease epidemiology: a systematic review. J Biomed Inform. 2014;51:287-98.
34. Pedro J, Silva C, Pinheiro MD. Integrating GIS spatial dimension into BREEAM communities sustainability assessment to support urban planning policies, Lisbon case study. Land use policy. 2019;83:424-34.
35. Harvey EM, Strobino D, Sherrod L, et al. Community-academic partnership to investigate low birth weight deliveries and improve maternal and infant outcomes at a Baltimore city hospital. Matern Child Health J. 2017;21:260-6.
36. Zhang Y, Shen Z, Ma C, et al. Cluster of human infections with avian influenza A (H7N9) cases: a temporal and spatial analysis. Int J Environ Res Public Health. 2015;12:816-28.
37. Kost GJ. Geospatial science and point-of-care testing: creating solutions for population access, emergencies, outbreaks, and disasters. Front Public Heal. 2019;7:329.
38. Kamel Boulos MN, Geraghty EM. 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. Int J Health Geogr. 2020;19:1-12.
39. Forsberg EM, Huan T, Rinehart D, et al. Data processing, multi-omic pathway mapping, and metabolite activity analysis using XCMS Online. Nat Protoc. 2018;13:633-51.
40. Indo ArcGIS Cloud and Managed Services | Esri India. Available at: https://www.esri.in/en-in/products/indo-arcgis/cloud-and-managed-services. Accessed on 28 November 2022.
41. Bhuvan-NHRR (National Health Resource Repository): HealthGIS. Available at: https://bhuvan-nhrr.nrsc.gov.in/nhrr/. Accessed on 28 November 2022.
42. NHA | Official website Ayushman Bharat Digital Mission. Available at: https://abdm.gov.in/press-releases. Accessed on 28 November 2022.
43. Huston P, Naylor CD. Health services research: reporting on studies using secondary data sources. C Can Med Assoc J. 1996;155:1697.

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