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Geospatial Health: achievements, innovations, priorities

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An expert panel discussion on achievements, current areas of rapid scientific progress, prospects, and critical gaps in geospatial health was organized as part of the 16th symposium of the global network of public health and earth scientists dedicated to the development of geospatial health (GnosisGIS), held at the Faculty of Geo-Information Science and Earth Observation (ITC) of the University of Twente in The Netherlands in November 2023. The symposium consisted of a three-day scientific event that brought together an interdisciplinary group of researchers and health professionals from across the globe. The aim of the panel session was threefold: firstly, to reflect on the main achievements of the scientific discipline of geospatial health in the past decade; secondly, to identify key innovation areas where rapid scientific progress is currently made and thirdly, to identify critical gaps and associated research and education priorities to move the discipline forward.

A group of internationally recognized scientists with different disciplinary backgrounds, each with a unique perspective (veterinary health, emergency preparedness and response, social sciences and wellbeing, Geographical Information Systems (GIS) methodologies, training and education), participated in the discussion that was guided by two moderators. The discussion results were analysed using the preparatory notes provided by the panellists and the transcript of the session video recordings. To capture the responses per topic and panellist, responses were first structured into a matrix and subsequently interactively synthesized involving all panellists. Below, we report our main findings.

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Key words: Geospatial Health; expert panel discussion; GnosisGIS.

Received: 16 October 2024.
Accepted: 16 October 2024.

Geospatial Health 2024; 19:1355
doi:10.4081/gh.2024.1355

Achievements

Geospatial health has actively embraced the opportunities of an increasingly enabling technological landscape. We have witnessed an exponential increase of well-documented and mostly open (global) datasets in a wide variety of formats. Examples include big data, small data, volunteered geographic information, Earth Observation (EO) data, mobile phone records, Global Positioning System (GPS) and other geo-sensor data. We have also seen the emergence of geospatial data sharing platforms and operational surveillance systems to store, curate, disseminate and communicate health(-related) data and information with stakeholders. These datasets, produced by authoritative and non-authoritative sources, support longitudinal studies. Meanwhile, geospatial methods, techniques and tools have improved, existing techniques matured (e.g., geographic accessibility modelling, geostatistical modelling) and many new techniques, such as multicriteria spatial risk assessments emerged. Data-driven approaches are gaining traction, in part due to the increased data availability but also due to advances in Artificial Intelligence (AI), and Machine Learning (ML). We have also benefitted from better computers (computing power, cloud and distributed computing, storage capacity) and better geospatial software (easier user interface, extended analytical functionality, open source).

Geospatial health is a more consolidated scientific discipline now than it was 10 years ago. It is a larger discipline in terms of topics, data and tools, researchers, practitioners, policymakers and available funding. It encompasses human, animal and environmental health recognizing that these are closely connected. Health and GIS specialists are still developing a common language but can already understand each other (much) better than before, while public health specialists are more familiar with geospatial data sources and data analysis approaches. Geospatial specialists are becoming increasingly interested in public health and epidemiological studies. Moving from an initial focus on infectious, water-borne and vector-borne diseases, the discipline now covers a wider array of health topics, such as lifestyle, health promotion, mental health, well-being and non-communicable diseases, as well as health systems and policy. The discipline has also shifted from basic reporting and mapping to understanding more complex pathogen-host-environment interactions including forecasting, even prevention, of health risks. Given its interdisciplinary and solution-oriented nature, geospatial health aligns well with current global health perspectives, such as *One Health* and *Planetary Health*.

Innovations

Rapid technological progress in air- and space-borne remote sensing continues to lead to more (spectrally) diverse and higher-resolution data. Although at a different spatial scale, AI-supported medical imaging and ML methods increasingly support diagnostics and detect health problems at the early stage. Other novel data sources such as crowd-sourced observations, social media, and mobile phone collected data (including mobility data) are increasingly used. We also observe the proliferation of affordable geo-sensors for monitoring biological, chemical and environmental properties. Data acquisition and (pre)processing are increasingly done via networked micro-sensors that are distributed in space; recorded data are transferred to processing and dissemination servers in real-time. Accompanying the geo-data revolution, we observe an expansion of data repositories and platforms (e.g., Global Health Observatory, World Health Integrated Data Platform) that follow findable, accessible, interoperable, reusable (FAIR) principles, while open-access publishing make data retrieval easier than before. Still, integrating the large diversity of data sources remains a challenge.

Next to data, there is an increasing refinement of modelling tools and spatial analysis techniques to study spatio-temporal patterns that improve health risk assessment and forecasts. Innovative modelling approaches are often based on AI and ML (including Deep Learning) methods that can learn and adapt without following explicit instructions. AI and ML methods make it feasible to sift through large datasets more efficiently and to detect subtle spatio-temporal patterns. We expect that this will lead to more sophisticated modelling approaches capable of representing real-world complexity. Still, ML algorithms are not "spatially aware", which means that more research is needed to resolve this shortcoming.

Besides new methods, we see a shift from response to anticipatory action. Research involving geospatial health has become increasingly efficient in designing studies that move away from purely reporting where things are happening, to approaches that can help us understand why things happen and delivering actionable information that can support policy makers and public health practitioners. Usually, response interventions are launched once the national health authorities officially declare an outbreak or epidemic. Hence, significant delays in responding can occur because financial or human resources may not be mobilized fast enough or because response scale-up is contingent on the official declaration of an epidemic (which can be highly political). Anticipatory action research aims to formalize 'early' or 'on time' action to prevent disease transmission and to keep cases to a minimum. Anticipatory action requires predictive modelling to forecast an epidemic's onset or development. Here, new techniques based on AI and ML can be used to model potential future events, with historical incidence data essential for the training of such models but usually very difficult to obtain.

Priorities

Acquiring and handling geospatial data remains complex so access and use of multi-dimensional and heterogeneous data must be made easier. This can be facilitated by ensuring that data are FAIR, while at the same time safeguarding ethical responsibility and governance. We also need to better understand possible shortcomings, uncertainties and biases associated with the use of highly diverse data types. Essential datasets to support health research and practice, including historical data to train our models, will need to be defined, preferably embedded into surveillance infrastructures and made available free of charge globally. In addition to routinely collected data, we need to learn how to capture and store qualitative data (local/indigenous knowledge, perceived health, wellbeing, adequacy and affordability of care etc.) using different media. It is important to actively involve local communities via participatory approaches and ensure that insights obtained are integrated into research and policy recommendations. In this way, social science-based medical anthropological approaches, e.g., including syndromic surveillance, would substantially enrich geospatial health research and practice.

Despite the progress, further improved analytical methods are required to better monitor and understand space-time trends and to detect public health risks at the early stage, e.g., by combining climate and epidemiological data (for climate-sensitive, vector-borne diseases) using AI and ML models to predict the probability of a future outbreak in a given country or location. Data-informed approaches should always be supplemented with theory-informed approaches to make sense of data and thus build knowledge and understanding of the health problem studied. We also need to make it less tedious and easier to perform complex analyses by designing intelligent workflows and developing transparent 'glass box' models rather than 'black box' models that stakeholders can easily accept. Embedding such models in decision-support systems would further facilitate rapid response to adverse public health events.

We must continue to build stronger relationships and work towards a common language between public health agencies and GIS scientists. One possible way for this is to jointly develop research strategies with key stakeholders based on real-life case studies that illustrate the power of new datasets and innovative geospatial modelling approaches. To accelerate scientific progress, we need to follow rigorous, scientific approaches empowering each other by openly sharing knowledge, data and geospatial tools. To achieve impact, it is crucial to build capacity and share technology between organizations in the Minority and the Majority world, given that the disease burden in low-income countries (where the world's poorest billion live) is much higher than that in high-income countries.

Geospatial health education is vital and needs to be strengthened. Medical, veterinary and public health schools normally have data science courses but often lack one on *spatial* data science, spatial statistics in particular. Reinforcement of education in geospatial health will make it more likely that (advanced) geospatial approaches will later be adopted in public health practice. Given its multi-disciplinary nature, we do not foresee a single geospatial health curriculum. Methodologists need to build new technologies, models and systems, while applied researchers should emphasize and employ these technologies and systems when addressing specific health problems. Capacity building in geospatial health in general will be essential to facilitate the adop-

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tion of spatial methods and models in public health care practice. Without local expertise and local ownership, it is unlikely that public health authorities will prioritize healthcare interventions based on geospatial technology. Future education in this area should not only include general data visualization courses but also embrace immersive and augmented reality as this can help public health professionals to better understand geospatial models and their outcomes. AI-based data augmentation techniques can help in the creation of realistic synthetic data (tailored to specific use cases without compromising privacy) to train better models. Federated learning, a decentralized approach to training machine learning models, could be another way to create more robust and generalizable models without compromising data privacy and ownership issues.

Finally, to increase the impact of our scientific achievements, communication is key. To date, geospatial health research is mostly published in dedicated scientific journals with a relatively narrow audience. To increase impact, we also need to actively reach out to health practitioners, policy makers and other stakeholders, and inform funding organizations of the contribution that geospatial tools offer. One promising way towards achieving this, for example, is geo-journalism, a novel communication approach that combines (online) interactive visualizations, StoryMaps, and infographics with easy-to-understand, evidence-based narratives tailored to various audiences.

Conclusions

The past few decades have seen major progress in global health. People are living longer than ever before, maternal and child mortality rates are declining, the development of new vaccines continues to save countless lives, and some neglected tropical diseases have been eliminated in several previously endemic countries. At the same time, urbanization, rural poverty, emerging infectious diseases, lack of access to essential and affordable health services, large numbers of people on the move and climate change effects all impact global health negatively. Work on current and future health challenges need geographic perspectives and impact-driven research approaches to achieve the relevant Sustainable Development Goals (SDGs), many of which are interlinked through space and time and across different geographic scales. We conclude that geospatial health can substantially contribute towards achieving the SDGs locally both globally and temporally with short-, medium- and longer-term goals in sight.

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