Meteorological data for public health surveillance

Michael Wimberly, Professor from the University of Oklahoma, walks us through integrating meteorological data for public health surveillance and disease forecasting

Public health surveillance involves the collection, analysis, interpretation, and dissemination of health-related data to plan, implement, and evaluate public health practices. The resulting information supports the detection of emerging health threats, planning interventions, and evaluating policies and programs to protect and improve population health.

Meteorological monitoring involves observing, recording, and analyzing weather and climate conditions like temperature, precipitation, and humidity. These data are used to study atmospheric phenomena, forecast weather, and analyze patterns of climate change.

Although public health and meteorology are distinctive disciplines, there is increasing awareness of the connections between environmental factors and infectious disease transmission cycles. Incorporating meteorological observations into public health surveillance is a transformational approach that can leverage diverse information to identify the places and times where disease risk is highest.

Rationale to integrate public health and meteorological data

Weather patterns can affect the spread of infectious diseases through multiple pathways. Changes in temperature, humidity, and rainfall affect populations of arthropod vectors such as mosquitoes and ticks, which transmit the pathogens that cause diseases like malaria, dengue, West Nile virus, and Lyme disease (Caminade et al., 2019). Many pathogens that infect humans are shared with other mammals and birds, and these zoonotic hosts are also sensitive to environmental fluctuations (Rupasinghe et al., 2022).

Weather also influences the seasonal transmission of airborne respiratory diseases such as influenza and coronavirus through direct effects on virus persistence in the environment and indirect effects on the behavior and contact rates of human hosts (Deyle et al., 2016; McClymont & Hu, 2021). Thus, data characterizing the environmental suitability for vectors, hosts, and pathogens can provide information about the risk of transmission to humans.

Public health surveillance and meteorological data have unique strengths and limitations (Moran et al., 2016). Although the occurrence of human disease is commonly used as an indicator of risk, the true number of infections is often underreported because of asymptomatic cases, mild cases for which medical attention is not sought, or misdiagnosis. Biases can arise from inconsistencies in healthcare access and diagnosis, and delays in reporting frequently make human cases a lagging indicator of outbreaks.

Pathogens can also be measured in vectors, hosts, water, and soil, but these data are typically collected at only a few isolated locations. Meteorological data from weather stations and Earth- observing satellites is highly consistent over time and space and is typically available within hours to days. However, meteorological variables only measure the suitability for disease transmission rather than the presence of the pathogen. Integrating diverse information streams offers the potential to leverage the strengths of each data source while minimizing its limitations.

Linking public health data with meteorological data methods

Linking public health data with meteorological data requires connecting the two types of observations in space and time. Observations of disease cases may be point-level observations of patients' home addresses or area-based summaries by ZIP codes or counties. Meteorological observations include point observations from weather stations and gridded satellite images.

These data must be spatially harmonized in a way that accounts for the movements of human, vectors, and zoonotic hosts and their exposure to the environment. Disease risk is influenced by the cumulative effects of environmental factors over weeks and months, and the integration of meteorological and public health data must account for these lagged effects.

Various types of models can be used to connect meteorological observations with public health data. Statistical and machine learning algorithms can identify patterns and correlations between weather conditions and disease outbreaks, allowing for the development of predictive models.

For instance, time-series analysis and regression models can forecast disease incidence based on historical weather patterns and current climate conditions (Imai et al., 2015).

Mechanistic models that account for vector population growth and buildup of host immunity can also be combined with data for forecasting (DeFelice et al., 2017). Approaches that integrate predictors from multiple data sources can improve forecast accuracy. For example, a model that predicted future West Nile virus case burdens based on weather variables combined with mosquito infection rates generated more accurate results than models based on only one of these data sources (Wimberly, Davis, et al., 2022).

Integrating public health and meteorological data challenges

Despite its potential, integrating public health and meteorological data faces several challenges. Public health organizations often lack the domain knowledge and software tools required to access, process, and interpret environmental data.

In contrast, environmental scientists are typically unfamiliar with the details of infectious disease transmission cycles, the complexities of public health surveillance systems, and the resulting limitations of surveillance data. Thus, developing transdisciplinary communities of practice is an essential step toward integrating and using these data effectively. Privacy concerns and restrictions on distributing and using many health datasets can also be a substantial barrier.

Developing software tools that automate key steps for data integration can facilitate access to environmental data and support implementation of predictive models for routine forecasting (Ceccato et al., 2018). Examples include the Retrieving Environmental Analytics for Climate and Health (REACH), a cloud-based application for accessing remotely sensed environmental data to support malaria early warning systems (Wimberly, Nekorchuk, et al., 2022), and Arbovirus Mapping and Prediction (ArboMAP) system, which was designed to automate data processing, modeling, and report generation steps for generating West Nile virus forecasts in state and municipal departments of health (Nekorchuk et al., 2024).

Future prospects: Environmental data to forecast infectious disease risk

The increasing availability of free environmental data will continue to offer new opportunities for integration with health data for modeling and forecasting infectious disease risk. However, the effort required to access, process, and harmonize these data, combined with the challenges of modeling complex disease transmission systems, will continue to present substantial challenges.

Future efforts to develop integrated forecasting platforms and use them operationally will require transdisciplinary teams to develop new protocols and software tools for data processing, modeling, and visualization and implement them in public health organizations where the resulting information can be used to enhance public health decision-making.

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