Chapter 3
Using Geographic Information for Disease Surveillance at Mass Gatherings

Abstract Mass gatherings present the medical community with an excellent window of opportunity to study infectious diseases that can be transmitted over long distances. This is because the venue of a mass gathering usually does not change year-to-year. As a result, special attention can be given to the public health risks that are introduced by travelers from around the world into these mass gatherings. Travelers can also be infected with diseases that are endemic in the host country and transport the locally acquired infectious diseases to their home environments. Therefore, mass gatherings can be thought of as global-to-local-to-global events because of the initial convergence of global populations and the subsequent divergence of populations throughout the world. This chapter discusses three active areas of geographic research that have emerged from our understanding of disease surveillance at mass gatherings: the role of transportation and population geographies in disease surveillance; the spatial and temporal dimensions of environmental geography in the spread of disease; and the advances in GIScience that provide real-world surveillance and monitoring of disease and injuries at mass gatherings.

Keywords Mass gatherings • Disease pandemics • Transportation geography • Population geography • Environmental geography • GIScience

3.1 Introduction

An aspect of disease surveillance that has received renewed attention in recent years is the public health risks associated with mass gatherings [1]. Mass gatherings are defined as public events – organized or spontaneous – that are held for a certain time period and attended by more than 25,000 people. Mass gatherings events can involve sporting events, religious, social, cultural, or political congregations, as well as gatherings of displaced populations due to natural disasters or conflict. Public health risks associated with mass gatherings include infectious disease outbreaks, non-communicable diseases, injuries, environmental exposures (such as heat-related illnesses), and trauma [2–4].

Infectious diseases at mass gatherings can be detected and understood at several levels. For instance, travelers from various global locations can introduce infectious diseases into mass gatherings that can then spread to residents in the local community.

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Conversely, travelers to mass gatherings can be infected with diseases that are endemic in the local community but not their home countries. These infected individuals – whether originating from the host country or elsewhere – can then transport locally acquire infectious diseases to their home countries, where they might then start new epidemics [5].

Infectious diseases, however, are not the greatest health risks associated with mass gatherings. Non-communicable diseases and injuries have caused more deaths and morbidity than have communicable diseases [6–8]. At the summer Olympic Games in Atlanta, GA, USA, more than 1,000 people received medical care for heat-related illnesses [9]. During the pilgrimage to Mecca, Saudi Arabia, in August 1985, 2,000 cases of heatstroke were reported and more than 1,000 of these individuals died within a few days [6]. In addition, the occurrence of severe acute cardiovascular events are twice as likely during mass gathering events that are associated with intense emotional stress, such as sporting tournaments [10, 11].

Historically, the oldest and largest annual mass gathering is the three-week long Muslim pilgrimage to the Hajj in Saudi Arabia, in which nearly three million pilgrims participate. The pilgrims come from more than 183 countries, which are mostly low-income with weak health systems. In addition to the environment-related health risks described above, these individuals are also likely to have pre-existing health conditions and be more susceptible to infections. This amalgamation of conditions, or "brewing the perfect storm," could lead to an outbreak at the mass gathering, with subsequent spread of infection, upon their return to their home country [12].

The contributions and thought leadership from professional geographers are well-suited to address these issues concerning the understanding, detection, and response to illnesses and disease at mass gatherings. First, since travel is a central and critical aspect of mass gatherings, a robust understanding of the spatial movements and interactions of certain populations is essential to assessing the health risks associated with a mass gathering event. The seasonality and timing of the mass gathering event are also crucial because public health risks are usually correlated with the temporal and spatial distribution of travelers to and from the city where the mass gathering event is hosted. Moreover, environmental and seasonal factors play a clinically relevant role in the infectious activity of pathogens with strong seasonal patterns (i.e., due to the effects of climate). Finally, in countries where public health surveillance and reporting infrastructures are often suboptimal, specialized and focused efforts – such as those on spatial data infrastructure and volunteered geographic information – are vital in the implementation of robust data gathering methods, enhanced analytic capabilities, and improved capacity for electronic disease surveillance [5, 13].

This chapter will expand on each of these ideas by presenting a brief history of disease surveillance at mass gatherings, describing the important health-related risk factors at mass gatherings, and explaining how professional geographers can contribute to the current understanding of disease surveillance at mass gathering events.

3.2 A Brief History of Disease Surveillance at Mass Gatherings

A notable quality of human beings is our willingness to travel long distances to gather in one place, for a variety of reasons – such as religion, politics, sport, and entertainment. Modern modes of transport – such as air, rail, train, and car – have enabled the number of people attending these gathering to increase, as well as the speed at which people travel to these events. Mass gatherings introduce a risk of the spread of infectious diseases, amongst other risks – such as burns, heat exhaustion, dehydration, trauma, human stampedes, and the potential for environmental and public health hazards.

One of the largest single mass gatherings on Earth is the Hindu festival of Kumbh Mela in India. It is believed that this festival likely contributed to the 1817–1824 Asiatic cholera pandemic. Pilgrims are thought to have carried the cholera bacteria from an endemic area in the lower Ganges to populations in the upper Ganges, from there to Kolkata and Mumbai, and across the subcontinent. Then, British soldiers and sailors transported the bacteria to Europe and to the Far East. The epidemic ended very abruptly in 1824, after a harsh and cold winter [14, 15]. In 2013, the same Haridwar-based event attracted approximately 80 million pilgrims between January and April. It is estimated that at least 16 million people were present at the height of the festival on April 14 [16]. Despite much rapid monitoring and public health interventions, diarrheal diseases (such as cholera) continue to be a risk at these mass gatherings today.

The largest annual mass gathering on Earth is the Islamic Hajj pilgrimage to Mecca, Saudi Arabia. During the first Hajj in 632 A.D., the pilgrims reported having a fever-like illness known locally as “Yethrib fever,” which is now believed to be malaria. Other major epidemics such as plague and cholera have been reported at the Hajj. In recently years, the number of people attending this event has doubled in the past decade, reaching 3 million in 2012; however, in 2013, concerns over a new SARS-like respiratory virus caused the attendance to decline to 2 million [17]. To place this event in its local context, the influx of pilgrims almost doubles the resident population of Mecca (which is approximately 1.4 million) every year [18]. Because the venue does not change and the event occurs annually, this mass gathering event provides the medical community with an excellent window of opportunity to research infectious diseases that not only affect a mass gathering event but also have the potential for pandemic spread [19, 20].

In recent decades, international sporting events such as the Olympics and the World Cup have attracted global audiences because of affordable air travel and local accommodations. As explained earlier, global attendance and travel can be associated with a heightened risk of imported diseases. For instance, there was a measles outbreak during the 2010 Winter Olympics, in Vancouver, British Columbia, Canada. The infection had spread quickly to the remote areas of British Columbia, causing substantial morbidity among its indigenous peoples [21]. In 2006, an outbreak of chicken pox occurred among members of the Maldives volleyball squad at Doha's Asian Games, but was successfully managed by use of quarantine, antiviral drugs, and vaccine [22].

Instances of respiratory infections at mass gathering events are generally very common. The duration of contact and the amount of shared air are key determinants of the spread of an infection. Influenza is an example of a viral infection that has a short incubation time and can cause both morbidity and mortality at mass gatherings. In July 2008, an outbreak of influenza was reported at the World Youth Day in Sydney, New South Wales, Australia. This outbreak was caused by several strains of influenza viruses, and the spread was expedited by crowded accommodation and low rates of vaccination [23]. Other similar outbreaks have been reported at the 2002 Winter Olympics in Salt Lake City, Utah, USA; and pandemic influenza A H1N1 has been reported at music festivals in Belgium, Serbia, and Hungary [24–27]. Furthermore, the results of a modelling study has suggested that mass gathering events that are held within 10 days before the peak of an influenza epidemic could lead to a 10 % relative increase in infection rates, therefore worsening the outcome for participants [28].

3.3 Important Public Health Risk Factors at Mass Gatherings

Diseases and injuries at mass gathering events can be categorized as communicable or non-communicable. Communicable diseases include infections resulting from a number of different modes of transmission (such as respiratory, food, water, vector, and animal pathogens). Non-communicable diseases are diseases and injuries caused by extreme weather conditions (such as floods, high winds, and high temperatures), acute cardiovascular stress, human stampedes, and acts of terrorism. While most of the public health response at mass gatherings has been on communicable diseases (due to their potentially huge consequences), non-communicable diseases and injuries have actually caused more deaths and morbidity at mass gatherings [29]. The public health response to both groups of diseases is similar to that for public health emergencies or crises in which the existing infrastructure is inadequate for the sudden surge in demand. This section will address the importance of identifying the appropriate environmental, socio-economic, and health characteristics of the mass gathering events and their participants.

The effects of infectious diseases at mass gatherings were first noted for food-borne illnesses, arising from person-to-person transmission. Although the spread of infectious diseases has been reported in relation to the Hajj, the earliest and best modern examples were outbreaks of gastrointestinal illness [30]. Food-borne and water-borne outbreaks of infectious diseases have the potential to spread very rapidly and on a large scale. Factors that influence the spread of infectious diseases include: the types of infections that are endemic to the host country, the types of infections that are endemic to the home countries of the visitors, and the manner in which the populations mix and interact. These factors can be amplified by the international travel and the subsequent dissemination in the home population – which is often faster than the incubation period of almost all infections. Furthermore, the spread of infection and drug-resistant organisms is expedited by the rapid mass movement and mixing of infectious and susceptible populations [14]. The infections that are likely to arise are also partly determined by the type of event – for instance, events with overcrowded accommodations will be more susceptible to outbreaks of respiratory infections, where as those with excessive consumption of recreational drugs and alcohol could increase the likelihood of sexually transmitted infections [31].

Since respiratory transmissions of infectious disease require close proximity between the infectious agent and host, this is the most common type of infection at events with overcrowded accommodations. The dynamics of transmission are determined by: incubation time, whether the infection is transmitted through droplets or is airborne, and nature of the infectious agent. Examples of respiratory infections are: influenza and other respiratory viruses, tuberculosis, measles, mumps, and meningococcal meningitis. Tuberculosis is a respiratory infection with a long incubation time. Because tuberculosis infections can remain latent for months to years, transmissions are often not noticed during mass gathering events. Although transmission has been reported during air travel, there is currently insufficient evidence to conclude that air travel is an important source of tuberculosis infection [32].

Furthermore, vector-borne diseases (such as malaria, dengue, West Nile encephalitis, and yellow fever) can cause outbreaks in countries where they are not endemic if a traveler is infected and an appropriate vector is present in the host country. Moreover, infectious diseases caused by known human pathogens or occasionally emerging infections can be transmitted from animals to people. For instance, in 1998, an outbreak of leptospirosis was reported among triathlon athletes in Springfield, Illinois, USA, where 11 % of tested participants were positive for the infection. This large outbreak likely arose from athletes drinking contaminated lake water, and demonstrated that unusual infections can occur among those who come into contact with fresh water during mass gathering events in temperate countries [33].

Weather and other environmental conditions, such as warm and cold temperatures, precipitation, and pollution, can contribute to the incidence of non-communicable illnesses, including life-threatening heatstroke, hypothermia, trauma, and dyspnea. A review of the effects of warm weather showed a strong correlation between high temperatures or humidity and the use of medical care during mass gathering events [34]. The heat index, a variable that combines measured air temperature and humidity, was found to be an important predictor of the demand for medical care [35]. Studies in Mecca have found that extreme environmental temperatures led to a major disaster – more than 1,000 deaths from heatstroke in just a few days [6]. In addition, cold temperatures, floods, high winds, and air pollution have been linked to health problems at mass gathering events as well [36–40].

3.4 Using Geographic Intelligence to Improve Disease Surveillance at Mass Gatherings

As demonstrated above, mass gatherings can exacerbate public health risks, on a global level, because travelers from around the world can introduce infectious diseases into mass gatherings, and these infectious diseases can then spread to other people in the host country. Travelers can also be infected with diseases that are endemic in the host country and can then transport locally acquired infectious diseases to their home environments, where they might then start new epidemics. Therefore, mass gatherings can be conceptualized as global-to-local-to-global events because of the initial convergence of global populations and the subsequent divergence of populations throughout the world. Three active areas of geographic research have emerged in our modern-day understanding of disease surveillance at mass gatherings: transportation and population geographies and their role in disease surveillance; the spatial and temporal dimensions of environmental geography in the spread of disease; and the ability of advances in GIScience to provide real-world surveillance and monitoring of disease and injuries.

3.4.1 Transportation and Population Geographies: Their Role in Disease Surveillance

Geographers have long observed that the mobility (of humans, of insect and animal vectors, and of pathogens) plays a prominent role in determining the observable patterns of disease outcomes [41–45]. Advances in modern-day commercial travel –by air, land, and water – have profoundly transformed the global movement of populations throughout the world. More than two billion people travel on commercial air flights every year, and this phenomenon presents new opportunities for locally emerging infectious diseases to quickly transform into international epidemics or pandemics [46, 47]. The accessibility of international modes of transportation has also contributed to an increase in the overall number, frequency, and scale of international mass gathering events. Since transportation and migration are central features of mass gatherings, transportation and population geographers can play a unique and essential role to our understanding of the spatial and temporal aspects of global outbreaks related to mass gatherings [48–52].

Mass gathering events often involve one of four major population groups: participants, observers, residents, and bystanders. Participants are those directly participating in the events, such as pilgrims at a religious festival. Observers are spectators of an event. Residents are those in the host country who interact with participants at the mass gathering – such as food vendors and hotel staff. Bystanders are those who travel to the host country for reasons unrelated to the mass gathering, but interact with people in the mass gathering environment. Since the global origins, mobility, and infectious disease burdens differ for each population group, understanding each group's daily mobility and transportation patterns is essential to assessing the public health risks at a mass gathering event [5].

Modelling the mobility of travelers from their global origins to a mass gathering event is complicated by the fact that the prior travel experiences to mass gatherings events in different locations and during different seasons may not be readily transferrable to future mass gathering events [53]. Considerations must also be given to the pre-departure health risks of each population group, their accommodations at the host country, and their interactions at the mass gathering event. For example, participants (i.e., political leaders and their entourages) of the G20 Summit would be expected to have low pre-travel risks of infectious disease, reside in privileged environments where food or water-borne diseases are unlikely, and be highly sequestered from other population groups at the mass gathering event. Conversely, pilgrims traveling to a religious mass gathering, such as the Kumbh Mela, may have pre-existing health issues, be living in environments where the risks of acquiring food or water-borne diseases are increased, and have extensive interactions with other population groups [5].

3.4.2 Understanding Disease Ecology's Contributions to Disease Surveillance

By necessity, disease surveillance at mass gathering events must take into account the environmental and social conditions that promote or sustain illness. Disease ecology is the branch of medical geography that is concerned with the integration of the environmental and social aspects of human lives into an understanding of diseases and injuries [54–57]. Since diseases obviously do not exist independently of environments or hosts, it is important to understand how human behavior, with its cultural and socioeconomic contexts, interacts with the environment to promote or prevent disease [58]. Anticipated (or unanticipated) disturbances in the environment – such as climate change, population growth, urbanization, and migration – can have either positive or negative effects on the incidence or spread of disease [59].

Medical geographer Dr. Melinda Meade recognized that human disease is the outcome of a complex and dynamic interaction between the internal and external environments of an individual or a population. She proposed a view of disease as being an intersection of three types of variables: population, environment, and behavior (Fig. 3.1). Population variables are factors that affect individuals' responses to disease as biological beings, such as nutritional and immunological status, age, and gender. Environmental variables are all aspects of the built, natural, and social environments that can affect disease outcomes. Behavior variables include both observable aspects of actions and culture, such as social organization, technology, diet, as well as less tangible variables like perceptions of risk. Disease outcomes are the result of place- and time- specific interactions among these variables [60, 61].

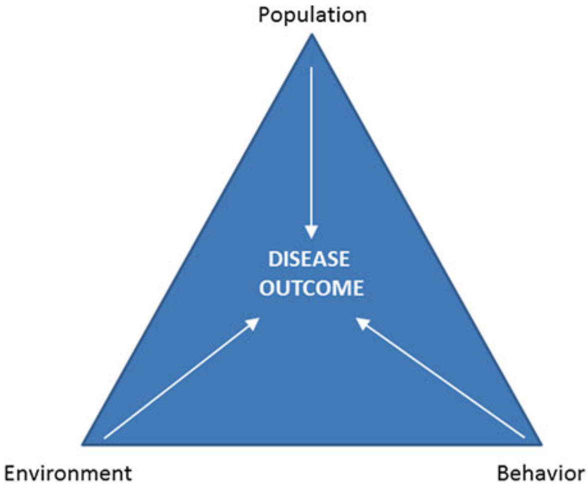

Fig. 3.1 Dr. Melinda Meade's triangle of human ecology

Understanding the relationship between disease ecology and disease surveillance is an essential component of preventing illness at mass gathering events because this knowledge can help health officials understand how pathogens cause disease in people and what factors affect the severity of these illnesses. Environmental factors, such as patterns of precipitation and minimum mean temperature, often influence the distribution and abundance of disease vectors worldwide. Without sufficient rain and temperature, disease vector communities cannot sustain themselves over time. Competition for resources in a drier climate can also lead to changes in vector community composition. These abiotic and site specific ecological factors determine where endemic disease is and is not sustainable [62–64]. Geographers play a crucial leadership role in identifying and filling in the current knowledge gaps about diseases, ranging from basic scientific research to the societal effects of infections and non-communicable illnesses. This information is important in modern public health and policy developments related to the planning for mass gathering events in the future [65].

3.4.3 GIScience and the Spatial Turn in Disease Surveillance

Geographic information science (GIScience) has a strong history of providing support to traditional disease surveillance. Many electronic disease surveillance systems have a mapping module to allow public health officials to visualize disease outbreaks on the map [66–69]. In addition, geographic information systems (GIS) provide a baseline for monitoring and evaluating outbreak investigations at mass gathering events, so that the geographic progression of disease is continually monitored. Public health field personnel use mobile GIS and global position system (GPS) devices to more efficiently navigate to locations for data collection.

Maps, imagery, and descriptive metadata are used to identify high-transmission areas or areas with environmental conditions ideal for disease vectors [45, 48, 50–52]. In short, GIS provides public health officials with the capabilities to spatially visualize and analyze complex spatio-temporal relationships between the infectious agent, host, and the environment at mass gathering events.

In addition, volunteered geographic information (VGI) has been shown to facilitate and improve public health reporting and communications at mass gathering events. Data collection and reporting of public health intelligence during a mass gathering event have been challenging tasks because of the large numbers of attendees, the rapid and large-scale movements of people, and their fairly short stay at the mass gathering event. Deploying VGI-based technology at mass gathering events is an effective way of gathering and disseminating public health information (as more than 90 % of the global population is covered by mobile phone networks and more than 140 countries provide third-generation wireless telecommunication services) [70–74].

An example of a successful deployment of VGI-based public health intelligence is during the 2009 Hajj, by the Saudi Arabian government. The goals were to use smart devices to assist in the early detection of emerging outbreaks of infectious diseases, and to improve the efficiency of case reporting and operational effectiveness, by using meaningful data visualizations and geo-statistical analyses with geographically tagged data (Fig. 3.2). This project monitored nine infectious diseases: pandemic influenza A H1N1, influenza-like illness, meningococcal meningitis, viral hemorrhagic fever, plague, yellow fever, cholera, foodborne illness, and poliomyelitis. Questionnaires about these diseases were uploaded to a central server, and wirelessly disseminated to laptops and smart devices in Saudi Arabia at different points of data gathering. Field investigators were assigned to local clinics and

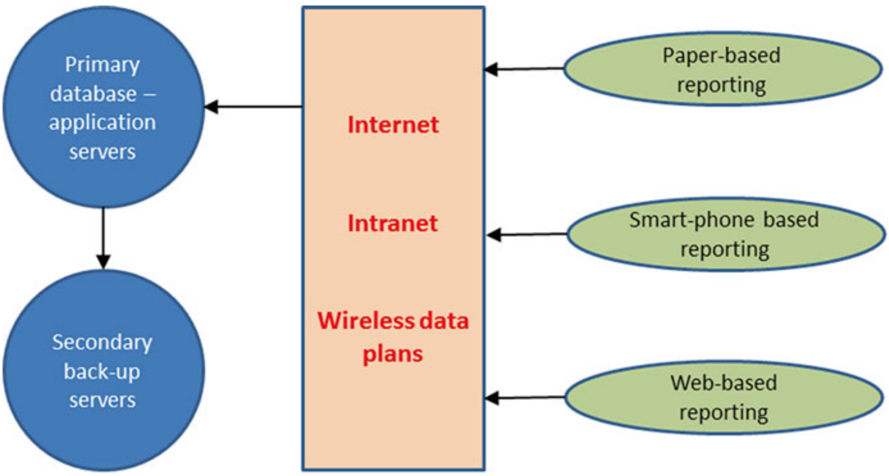

Fig. 3.2 Information technology infrastructure used for public health surveillance during the 2009 Hajj, Mecca, Saudi Arabia (Adapted from Khan et al. [12])

hospitals in and around Mecca. Real-time information from these investigators was quickly analyzed and synthesized by epidemiologists and presented to public health officials in the form of daily reports.

This project demonstrated that VGI-based smart technology could be swiftly and successfully integrated into the existing information technology infrastructure of Saudi Arabia's Ministry of Health. Wireless telecommunications provided ample opportunities for field investigators to gather geographically tagged health information electronically, at the point of contact with the pilgrims at the mass gathering event. This efficient real-time transfer of information formed the basis of an integrated platform used to synthesize epidemiological, clinical, and laboratory information into actionable public health intelligence for this mass gathering event [5].

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