Chapter 2
Geography of the Pandemic

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Personal Story
I used to travel almost every month to far and distant places – and I loved it. I loved going to a new country, experiencing the culture, food, music, but, most importantly, the people. My last trip was in February 2020. I was in Kyiv, Ukraine, watching the unfolding of the first stages of the global shutdown and wondering if I was going to get back to the United States. The only trip I have been on in the past 2 years is to Cleveland, Ohio, to visit family in July 2021 when we thought the pandemic was starting to ebb. Instead, it has continued to flow, and I am reluctant to travel. I made an investment in adopting a cautious approach to the pandemic and wonder when I will decide to compromise. However, I have been exploring the world at my fingertips through virtual travel to exotic locations. I have visited places I never thought to explore before – Chernobyl, Mars, and Iceland's oldest shipwreck. It isn't quite the same but does fill a bit of the void. *Melinda Laituri*

Introduction

Geography is central to the COVID-19 story, the underlying science of pandemic exposure and spread, and the societal responses to control and manage the virus and its effects. The current pandemic is a spatial story that crosses boundaries, scales, and cultures and can be told through maps – the language of geography. Descriptions of the pandemic are rife with references to geographies of location, wayfinding, and direction – navigating health responses, uncharted territory of a rapidly expanding pandemic, waves of transmission, invasion of habitats by humans, the shifting

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epicentre of the virus, shelter in place, remote learning, mapping the virus genome, global research roadmap, paths of transmission, and downstream or cascading effects of the pandemic. This volume of case studies focuses on the geographies of COVID-19 around the world. These geographies are located in both time and space, revealing impacts that are both immediate and long-term. The story of the pandemic is dynamic, in constant flux, and flush with ephemeral observations. The COVID-19 pandemic will be prolonged due to the onset of variants as well as setting the stage for similar future events. This chapter provides a synopsis of how geography and geospatial approaches are used to understand this event and the emerging "new normal."

Maps are created through mapping – the process of using the tools of geography that include geospatial data, remote sensing, mobile devices, and interactive visualizations yielding dynamic results. These products derived from a geographic perspective – grounded in a location and using a geospatial approach for analysis – are central to understanding the pandemic. What do maps – or more importantly – geography tell us about the pandemic? There are four general themes to consider. First, geography and questions of *where* are central to this story. *Where* is it present? *Where* is it spreading? *Where* is it most pronounced? *Where* am I in relation to it? Second, the geographic concept of scale is important in how the story is depicted – a global, generalized picture tells a significantly different story than the story in my hometown and is dependent upon the availability of and access to data at the appropriate resolution and scale. Third, place matters – where we live defines access to resources and essential services, revealing racial, social, and economic disparities. And finally, what has emerged about the pandemic is a complex story of uncertainty and vulnerability where the virus defies generalities, manifesting itself differently in different places with long term impacts that we will have to contend with (see The Geography of COVID-19, Parts 1–4 blog post, Laituri et al., 2020).

This chapter provides a historical and geographical overview of the use of geospatial tools and technologies – geographic information science (GIS) – to address pandemics and disasters in general, COVID-19 specifically, and longer-term adaptation to extreme events. Situating such events in place and time emphasizes the importance of using these tools and how they shape the stories we tell. The geography of the pandemic is twofold: the virtual geography of the pandemic and the consequential geography of the pandemic in places across the globe. The virtual pandemic is told in maps, data, and dashboards, creating living, dynamic maps of a global catastrophe. The ecosystem of the virtual pandemic includes big data, dashboards, dynamic maps, algorithms, coding, satellite imagery, and social media. Data dashboards – built upon a suite of geospatial and technical tools – use base maps of political geography (countries, states, and provinces) to display and visualize data about the pandemic (statistics on case numbers, deaths, and transmission) to showcase distributional impacts through concepts of human and medical geography. These dashboards are simplifications of the complex landscape of the pandemic and highlight the need for regional, subnational, city, and sub-city data or specifically, local data to tell the local story (Bakari et al., 2021).

Consequential Geographies

In *Seeking Spatial Justice*, Edward Soja coined the term "consequential geography" in reference to understanding the "social production of space" comprised of the social, political, and economic organization of places (2010, p 31). The consequential geography of the pandemic is manifested in myriad places around the world with uneven and inequitable impacts on economies, environments, societies, and cultures. This consequential geography reveals the relationship between places through the connectivity exhibited by the infrastructure (i.e., physical infrastructure of wired networks and cables of the Internet; transportation networks that support supply chains; medical facilities that provide access to vaccines) of the functional geography of who and how people are connected (Khanna, 2016). Connectivity is reflected through financial flows, integrated economies, supply chains, and mobile populations that transcend boundaries. Similarly, the consequential geography of the pandemic defines how pathogens are spread due to the intersection of social relations, economic flows, environmental factors, and human behaviours.

The geographic legacy of past pandemics is evident in multiple ways. In 2015, the World Health Organization issued new guidelines for naming conventions of human infectious diseases to minimize negative effects on nations, economies, and people (WHO, 2015). Prior to this best practice numerous pathogens were named for places; examples include Rocky Mountain spotted fever, West Nile virus, Middle East respiratory syndrome, and the Spanish flu (Christakis, 2020, p. 174). This geographic legacy is also reflected in the many monuments, churches, hospitals, and cemeteries built in response to past epidemics. In 1423, Venice established one of the first quarantine sites or lazarettos to manage bubonic plague; a stone pillar in Vienna commemorates the Black Death of 1679. A cemetery, Disco Hill, was established in Liberia to allow burial teams to dispose of the dead due to the Ebola virus in 2014; and a memorial grove in San Francisco commemorates those lost to AIDS since the 1980s (Ben-Ami, 2021).

Geography, Maps, and Technology

Maps and charts are essential to understanding human relationships to the environment and disease. Two examples demonstrate how geographic data were used to create maps and charts of disease and transmission. An early example of understanding the consequential geography of a pandemic was John Snow and his collaboration with Henry Whitehead to map the cholera epidemic in London in 1854. John Snow created a map of cholera cases and water pumps that when coupled with local knowledge supplied by Henry Whitehead supported the theory of cholera as a water-borne disease, leading to reforms in public infrastructure and waste management (Johnson, 2006; Tufte, 1997). Once scientific opinion accepted the waterborne theory of cholera, Snow's map became an important demonstration of the integration of science and local knowledge, linking an artifact of the built environment to a pattern of disease and disaster. Minard's 1896 statistical graph of Napoleon's march to Moscow (1812) and return is the representation of two dimensions of six different types of data (the number of Napoleon's troops, distance, temperature, latitude and longitude, direction of travel, and location relative to specific dates) (Tufte, 2002). This rendering of time and space offered an innovative way to integrate multiple types of geographic data. Reading Snowden's narrative account (2019) of Napoleon's misadventures illuminated the role of disease – dysentery and typhus – in the diminutive numbers that returned to Paris, which is not part of the data of the original graph, revealing a story of disease and death in time and place.

The full trajectory of geography is beyond the scope of this chapter; however, there are some pivotal technical developments that significantly contribute to using a geospatial approach in understanding the consequential geography of the pandemic. In the 1980s, geography underwent a second quantitative revolution[1] with the development of geographic information systems (GIS). Location-based data, georeferenced information, and computer modelling combined to develop applications for place-based decision-making. Increasing availability of satellite imagery and the use of global positioning systems (GPS) to assess land use/land cover change and sensors to track environmental conditions furthered the use of GIS in university curriculums, business applications, and government uses. Geographical approaches embedded in the tools of GIS demonstrated the fundamental nature of integrated analysis of multiple and disparate types of data to yield new information and new insights (Tomlinson, 2003). Characterized as the spatial turn (Torre, 2008), the 1990s was a period of further development of geospatial techniques, increasing accessibility of computer-based software tools, and development of spatial concepts (i.e., place, landscapes, relative space, or spatiality), fuelling transdisciplinary approaches across the natural and social sciences as well as the humanities (NRC, 2006) and strengthening partnerships between universities, government, and industry (Craglia & Shanley, 2015).

Geospatial approaches enabled transdisciplinary research to examine disasters, environmental change, and the geography of vulnerable populations (Laituri, 2021). A key contribution in the late 1980s was the United Church of Christ's Commission for Racial Justice report "Toxic Waste and Race in the United States," which revealed the disproportionate environmental impacts on people of color and low-income communities of hazardous waste sites. Maps overlaid demographic data (US Bureau of Census) and Environmental Protection Agency's (EPA) locations of hazardous facilities to reveal "communities with the greatest number of commercial hazardous waste facilities had the highest composition of racial and ethnic residents" (Chavez & Lee, 1987, pg. xiii). These maps were part of ground-breaking efforts to depict inequitable landscapes and launched the environmental justice movement in the United States (Bullard, 1993). In 2015, the Global Atlas of

[1] The first quantitative revolution occurred in the 1960s, ushering in an emphasis on science and mathematics using statistical and other quantitative methods such as multivariate analysis, spatial and simulation modeling (Preston, 1972).

Environmental Justice (https://ejatlas.org/) provided descriptions of locations and types of environmental justice case studies around the world. These descriptions include categories of waste management, climate justice, biodiversity, and water management. Early in the COVID-19 pandemic, it was evident that the virus impacts people of color disproportionately, reaffirming that fundamental tenet of environmental justice (Winskill et al., 2020). Where poor people live and the preconditions to getting sick are critical questions that are part of current efforts to assess the pandemic and understand the underlying geography.

Peter Gould's The Slow Plague (1993) described the AIDS pandemic using maps and geographic concepts – diffusion and spatial modelling – to trace the transmission in Africa, Thailand, and the United States. He applied a geographic perspective to examine the cultural underpinning of the AIDS pandemic through the interplay of sex, poverty, transportation (i.e., air travellers carrying AIDS to distant locations) and place. Gould documented the rapid spread, pathways and trajectories across different spatial scales, applying analysis of socio-economic data and AIDS cases to trace those most impacted – poor and ethnic minorities concentrated in urban centres.

In 2011, Emory University developed the first interactive online map of HIV – AIDSvu – that maintains current data on AIDS in the United States at the state, county, and city levels. These data include demographics, transmission patterns, and data comparisons of socio-economic characteristics. The interactive maps are representations of the diversity and complexity spanning the global reach of the AIDS pandemic, laying the groundwork for future geographic examinations of infectious disease.

The US Disaster Mitigation Act of 2000 supported efforts to better plan for disasters through hazard mapping, community participation, and risk. Susan Cutter et al. (2003) and her team created the social vulnerability index (SoVI) to environmental hazards using county-level socio-economic and demographic data. This approach facilitated the development of such tools as the Social Vulnerability Index (2006–2014) for multi-hazard vulnerability assessments using GIS to spatially combine vulnerability of populations, physical geographic characteristics, socio-economic data, and social fabric across multiple hazards. (Tate et al., 2010). Cutter's work was foundational for the development of the Centre for Disease Controls' (CDC) social vulnerability index (SVI) (Flanagan et al., 2011) for disaster management. The Agency for Toxic Substances and Disease Registry hosts an interactive map of the SVI in the United States with prepared maps at the census tract level of four thematic areas (socioeconomic status, household composition, housing type, and ethnicity) that are then combined to calculate the SVI of a community's capacity to respond to disasters. These web-based platforms exemplify the nature of interactive maps using datasets from multiple sources, representing the geography of vulnerability.

In the early 2000s, multiple disasters drove further advancements in using the suite of integrated spatial technologies and extending the reach of web-based platforms. The 2004 Indonesian tsunami saw the establishment of methods for increasing access to and sharing of high-resolution satellite imagery across humanitarian agencies to assess damages and provide information to first responders. In 2005, Hurricane Katrina demonstrated the use of mashups to create message boards and web portals, to locate shelters and missing persons (Laituri & Kodrich, 2008). The Haitian earthquake of 2010 identified how remote mappers could use high resolution satellite imagery and the platform – OpenStreetMap – to map urban areas, road networks, buildings, and other infrastructure to share with on-site first-responders and local mappers to assess and ground truth the rapidly generated new data (Radford, 2020). The Humanitarian OpenStreetMap team and Red Cross Missing Maps offer venues in response to disasters for remote and local community mappers to provide baseline data for under-mapped locations. These efforts have expanded who makes the map. Citizen science projects solicit participation from the public in scientific investigations. For example, the Cornell Lab of Ornithology and the National Audubon Society sponsor the Great Backyard Bird Count annually – a four-day event to identify, count, and share birding observations. Crowdsourcing refers to users contributing to specific mapping tasks. One example is OpenStreetMap, a platform to map the world – particularly under-mapped areas – created by volunteers termed a "community of mappers" (Craglia & Shanley, 2015, pg. 4).

Virtual Geography: Interactive Maps and Data Dashboards

These types of interactive, web-based platforms have set the stage for the numerous data dashboards developed during the pandemic, creating an expansive virtual geography of the pandemic. Ivanković et al. (2021) examine 158 dashboards from 53 countries developed by governmental agencies using both maps and graphs. Data dashboards use the tools of geospatial analysis to access big data, such as social media feeds and satellite imagery, and statistics. Interactive maps are embedded in interfaces for querying data across time and space. Creating these data dashboards demands a number of unique skills: coding, statistical understanding of data (COVID-19 case numbers, demographic data), methods to extract data from multiple databases, access to real-time data, and visualization (choropleth maps, graphic design). Multiple software companies have created off-the-shelf templates to rapidly create data dashboards – Esri, Tableau, and Microsoft Power BI (Pantino, 2021). This intersection of government data, private software companies, the Internet, and public need demonstrates how geospatial approaches create linkages across sectors.

The virtual geography of the pandemic exposes several limitations of geospatial tools, platforms, and dashboards in describing local and regional geographies. Data are the backbone of stories about a virus that transcends political boundaries as it ebbs and flows around the world. However, data are limited. While data at the appropriate scale enables the telling of local stories that represent people and places, most data dashboards depict information at the country, state, and major city scale. Scale and resolution matter particularly when data that are too coarse can hide and obscure not only variables, but people represented by those variables (O'Neal, 2016). Our stories are only as good as the data we have. The data are constrained by what is collected (or not), how numbers are aggregated, the level of precision of data collection instruments, and algorithms. Maps and associated models are simplifications – "opinions embedded in mathematics" (O'Neal, 2016). The analyses undertaken and shared on data dashboards need to include data sources, disclaimers, and limitations in the results presented as these representations of data are increasingly ubiquitous.

Use of off-the-shelf data dashboards has enabled multiple applications and enhanced access to pandemic information. However, these dashboards have built in defaults which may not reflect regional conditions and local needs requiring coding skills to modify and customize the interface. Coders have been in increased demand during the pandemic – but coders with multiple skills to analyze statistical data and understand the nuances of geospatial statistics are also needed and in limited supply. Open Watch Data describes the "data value chain" – availability, openness, dissemination, use and uptake – tracking best practices and guidelines from multiple organizations and users. Rudow, et al. (2021) provide an overview of lessons learned that include: the collection of timely data for rapid dissemination; adequate demographic data with an emphasis on gender, disabled people, and indigenous communities; attention to privacy; and improvement in data interoperability, standards, and data management.

Geography of the Digital Divide

The virtual pandemic-scape also exposes the digital divide – a key driver of inequality in the digital age (CNUCED, 2020). This digital divide is characterized by a lack of access to basic technology such as computers and cell phones, inadequate Internet infrastructure of wires and networks, and a reliance on spatial modelling dependent on social media. The digital divide is still a problem where a lack of Internet services and infrastructure limits access to schools, places of work, and other services (Lai & Widmar, 2021). Least developed countries lag behind in terms of digital readiness in terms of Internet accessibility, broadband quality, and mobile data costs. This digital divide inhibits and limits how geospatial tools, applications, and solutions can be used to address data-driven decision-making in many areas of the Global South. Additionally, the reliance of many models and algorithms on social media (a source of big data) emphasizes those who are connected. An examination of networks illuminated by twitter feeds, such as the COVID tracking project, not only reveals connectivity provided by mobile technologies (i.e., cell phones and global positioning systems) but also offers an avenue to identify gaps and exposing the emphasis on the built environment – often where the infrastructure exists vs. those areas where there may be limited infrastructure. How do the algorithms about these data impact those not adequately represented? Understanding and identifying under-represented populations in big data is essential for improved planning and data driven decision-making in a "post-virus" world.

An established avenue of geographical research has been environmental monitoring (land use/land cover change) and modelling (climate change predictions) using Earth observation satellite imagery and geospatial analysis (Phiri & Morgenroth, 2017). Since 1972, Landsat has provided satellite imagery of the earth, enabling analysis of land use and land cover change. Improvements in imaging capability and enhanced sensors have expanded the use of remotely sensed data to analyse environmental conditions over time (Loveland & Dwyer, 2012). There are two examples of how these approaches have contributed to understanding this pandemic: the impacts of land use induced zoonotic "spillover" in opening avenues for disease transmission from wildlife to humans (Plowright et al., 2021); and the environmental impacts of the "anthropause" due to the global lockdown and reduced human activity (Rutz et al., 2020).

Land use/land cover change analysis in the form of urban growth, hydroelectric dam construction, mining, and deforestation increase human/wildlife interaction (Grossman, 2021). The turn of the century saw a rapid expansion of the human footprint with intensifying development and urbanization in areas of rich biodiversity and sensitive habitats (tropical forests) (Venter et al., 2016). Illegal bush meat markets and trafficking in wildlife across international borders yield lucrative economic flows of cash and viral flows of disease with new avenues of movement (Swift et al., 2007). The use of satellite imagery, GPS tracker collars, and drones has been used to track wildlife movement patterns that may indicate suspicious activity and enforcement response due to wildlife trafficking (Wheeler, 2014). While wild animals are threatened by the bushmeat trade and wildlife trafficking, so too are humans who handle, prepare, and cook certain kinds of animals. Bats and pangolins have been cited as potential hosts for the type of coronavirus, a zoonotic disease that is also found in international bush markets (Quammen, 2020). In addition to mobile and satellite technology, phylogeny graphs – a form of genetic mapping, transmission diagrams of viral diffusion, and maps of contact tracing and disease spread contribute to illustrating the complex, geographic nature of epidemics. Other analytical tools include identifying hotspots of outbreaks of contagion through using integrated data about the numbers of disease cases, population density, settlement patterns, and transportation networks. Such an approach was used to create the Ebola Mapping Tools to create potential risk maps of future Ebola outbreaks based on environmental variables, such as bat habitat and Ebola outbreaks (Fortunati, 2016).

Geographies of Transformation

The pandemic ushered in a year of lockdowns, quarantines, and isolation – the Great Pause or anthropause (Rutz et al., 2020). An outcome of the Anthropause was the application of multiple geospatial applications to track changing patterns of the natural world in response to the pandemic. The consequential geography of a "human pause" had dramatic impacts on the natural world. Rutz et al. (2020) examine the impact on reduced human mobility and wildlife activity through creating a bio-logging application using social media, sensor networks, and citizen scientists. The World Forum for Acoustic Ecology captures COVID-19 Soundscapes from around the world, integrating sound and space. Satellite imagery of night lights was used to assess the impacts on energy consumption, transportation, and social interactions, linking spatio-temporal changes, population density, and anthropogenic light emissions (Rubinyi et al., 2020). The Great Pause gave us a moment to consider the unintended consequences of slowing down the world where the pandemic constrained our physical space while expanding our virtual space.

The pandemic is a transformative event on the world stage. The consequential geography of the pandemic is central to examining the intertwined dynamics of biological and social phenomenon to identify impacts across different spatial scales, from the molecular to the global. Epidemics set the stage where social conditions – social and economic inequalities over time and place – amplify biological factors and exacerbate conditions of oppression. Initial waves of the Black Death (1347–1351) resulted in large scale population loss where famines, high levels of poverty, and low wages led to precarious conditions of health. Wealthier people could travel to the countryside; poorer people sheltered in place with death. Successive waves of the Black Death resulted in adaptive practices such as quarantines, isolation, and social distancing. However, the resulting decline in population meant that labor was in demand and wages increased as Europe rebounded from the pandemic of the plague, changing social and economic patterns (Wright, 2020). Pandemics lead to discovery and changing attitudes and practices. In the early 1800s, the coincidence of germ theory (infectious diseases caused by microbes) and the sanitary reform movement (clean water systems, sanitation, and safe housing regulation) reduced the transmission of deadly pathogens in European and US cities (Shah, 2020). New institutional structures were formed to manage sanitation practices such as boards of health and hospitals organized into specific wards (Shah, 2020). We will experience multiple changes due to the COVID-19 pandemic which, as of this writing, is still apparent around the world.

The consequential geography of the pandemic exposes a landscape of inequality and vulnerable populations. The pandemic illuminates differential access to critical infrastructure for remote learning, availability of health care, and access to basic services. This crisis magnifies fundamental inequalities that require robust data to track the virus in at-risk populations as well as identify innovative solutions for both economic and community health at a local scale. Crime (Ceccato et al., 2021), domestic violence (Brink et al., 2021), and corruption (Gallego et al., 2020) are all facets of the pandemic that are mapped, exposing the geographies of risk. The identification of vulnerable populations (who are they?), the landscape of inequity (where are they?), and what do they need (where are basic services?) are examples of how examining the contributions of geography and geospatial technologies can support place-based strategies for solutions.

We will need innovative approaches to address the long-term impacts of the pandemic. In May 2021, UNESCO declared environmental education for sustainable development as essential to the core curriculum to transform society and ensure human and planetary health and well-being. An integrated approach to education built on environmental stewardship, civic engagement, and collaborative skills centred on place-based learning. Geography is central to this approach and the skillset associated with geospatial tools is inherently collaborative, enabling a robust workforce. Additionally, the pandemic also reveals the need for conversations across disciplines for comprehensive, innovative solutions. The COVID-19 virus has catalyzed an international research effort tracked and coordinated by WHO to conduct research that is cross-cutting and inclusive of both natural and social sciences. WHO has also identified 15 international laboratories that coordinate with national labs around the world to increase connectivity within the science community. Essential to this effort is the virtual geography that has emerged from the pandemic of sharing data, demonstrating interoperability, and using geospatial tools for place-based and data-driven decision-making. Our responsibility as geographers and geospatial students, practitioners, and scientists is to ensure grounded, ethical, and sound scientific approaches in addressing the profound problems we face.

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