Chapter 3
Defining First- and Second-Order Impacts Through Maps

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Personal Story

My personal experience during the COVID-19 pandemic is delineated into two distinct phases. The first phase was a lockdown, but with the companionship of a pet. I had just relocated to Washington, DC, USA for a one-year fellowship, and I was accompanied by my 14-year-old dog and quarantine buddy, Toohey. Typically, I would have been at work at my university campus for around 8 hours a day, but in this new era, I worked from home every day with Toohey at my side. She and I went for long walks in our new city, visiting parks and trails, and meeting the neighbors, and we grew more attached to each other in this new lockdown lifestyle. However, a year into the pandemic, Toohey's physical health and quality of life diminished quickly, and it became apparent that I had to say goodbye to her. At 15 years old and in frail condition, it was time to let her go. Thus began the second phase of the pandemic, which for me has been marked by mixed emotions, including grief, gratitude, and loneliness, but also relief in knowing that rapidly developed vaccines will help us end this global crisis. In this second phase, I miss Toohey a great deal, and I still feel her absence. The one-year fellowship in Washington, DC, has ended, and I now look forward to a new chapter of life, without Toohey, even as the story of the pandemic continues to unfold.

Introduction

The impacts of the COVID-19 pandemic have been significant and wide-ranging, and they have touched nearly every dimension of the human experience globally, even as the effects have been felt unevenly. It is important to emphasize that the impacts of the pandemic are also still ongoing, and our understanding of its effects on our lives—across time and space—is still emerging as the novel coronavirus continues to spread globally. This chapter introduces a characterization of the

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impacts of the COVID-19 pandemic and defines both the direct and indirect effects of the virus and of efforts to contain it and mitigate its negative consequences. In addition, the chapter describes how these impacts can be better understood through maps.

The virus initially emerged with the first known case in Wuhan, China, in December 2019, and it quickly became a global concern. On January 30, 2020, the World Health Organization (WHO) declared the coronavirus a Public Health Emergency of International Concern (WHO, 2020a). Soon after, on March 11, 2020, the WHO Director-General announced that the COVID-19 disease could be characterized as a pandemic because of the alarming levels of spread, severity, and inaction. Since that time, numerous institutions have provided near real-time data dashboards with information about daily new cases and deaths (e.g., CDC, 2020; JHU, 2020; WHO, 2020b), and each of these resources uses maps at different scales to depict the spread of known infections, and the locations where severe cases have led to deaths. These institutions provide a range of practical online and mobile mapping dashboards and applications for tracking the COVID-19 pandemic and associated events as they unfold around the world over time (Boulos & Geraghty, 2020). These data and their associated maps communicate information about the direct effects of the virus and cases of the COVID-19 disease—that is, the first-order impacts of the pandemic. This information has been critical to efforts to contain the outbreak of the virus and mitigate its effects.

As the virus spread globally, governments, communities, businesses, and individuals responded with a variety of actions, policies, and behaviors aimed at containing the spread of the virus. Local responses included the rapid deployment of testing capacity and contact tracing. Other measures ranged from travel restrictions and border closures to the suspension of in-person education at all levels, the closure of office activities, face covering requirements, and social distancing guidelines. These responses to the COVID-19 pandemic, in turn, sparked a wave of second-order impacts that will likely continue to be felt globally for years, including a global economic crisis. Second-order impacts have specific ramifications and tangible consequences that derive from human responses to the pandemic, rather than from the virus itself (Laituri et al., 2021). For example, the pandemic has exacerbated pre-existing inequities in areas such as income inequality, poverty, and food insecurity, effectively reversing previous gains and setting back hard-earned progress toward sustainable development. Some of these second-order impacts can be easily measured, analyzed, and mapped, such as economic impacts, migration, shifts in demographic trends, and other effects for which data are available. Other second-order impacts may be more difficult to measure, such as the effects of the disruption in traditional learning in schools, the psychological effects of increased social isolation, and the effects of misinformation about the virus on trust in science and institutions. Nevertheless, measuring and mapping the second-order impacts of the COVID-19 pandemic will be crucial in mitigating negative effects and informing investments in recovery and resilience.

Many research questions related to the impacts of the COVID-19 pandemic are geographic in nature, as emphasized in Chap. 1 of this volume. The first- and second-order impacts of the pandemic are seasonal, spatial, and scalar across multiple sectors of society, and geospatial approaches to examining these impacts can be useful to policy makers and inform their efforts to mitigate their negative effects (Laituri et al., 2021). Not surprisingly, the virus and the COVID-19 disease have inspired the rapid publication of research related to the pandemic across many scientific disciplines, and many researchers have used geospatial approaches for examining, tracking, and projecting the many impacts of the pandemic. Much of this published research acknowledges the limitations and challenges associated with geospatial applications, such as time, space, and scale, as well as other challenges associated with data collection during a pandemic, and the need to minimize contact in order to contain the spread of the disease.

Early in the pandemic, the scientific and medical communities quickly recognized that a global response to contain the spread of the virus would certainly involve some sort of immunization program. Developing, testing, approving, and deploying effective vaccines to increase immunity to the virus became a global priority. Vaccine development is typically a lengthy and arduous process that has required 10–15 years to accomplish; the fastest a vaccine has ever been developed, the mumps vaccine in 1967, took 4 years (Roos, 2021). By July 2020, two biopharmaceutical companies—Pfizer and Moderna—emerged as leaders in the race to develop a COVID-19 vaccine using rapidly-deployed clinical trials. The Pfizer vaccine—developed in collaboration with the German-based BioNTech—was approved for WHO Emergency Use Listing in December 2020, and this approval was soon followed by the listing for the vaccines developed by AstraZeneca, Johnson & Johnson, Moderna, and others in early 2021 (WHO, 2021). These actions sparked a global movement to vaccinate the public, and maps depicting vaccination rates by country were soon part of many COVID-19 data dashboards. Vaccinations continue to be tracked and mapped, although vaccination rates vary widely by country, depending on vaccine availability, deployment capacity, and public willingness to receive the injection.

Mapping First-Order Impacts

Maps have been central to the story of the COVID-19 pandemic and its first-order impacts. The proliferation of interactive maps related to the first-order impacts of the pandemic has been an important contribution towards better understanding the evolving threat of the virus. Since the onset of the pandemic, information related to daily new cases, hospitalizations, and deaths from COVID-19 has been collected and published on the websites of numerous public health institutions (e.g., CDC, 2020; JHU, 2020; WHO, 2020b), and each of them portrays this information spatially using maps at different scales—from county to nation to world maps (Boulos & Geraghty, 2020). These choropleth maps illustrate the prevalence of the disease using shaded colors of countries by rates of transmission. Daily rates of new infections are reported as average daily cases per 100,000 people, which allows for comparison across jurisdictions with different population sizes. Average daily cases are provided as the average number of new cases a day for the past 7 days, as a seven-day rolling average is calculated to smooth out fluctuations in daily case count reporting (CDC, 2021; Mayo Clinic, 2021). These maps and data dashboards highlight the importance of sharing and visualizing public data in the interests of public health (Laituri et al., 2021). Tracking these maps of daily new cases and deaths from COVID-19 became a daily routine for many people, and the maps and data were provided on news media sites around the world. In addition, these maps were used by policymakers to identify hot spots and trends and respond with actions aimed at protecting public health.

The COVID-19 pandemic has enabled and accelerated scientific research across many disciplines, and numerous publications using geospatial approaches have examined the spread of the virus, mapped infection hot spots, and analyzed death rates. Incorporating geographic information systems (GIS) into COVID-19 pandemic surveillance, modeling, and response enhances understanding and control of the disease. Applications of GIS include (i) surveillance and data sharing, (ii) infectious disease forecasting, (iii) digital contact tracing, (iv) integrating geographic data in COVID-19 modeling, (v) investigating geographic social vulnerabilities and health disparities, and (vi) communicating the status of the outbreak or status of facilities for return-to-normal operations (Smith & Mennis, 2020). The locations and availability of personal protective equipment, ventilators, hospital beds, and other items can be optimized with the use of GIS and other geospatial approaches to examining and managing the virus. There are numerous challenges in applications of GIS, including the protection of individual privacy and civil liberties and the integration of knowledge from geography with the fields of medicine, public health, and public policy (Kim et al., 2021). However, geospatial technologies may provide a balanced solution for enabling effective use of location-based data while protecting citizens' privacy. For example, developing innovative spatio-temporal computing and aggregation algorithms could enable the efficient extraction of population flows from less sensitive social media data (Yang et al., 2020).

In a scoping review of the geospatial techniques and associated findings in relation to the characteristics of the pandemic, Fatima et al. (2021) provided a synthesis of published, peer-reviewed journal articles based on the spatial analysis of COVID-19. The authors found that researchers used a wide range of spatial and statistical software to apply spatial analysis for the purpose of disease mapping, exposure mapping, and epidemiological modeling. Factors limiting the use of these spatial techniques included the limited availability and bias of COVID-19 data—as well as the scarcity of fine-scaled demographic, environmental, and socioeconomic data—which restrained most of the researchers from exploring causal relationships of potential influencing factors of COVID-19. Most of the studies found centered on Asia and the Americas, which highlights the need for more comparable spatial studies using geographically fine-scaled data in other areas of the world.

Geospatial technologies have been critical tools for tracking the spread of the virus, examining transmission rates, and mapping death counts worldwide (Ahasan et al., 2020). These technologies have aided local and national decision makers in their efforts to slow the spread of the virus and contain the COVID-19 disease. Multiple data dashboards and maps have been developed to track global and country-level data and depict geographic visualizations of cases, hospitalizations, and deaths that allow for the dissemination of vital information in the interests of public health.

Mapping Second-Order Impacts

Early in the pandemic, responses to the novel coronavirus were implemented swiftly and ranged from executive actions such as business closures, travel restrictions, and lockdowns, to individual actions such as changes in consumption patterns, the use of face coverings, and maintaining physical distance from others. These responses triggered wide-ranging second-order impacts of the pandemic, such as increased unemployment, migration, and food insecurity, among others (Laituri et al., 2021). The COVID-19 pandemic has interrupted the functioning of social and economic systems worldwide in ways that are evolving and are not yet fully understood. Disruptions to education, income losses, mental health effects, and socio-political divisions related to the virus and the efficacy of vaccines are just a few examples of second-order impacts of the pandemic. There is evidence that COVID-19 has had significantly negative effects on psychological well-being, in part because of loneliness, social isolation, and the added anxiety and stress related to coping with the changes associated with the pandemic (Groarke et al., 2020; Okruszek et al., 2020). Furthermore, research has shown that the COVID-19 pandemic has exacerbated gender, racial, and economic inequality (Alon et al., 2020; Abedi et al., 2021).

The World Bank maintains the COVID-19 Household Monitoring Dashboard, one of the most comprehensive sources of second-order impacts of the COVID-19 pandemic across developing regions (World Bank, 2021). The Dashboard provides data and maps depicting the socioeconomic impacts of COVID-19 on households and individuals across 72 countries, based on 142 harmonized indicators across 16 topics ranging from education and income to food security, health, and housing, among others. The indicators are based on high-frequency phone surveys, and the Dashboard allows for comparisons among countries and over time. Figure 3.1 provides an example of a map of these countries depicting the share of the working population that stopped working since the COVID-19 outbreak. The Dashboard reveals a complex spatio-temporal story about the pandemic, including information about the actions taken to cope with the impacts of the pandemic, such as reducing consumption or selling assets to pay for basic living expenses.

The coronavirus outbreak led to severe consequences in significant sectors of the global economy (Sharma et al., 2021). The economic impacts of the COVID-19 pandemic can be measured and mapped to portray spatial and temporal information about trends in unemployment, wages, spending, and prices for basic goods and services, among others (Chetty et al., 2020). A group of scholars, in collaboration with Opportunity Insights, developed an online economic tracker that monitors the

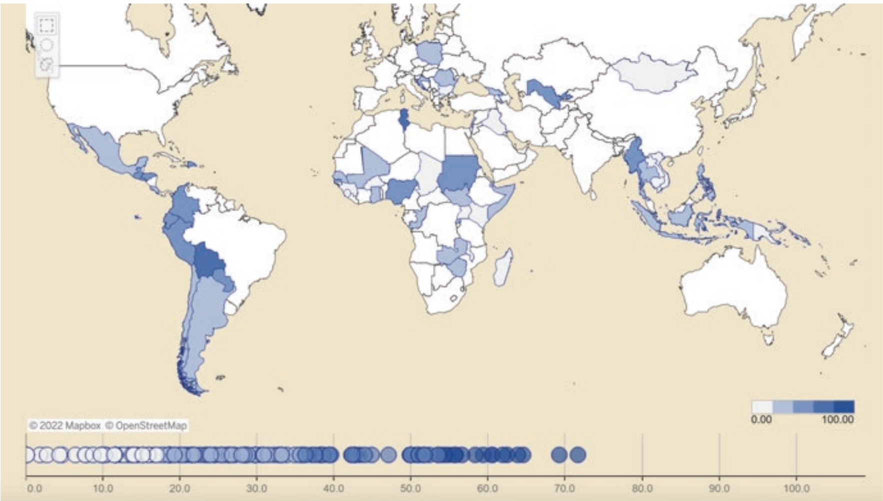

Fig. 3.1 Map of 72 countries depicting the share of respondents to a high-frequency phone survey that stopped working since the COVID-19 outbreak. (Source: World Bank, 2021 © 2022 Mapbox, © OpenStreetMap)

economic impacts of COVID-19 on people, businesses, and communities across the United States in real time (Opportunity Insights, 2021). The Economic Tracker provides data and visualizations that depict trends in economic indicators since the beginning of the pandemic, including consumer spending, small business revenue, and employment, among others. The Economic Tracker is interactive, and indicators can be mapped to allow for visual comparison between states or counties.

The economic impacts of the COVID-19 pandemic have been most acutely and widely faced in areas where the hospitality and tourism sectors are important to regional economies (Laituri et al., 2021). Indicators of these impacts include trends in air travel, hotel bookings, restaurant revenues, and visitation to attractions, and this information can be collected as data and mapped to understand trends in the travel and tourism industries, including their impacts from the pandemic and rates of recovery. Research on the impacts of the COVID-19 pandemic on the tourism sector has expanded rapidly, and the literature on this topic has been summarized in an integrative review that identifies important gaps and highlights a future research agenda (Zopiatis et al., 2021). Geospatial approaches have been applied to map and assess the economic impacts of the COVID-19 pandemic on tourism that has expanded rapidly to include studies on tourism in China (Qiu et al., 2020), India (Chandel et al., 2021; Singh et al., 2021), Nepal (Sah et al., 2020), and South Africa (Rogerson & Rogerson, 2020), among others.

Food insecurity has risen sharply during the pandemic, particularly in urban areas. The United Nations World Food Programme (WFP) estimates that 768 million people faced chronic hunger in 2020, up nearly 20% from 2019 (WFP, 2021). Urban food security has deteriorated during the COVID-19 pandemic in part because of disruptions to national and globalized food supply chains that drove up food prices, highlighting concerns about the vulnerability of food systems (Laborde et al., 2020). WFP has developed the HungerMap^{LIVE} dashboard to track and predict key aspects of food insecurity every day, including key indicators such as the number of people with insufficient food consumption and those employing crisis-level or above coping strategies. HungerMap provides maps and other visualizations depicting various dimensions of food security at global, national, and subnational levels. Indicators include the prevalence of insufficient food consumption and acute malnutrition, along with spatial markers representing some of the drivers of food insecurity, such as conflict, hazards, drought, and economic shocks.

In addition, the NASA Harvest COVID-19 Dashboard provides worldwide data and maps depicting regional trends in virus cases by country, as well as measures of food security, crop conditions, trade, and market prices for food and other commodities (NASA, 2021). The Dashboard is part of the NASA Harvest Portal, which aims to enable and advance adoption of satellite Earth observations to benefit food security, agriculture, and human and environmental resilience worldwide.

One of the most significant social impacts of the COVID-19 pandemic is the disruption to education at all levels. The suspension of in-person learning in schools prompted changes in the delivery of education that ranged from digital learning platforms and online classes to the provision of learning resources via radio and television (Tadesse & Muluye, 2020). School closures have been substantial and uneven across countries. The United Nations maintains data dashboards on the global monitoring of school closures caused by the COVID-19 pandemic, including visualizations depicting regional and country-level data. Early in the pandemic, on April 1, 2020, schools and higher education institutions were closed in 185 countries, affecting more than 1.5 billion learners, or 89.4% of total enrolled students (UNESCO, 2021). Their data show that poorer countries reported the longest average duration of closures, widening the learning gap between countries. Availability of remote learning modalities has varied widely by socioeconomic levels. Research has suggested that the global lockdown of educational institutions during the pandemic will cause long-term interruptions in students' learning and development, and that learning losses due to COVID-19 school closures could continue to accumulate even after students return (Kaffenberger, 2021).

The outbreak of COVID-19 has affected global mobility in complex and unprecedented ways in the form of various travel restrictions, suspensions of air travel, and border closures imposed by governments and authorities since the onset of the pandemic. To better understand this, the UN International Organization for Migration (IOM) has developed a global mobility database to map these impacts on human mobility, across global, regional. and country levels (IOM, 2022). Figure 3.2 provides a map of countries depicting the operational status at various points of entry, including airports, land borders, and maritime borders.

Since human movement is an important driver of the transmission of infectious diseases (Kraemer et al., 2019), geospatial data sources, such as public transportation use, geotagged social media data, and mobile phone data, can be used to detect and map such movement (Yang et al., 2020), although using such data to track human mobility prompts privacy concerns (de Montjoye et al., 2018; Kim & Kwan, 2021). The COVID-19 pandemic has significant implications for migrant workers,

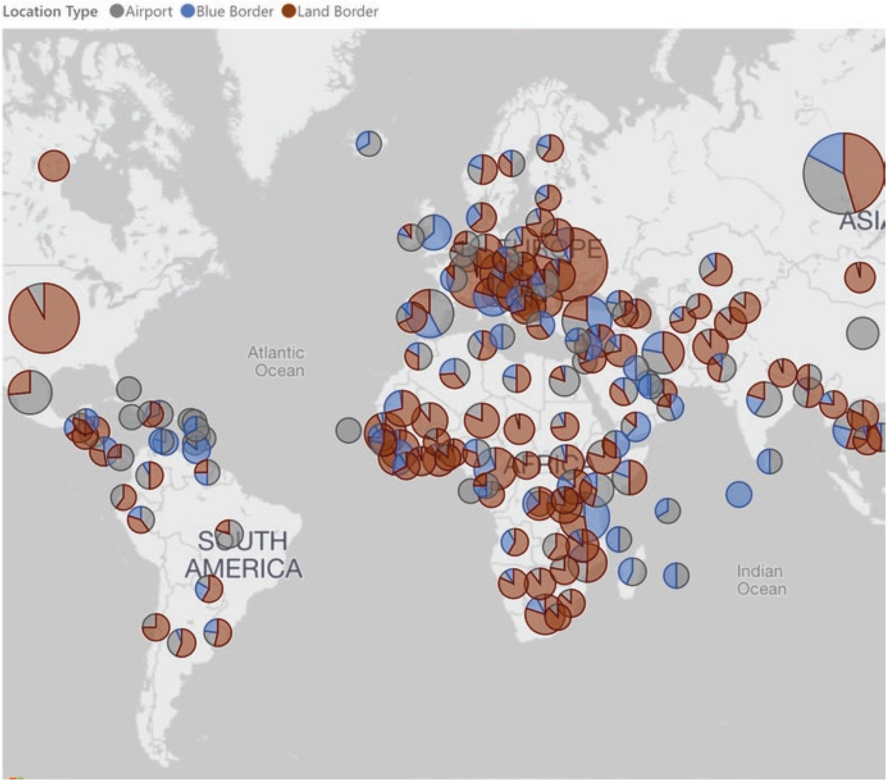

Fig. 3.2 Map of countries depicting the operational status of points of entry. (Source: IOM, 2022 © 2022 TomTom, © 2022 Microsoft Corporation, © OpenStreetMap)

livelihoods, and remittance flows in numerous regions throughout the world (Laituri et al., 2021). Reverse migration—from urban to rural areas—has been a major second-order impact of COVID-19 primarily because of job losses, and one study described the effect as the largest mass migration in India in nearly 75 years (Mukhra et al., 2020). Figure 3.3 provides a map of India depicting the flows of migrants across states in response to the outbreak of COVID-19.

The environmental impacts of the COVID-19 pandemic have largely reflected the changes in human behavior globally. Numerous case studies have documented improvements in air quality, particularly in cities where lockdown measures were implemented in response to the spread of the virus. As such, these areas have been marked by a decrease in industrial activity and automobile travel, and a decline in greenhouse gas emissions in the short-term. Geospatial applications have been used to assess the effects of pandemic-induced lockdown measures on air quality in regional, country, and city scales in the South and Southeast Asian regions using satellite-based data (Roy et al., 2021). Other studies have found similar improvements in air quality from lockdown measures in Brazil (Nakada & Urban, 2020), China, (Xu et al., 2020), Ecuador (Zalakeviciute et al., 2020; Zambrano-Monserrate

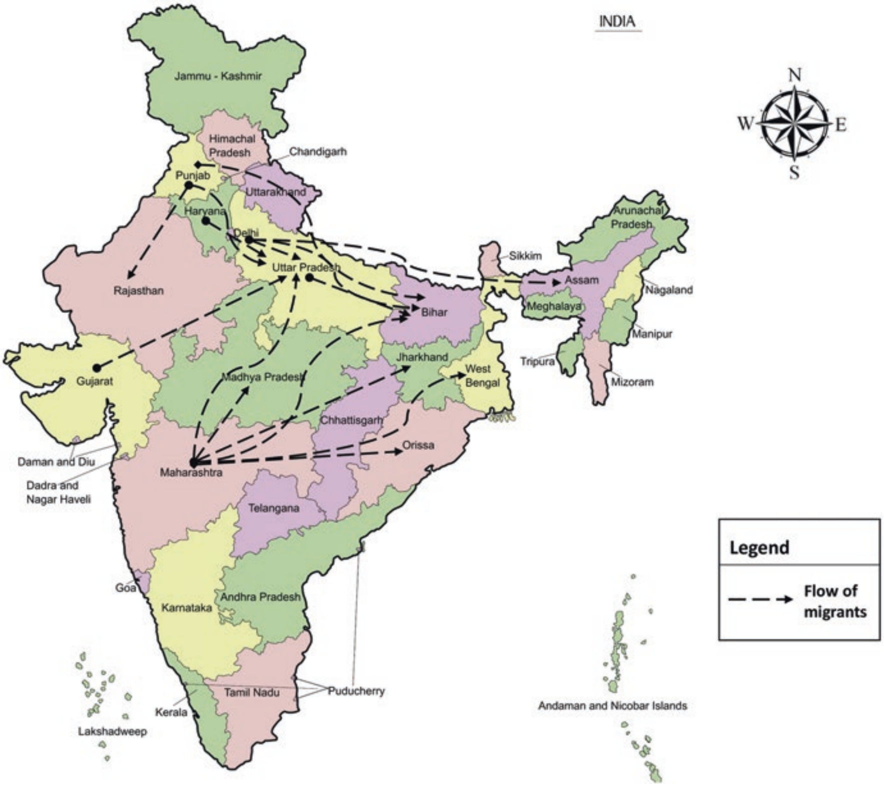

Fig. 3.3 Map of India depicting the migration trends between states. (Source: Mukhra et al., 2020)

& Ruano, 2020), Egypt (Mostafa et al., 2021), India (Singh & Chauhan, 2020), and the United Kingdom (Ropkins & Tate, 2021).

Research has also shown that the rapid decline in tourism activity in many regions has been associated with temporarily improved environmental conditions, such as reduced noise pollution, litter, and coastal water pollution (Cecchi, 2021; Ormaza- González et al., 2021). However, some studies have provided evidence that changes in household consumption during the pandemic have generated greater volumes of municipal waste, including packaging from shipments, household waste, personal protective equipment, and medical waste (Mostafa et al., 2021), which has created additional burden on waste management systems and recycling centers (Kulkarni & Anantharama, 2020).

Other research has focused on the flows of information during the pandemic, including the political polarization and social divisions that have been exacerbated during the COVID-19 outbreak (Jiang et al., 2020). Some studies have used geospatial applications to map the worldwide spread of misinformation and conspiracy theories about coronavirus (Stephens, 2020). Such misinformation has contributed to a rejection of COVID-19 containment measures, vaccine hesitancy, and eroding trust in science (Morgan et al., 2021).

Conclusion

Modern geospatial technologies that integrate web-based tools, improved data sharing, and real-time information provide critical support to public and private decision-making (Boulos & Geraghty, 2020). COVID-19 dashboards are based on the integration of these elements, and they have been vital tools for sharing information and advancing awareness of the spread of the SARS-CoV-2 coronavirus. Communication through map-based dashboards offers accessible information to people around the world eager to protect themselves and their communities. Furthermore, these dashboards are useful to policymakers and other decision makers who aim to lessen the downstream effects of the ongoing transmission of the disease. This chapter introduced merely a few examples of geospatial applications that examine the second-order impacts of COVID-19, and the body of knowledge that uses maps to convey information about the impacts of the pandemic continues to expand. However, these examples highlight the vast potential for geospatial approaches to investigate the impacts of COVID-19. Maps and other visualizations have been central to understanding both first- and second-order impacts of the COVID-19 pandemic across space and time, and at different scales, and they can be valuable tools for identifying and mitigating the most negative impacts.

Disclaimer The views expressed in this report are solely those of the authors and do not represent those of the US government agencies or any of the organizations mentioned. Assumptions made within the analysis are not a reflection of the position of any U.S. government entity.

References

Abedi, V., Olulana, O., Avula, V., Chaudhary, D., Khan, A., Shahjouei, S., Li, J., & Zand, R. (2021). Racial, economic, and health inequality and COVID-19 infection in the United States. *Journal of Racial and Ethnic Health Disparities, 8*(3), 732–742. https://doi.org/10.1007/s40615-020-00833-4

Ahasan, R., Alam, M. S., Chakraborty, T., & Hossain, M. M. (2020). Applications of GIS and geospatial analyses in COVID-19 research: A systematic review. *F1000Research, 9*, 1379. 10.12688/f1000research.27544.1.

Alon, T., Doepke, M., Olmstead-Rumsey, J., & Tertilt, M. (2020). *The impact of COVID-19 on gender equality*. National Bureau of Economic Research, Working Paper 26947.. https://doi.org/10.3386/w26947

Boulos, M. N., & Geraghty, E. M. (2020). 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. *International Journal of Health Geographics, 19*(1), 8. https://doi.org/10.1186/s12942-020-00202-8

CDC (Centers for Disease Control and Prevention). (2021). *COVID data tracker*. Centers for Disease Control and Prevention. Available at: https://covid.cdc.gov/covid-data-tracker/

Cecchi, T. (2021). Analysis of volatiles organic compounds in Venice lagoon water reveals COVID 19 lockdown impact on microplastics and mass tourism related pollutants. *Science of the Total Environment, 783*, 146951. https://doi.org/10.1016/j.scitotenv.2021.146951

Chandel, R. S., Kanga, S., & Singh, S. K. (2021). Impact of COVID-19 on tourism sector: A case study of Rajasthan, India. *Aims Geosciences, 7*(2), 224–243. https://doi.org/10.3934/geosci.2021014

Chetty, R., Friedman, J. N., Hendren, N., Stepner, M., & The Opportunity Insights Team. (2020). *How did COVID-19 and stabilization policies affect spending and employment? A new real-time economic tracker based on private sector data* (pp. 1–109). National Bureau of Economic Research, Working Paper 27431.. https://doi.org/10.3386/w27431

De Montjoye, Y. A., Gambs, S., Blondel, V., Canright, G., De Cordes, N., Deletaille, S., Engø-Monsen, K., Garcia-Herranz, M., Kendall, J., Kerry, C., Krings, G., Letouzé, E., Luengo-Oroz, M., Oliver, N., Rocher, L., Rutherford, A., Smoreda, Z., Steele, J., Wetter, E., et al. (2018). On the privacy-conscientious use of mobile phone data. *Scientific Data, 5*(1), 1–6. https://doi.org/10.1038/sdata.2018.286

Fatima, M., O'Keefe, K. J., Wei, W., Arshad, S., & Gruebner, O. (2021). Geospatial analysis of COVID-19: A scoping review. *International Journal of Environmental Research and Public Health, 18*, 2336. https://doi.org/10.3390/ijerph18052336

Groarke, J. M., Berry, E., Graham-Wisener, L., McKenna-Plumley, P. E., McGlinchey, E., & Armour, C. (2020). Loneliness in the UK during the COVID-19 pandemic: Cross-sectional results from the COVID-19 Psychological Wellbeing Study. *PLoS One, 15*(9), e0239698. https://doi.org/10.1371/journal.pone.0239698

IOM (International Organization for Migration). (2022). COVID-19 mobility impacts. Available at: https://migration.iom.int/

JHU (Johns Hopkins University). (2020). *Coronavirus Resource Center*. Johns Hopkins University & Medicine. Available at: https://coronavirus.jhu.edu/

Jiang, J., Chen, E., Yan, S., Lerman, K., & Ferrara, E. (2020). Political polarization drives online conversations about COVID-19 in the United States. *Human Behavior and Emerging Technologies, 2*(3), 200–211. https://doi.org/10.1002/hbe2.202

Kaffenberger, M. (2021). Modelling the long-run learning impact of the Covid-19 learning shock: Actions to (more than) mitigate loss. *International Journal of Educational Development, 81*, 102326. https://doi.org/10.1016/j.ijedudev.2020.102326

Kim, J., & Kwan, M. P. (2021). An examination of people's privacy concerns, perceptions of social benefits, and acceptance of COVID-19 mitigation measures that harness location information: A comparative study of the US and South Korea. *ISPRS International Journal of Geo-Information, 10*(1), 25. https://doi.org/10.3390/ijgi10010025

Kim, J., Kwan, M. P., Levenstein, M. C., & Richardson, D. B. (2021). How do people perceive the disclosure risk of maps? Examining the perceived disclosure risk of maps and its implications for geoprivacy protection. *Cartography and Geographic Information Science, 48*(1), 2–20. https://doi.org/10.1080/15230406.2020.1794976

Kraemer, M. U. G., Golding, N., Bisanzio, D., Bhatt, S., Pigott, D. M., Ray, S. E., Brady, O. J., Brownstein, J. S., Faria, N. R., Cummings, D. A. T., Pybus, O. G., Smith, D. L., Tatem, A. J., & Reiner, R. C. (2019). Utilizing general human movement models to predict the spread of emerging infectious diseases in resource poor settings. *Scientific Reports, 9*(1), 1–11. https://doi.org/10.1038/s41598-019-41192-3

Kulkarni, B. N., & Anantharama, V. (2020). Repercussions of COVID-19 pandemic on municipal solid waste management: Challenges and opportunities. *Science of the Total Environment, 743*, 140693. https://doi.org/10.1016/j.scitotenv.2020.140693

Laborde, D., Martin, W., Swinnen, J., & Vos, R. (2020). COVID-19 risks to global food security. *Science, 369*(6503), 500–502. https://doi.org/10.1126/science.abc4765

Laituri, M., Richardson, R. B., Kim, J., Cline, L. V., Viscuso, S., & Schwartz, L. (2021). Examining second-order impacts of COVID-19 in urban areas. *Annals of GIS*, 1–12. https://doi.org/10.1080/19475683.2021.1954087

Mayo Clinic. (2021). *COVID-19 patient and visitor guidelines*. Mayo Foundation for Medical Education and Research. Available at: https://www.mayoclinic.org/coronavirus-covid-19

Morgan, V., Auskova, A., & Janoskova, K. (2021). Pervasive misinformation, COVID-19 vaccine hesitancy, and lack of trust in science. *Review of Contemporary Philosophy, 20*, 128–138. https://doi.org/10.22381/RCP2020218

Mostafa, M. K., Gamal, G., & Wafiq, A. (2021). The impact of COVID 19 on air pollution levels and other environmental indicators-A case study of Egypt. *Journal of Environmental Management, 277*, 111496. https://doi.org/10.1016/j.jenvman.2020.111496

Mukhra, R., Krishan, K., & Kanchan, T. (2020). COVID-19 sets off mass migration in India. *Archives of Medical Research, 51*(7), 736–738. https://doi.org/10.1016/j.arcmed.2020.06.003

Nakada, L. Y. K., & Urban, R. C. (2020). COVID-19 pandemic: Impacts on the air quality during the partial lockdown in São Paulo State, Brazil. *Science of the Total Environment, 730*, 139087. https://doi.org/10.1016/j.scitotenv.2020.139087

NASA (National Aeronautics and Space Administration). (2021). NASA harvest COVID-19 dashboard, NASA Harvest Portal. Available at: https://harvestportal.org/dashboard/

Okruszek, Ł., Aniszewska-Stańczuk, A., Piejka, A., Wiśniewska, M., & Żurek, K. (2020). Safe but lonely? Loneliness, anxiety, and depression symptoms and COVID-19. *Frontiers in Psychology, 11*, 3222. https://doi.org/10.3389/fpsyg.2020.579181

Opportunity Insights. (2021). *The opportunity insights economic tracker: Supporting the recovery from COVID-19*. Opportunity Insights. Available at: https://opportunityinsights.org/

Ormaza- González, F. I., Castro-Rodas, D., & Statham, P. J. (2021). COVID-19 impacts on beaches and coastal water pollution at selected sites in Ecuador, and management proposals post-pandemic. *Frontiers in Marine Science, 8*, 710. https://doi.org/10.3389/fmars.2021.669374

Qiu, R. T., Park, J., Li, S., & Song, H. (2020). Social costs of tourism during the COVID-19 pandemic. *Annals of Tourism Research, 84*, 102994. https://doi.org/10.1016/j.annals.2020.102994

Rogerson, C. M., & Rogerson, J. M. (2020). COVID-19 and tourism spaces of vulnerability in South Africa. *African Journal of Hospitality, Tourism and Leisure, 9*(4), 382–401. https://doi.org/10.46222/ajhtl.19770720-26

Roos, D. (2021). How a new vaccine was developed in record time in the 1960s. *History.com*. Available at: https://www.history.com/news/mumps-vaccine-world-war-ii

Ropkins, K., & Tate, J. E. (2021). Early observations on the impact of the COVID-19 lockdown on air quality trends across the UK. *Science of the Total Environment, 754*, 142374. https://doi.org/10.1016/j.scitotenv.2020.142374

Sah, R., Sigdel, S., Ozaki, A., Kotera, Y., Bhandari, D., Regmi, P., Rabaan, A. A., Mehta, R., Adhikari, M., Roy, N., Dhama, K., Tanimoto, T., Rodríguez-Morales, A. J., & Dhakal, R. (2020). Impact of COVID-19 on tourism in Nepal. *Journal of Travel Medicine, 27*(6), taaa105. https://doi.org/10.1093/jtm/taaa105

Sharma, N., Yadav, S., Mangla, M., Mohanty, A., Satpathy, S., Mohanty, S. N., & Choudhury, T. (2021). Geospatial multivariate analysis of COVID-19: A global perspective. *GeoJournal*, 1–15. https://doi.org/10.1007/s10708-021-10520-4

Singh, R. P., & Chauhan, A. (2020). Impact of lockdown on air quality in India during COVID-19 pandemic. *Air Quality, Atmosphere & Health, 13*(8), 921–928. https://doi.org/10.1007/s11869-020-00863-1

Singh, A. L., Jamal, S., & Ahmad, W. S. (2021). Impact assessment of lockdown amid covid-19 pandemic on tourism industry of Kashmir Valley, India. *Research in Globalization, 3*, 100053. https://doi.org/10.1016/j.resglo.2021.100053

Smith, C. D., & Mennis, J. (2020). Incorporating geographic information science and technology in response to the COVID-19 pandemic. *Preventing Chronic Disease, 17*, E58. https://doi.org/10.5888/pcd17.200246

Stephens, M. (2020). A geospatial infodemic: Mapping Twitter conspiracy theories of COVID-19. *Dialogues in Human Geography, 10*(2), 276–281. https://doi.org/10.1177/2043820620935683

Tadesse, S., & Muluye, W. (2020). The impact of COVID-19 pandemic on education system in developing countries: A review. *Open Journal of Social Sciences, 8*(10), 159–170. https://doi.org/10.4236/jss.2020.810011

UNESCO (United Nations Educational, Scientific and Cultural Organization). (2021). *COVID-19 education response*. UNESCO. Available at: http://covid19.uis.unesco.org/global-monitoring-school-closures-covid19/

World Bank. (2021). *COVID-19 household monitoring dashboard*. The World Bank Group. Available at: https://www.worldbank.org/en/data/interactive/2020/11/11/covid-19-high-frequency-monitoring-dashboard

WFP (World Food Programme). (2021). HungerMap^{LIVE}. Available at: https://hungermap.wfp.org/

WHO (World Health Organization). (2020a). *Coronavirus disease (COVID-19) pandemic: Interactive timeline*. World Health Organization. Available at: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/interactive-timeline/#!

WHO (World Health Organization). (2020b). *WHO coronavirus (COVID-19) dashboard*. World Health Organization. Available at: https://covid19.who.int/

WHO (World Health Organization). (2021). *Coronavirus disease (COVID-19): Vaccines*. World Health Organization. Available at: https://www.who.int/news-room/questions-and-answers/item/coronavirus-disease-(covid-19)-vaccines

Xu, K., Cui, K., Young, L. H., Hsieh, Y. K., Wang, Y. F., Zhang, J., & Wan, S. (2020). Impact of the COVID-19 event on air quality in central China. *Aerosol and Air Quality Research, 20*(5), 915–929. https://doi.org/10.4209/aaqr.2020.04.0150

Yang, C., Sha, D., Liu, Q., Li, Y., Lan, H., Guan, W. W., Hu, T., Li, Z., Zhang, Z., Thompson, J. H., Wang, Z., Wong, D., Ruan, S., Yu, M., Richardson, D., Zhang, L., Hou, R., Zhou, Y., Zhong, C., et al. (2020). Taking the pulse of COVID-19: A spatiotemporal perspective. *International Journal of Digital Earth, 13*(10), 1186–1211. https://doi.org/10.1080/17538947.2020.1809723

Zalakeviciute, R., Vasquez, R., Bayas, D., Buenano, A., Mejia, D., Zegarra, R., Diaz, A., & Lamb, B. (2020). Drastic improvements in air quality in Ecuador during the COVID-19 outbreak. *Aerosol and Air Quality Research, 20*(8), 1783–1792. https://doi.org/10.4209/aaqr.2020.05.0254

Zambrano-Monserrate, M. A., & Ruano, M. A. (2020). Has air quality improved in Ecuador during the COVID-19 pandemic? A parametric analysis. *Air Quality, Atmosphere & Health, 13*(8), 929–938. https://doi.org/10.1007/s11869-020-00866-y

Zopiatis, A., Pericleous, K., & Theofanous, Y. (2021). COVID-19 and hospitality and tourism research: An integrative review. *Journal of Hospitality and Tourism Management, 48*, 275–279. https://doi.org/10.1016/j.jhtm.2021.07.002