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Challenges in Contact Tracing by Mining Mobile Phone Location Data for COVID-19: Implications for Public Governance in South Africa

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Abstract

Aim/Purpose	The paper's objective is to examine the challenges of using the mobile phone to mine location data for effective contact tracing of symptomatic, pre-symptomatic, and asymptomatic individuals and the implications of this technology for public health governance.
Background	The COVID-19 crisis has created an unprecedented need for contact tracing across South Africa, requiring thousands of people to be traced and their details captured in government health databases as part of public health efforts aimed at breaking the chains of transmission. Contact tracing for COVID-19 requires the identification of persons who may have been exposed to the virus and following them up daily for 14 days from the last point of exposure. Mining mobile phone location data can play a critical role in locating people from the time they were identified as contacts to the time they access medical assistance. In this case, it aids data flow to various databases designated for COVID-19 work.

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Methodology The researchers conducted a review of the available literature on this subject drawing from academic articles published in peer-reviewed journals, research reports, and other relevant national and international government documents reporting on public health and COVID-19. Document analysis was used as the primary research method, drawing on the case studies.

Contribution Contact tracing remains a critical strategy in curbing the deadly COVID-19 pandemic in South Africa and elsewhere in the world. However, given increasing concern regarding its invasive nature and possible infringement of individual liberties, it is imperative to interrogate the challenges related to its implementation to ensure a balance with public governance. The research findings can thus be used to inform policies and practices associated with contact tracing in South Africa.

Findings The study found that contact tracing using mobile phone location data mining can be used to enforce quarantine measures such as lockdowns aimed at mitigating a public health emergency such as COVID-19. However, the use of technology can expose the public to criminal activities by exposing their locations. From a public governance point of view, any exposure of the public to social ills is highly undesirable.

Recommendations for Practitioners In using contact tracing apps to provide pertinent data location caution needs to be exercised to ensure that sensitive private information is not made public to the extent that it compromises citizens' safety and security. The study recommends the development and implementation of data use protocols to support the use of this technology, in order to mitigate against infringement of individual privacy and other civil liberties.

Recommendations for Researchers Researchers should explore ways of improving digital applications in order to improve the acceptability of the use of contact tracing technology to manage pandemics such as COVID-19, paying attention to ethical considerations.

Impact on Society Since contact tracing has implications for privacy and confidentiality it must be conducted with caution. This research highlights the challenges that the authorities must address to ensure that the right to privacy and confidentiality is upheld.

Future Research Future research could focus on collecting primary data to provide insight on contact tracing through mining mobile phone location data. Research could also be conducted on how app-based technology can enhance the effectiveness of contact tracing in order to optimize testing and tracing coverage. This has the potential to minimize transmission whilst also minimizing tracing delays. Moreover, it is important to develop contact tracing apps that are universally interoperable and privacy-preserving.

Keywords COVID-19, contact tracing, public governance, South Africa

INTRODUCTION

A novel outbreak of an infectious viral disease tagged COVID-19, or SARS-CoV-2, was reported in Wuhan, a city in the Hubei province of China in December 2019 (Ceraolo & Giorgi, 2020). The disease, which has since spread to different continents, was implicated in about 32,029,704 confirmed morbidity and 979,212 mortality cases across 213 countries as of 25th September 2020 (Wang et al., 2020; World Health Organization [WHO], 2020). In January 2020, the World Health Organization (WHO) declared this outbreak a Pandemic Public Health Emergency of International Concern (Enayatkhani et al., 2020), with serious global economic distress (Ahmed et al., 2020). The epidemiology of human-human transmission of this virus has been attributed to sneezing and coughing, whereby it is transmitted (Y. Chen et al., 2020). The symptoms include fever, a sore throat, and pneumonia (Q. Chen et al., 2020). To date, there is no certified cure (Igić, 2020). Treatment relies on symptomatic relief and self-isolation to prevent infection of other people, and the recommended mode of prevention is social distancing. The process of identifying individuals who have been in close contact with an infected person is referred to as contact tracing (Baraniuk, 2020; Keyvanpour et al., 2011). This strategy, which proved helpful during an Ebola outbreak (WHO, 2015), has been proposed as a possible mode of limiting the spread of COVID-19 in many nations (Anglemyer et al., 2020). Contact tracing also has the inherent potential to produce the data required to track disease trends (Radcliffe & Clarke, 1998).

Contact tracing is a data mining process. It is implemented through physical and electronic tracing of infected persons to identify those that have come within two meters of an infected person for a period of 15 minutes or more. The European Centre for Disease Prevention and Control (ECDPC, 2020a, 2020b) recommends that such persons should be advised to remain isolated until they are declared disease free or manifest disease symptoms. There has been widespread adoption of contact tracing as a COVID-19 intervention. The African Union, through the Africa Centre for Disease Control and Prevention (ACDCP), adopted it as a possible step to slow down the spread of disease (ACDCP, 2020). In South Korea, apart from telephonic engagement, information was also sourced through CCTV footage, Global Positioning System (GPS) location data from smartphones, and credit card transaction records (Baraniuk, 2020). Other countries in Asia, Europe, and the USA have introduced software in gadgets like phones, wrist bands, and wristwatches. However, African countries have lagged behind in terms of preparedness and adoption of contact tracing, particularly during the current time against a pandemic disease like COVID-19.

According to Hellewell et al. (2020), 70% of contacts need to be traced to control most outbreaks. R. Li et al.'s (2020) study found that 86% of COVID-19 cases were undocumented (pre-symptomatic) and that these cases were responsible for causing 55% of all documented cases.

> The key research question of the study on which this paper is based is, "What are the challenges associated with contact tracing while mining mobile-phone location data in a public health emergency context such as COVID-19?"

Contact tracing can be capital and resource-intensive, especially for African countries that suffer from low levels of economic development. Challenges relating to technology, technical know-how, and trained personnel to implement this strategy, particularly at short notice, could be overwhelming. The researchers thus conducted a literature review on contact tracing in the era of COVID-19 to establish how this process influences public governance, with a focus on South Africa.

Research Methodology

In order to answer the key research question, this exploratory study drew its data primarily from the disciplines of public health and Information Communication Technologies (ICTs). A systematic review was undertaken of journal articles, books, policy briefs, and reports as well as South African government reports on the pandemic, policy documents, and South African Census Statistics. This approach was preferred because primary data could not easily be collected due to COVID-19 restrictions imposed by the government to curb the spread of the virus. The advantages of conducting a literature review include an assessment of current empirical evidence on a particular topic, the identification of key questions about the topic that require further research, and the identification of methodologies used in previous studies on the same or similar topics. Moreover, a literature review assists in identifying experts on a particular topic as well as their current research, thereby providing some guidance to researchers working on the same topic about where their focus should lie. On the other hand, a literature review is time consuming and complex in nature because it requires a specific set of skills to conduct it effectively. Furthermore, given that such reviews employ specific keywords, they offer limited access to information and overlook other important information not covered by the keywords. In addition, they rely on databases that support the keywords search and can thus miss essential information that is not captured in the databases.

The researchers accessed several search indices such as Google Scholar, EBSCO, and Scopus to identify relevant articles that cover topics such as contact tracing, COVID-19 and public health, to name but a few. Information was also accessed from government communication portals, and documentary analysis was undertaken of publications on other international and national local government associations' information portals. The papers extracted were recent ones that were published prior to November 2020. The search led to the extraction of 130 research papers, of which 72 were found usable for analysis.

Inclusion and Exclusion Criteria

The subject area of our search was limited to such disciplines as "public health", "information technology", "communications", and "multidisciplinary". Data extraction involved using keywords in titles and abstracts such as "contact tracing", "data mining", "pandemic", "health", "public", and "government" (See Table 1). Articles were assessed and screened for eligibility using the above (i.e., "contact tracing", "data mining", "pandemic", "health", "public", and "government") pre-specified eligibility search criteria. Those that did not meet the criteria were excluded. Likewise, articles such as abstracts, editorials and comments that were not original research were excluded (See Figure 1) as well as those not written in English.

Table 1: Search terms used in the review

Category type	*Search terms*
Contact tracing	Contact tracing mobile Apps deployment COVID-19 Contact tracing Digital contact tracing and pandemics
Data mining	Data mining techniques and applications Crime investigation using data mining. Data mining for COVID-19
Pandemic	Pandemic diseases COVID-19 pandemic Guidance for contact tracing for COVID-19 pandemic Epidemic contact tracing via communication traces
Health	The hazards of data mining in healthcare Public health sites for forced isolation Data mining technology and public health emergencies Data mining using big data in health informatics.
Public	Challenges of contact tracing for COVID-19 COVID-19 and digital inequalities Public sentiments in a COVID-19 environment Digital contact tracing and human rights
Governance	Implications of contact tracing for public governance Fighting COVID-19 through government initiatives South Africa's COVID-19 Tracing Database

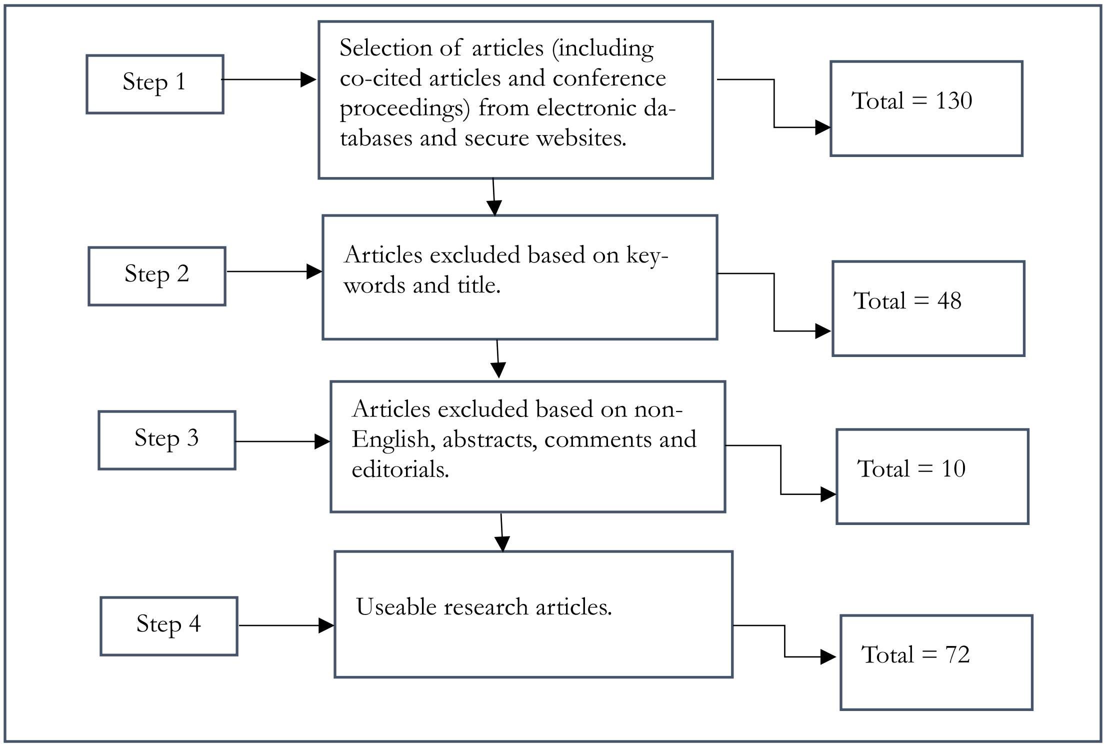
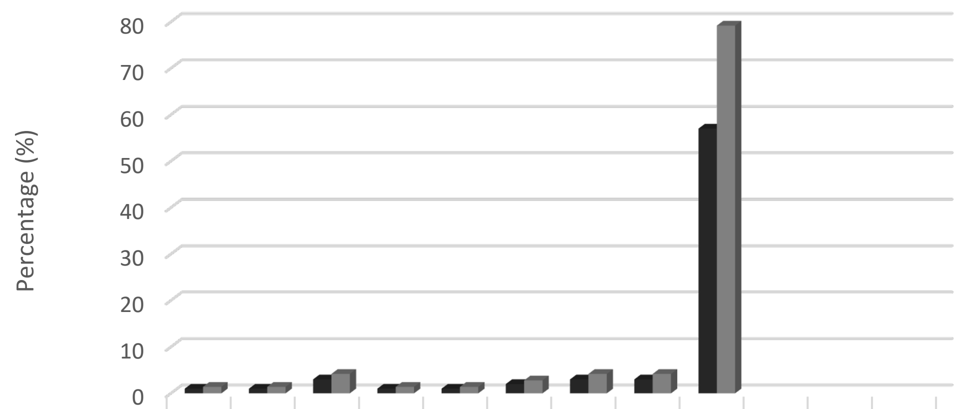


Figure 1: Steps in the selection process

Document analysis was employed to extract important information from the documents. According to Gülden (2020), document analysis is a type of qualitative research in which documents are reviewed based on a suggested procedure. Information is coded into categories and then analyzed to give meaning to a theme topic. Bowen (2009) notes that document analysis requires that data be examined and interpreted to give "meaning", "gain understanding" and "develop empirical knowledge." Inductive and deductive reasoning were applied, and the analytic procedure entailed finding, selecting, appraising, and synthesizing the data in the reviewed documents. The researchers integrated information from multiple sources through document analysis, seeking confluence of evidence to enhance credibility.

Moreover, to gain further insight from the disciplines contributing to this emerging research area, the researchers included co-cited articles that met the above eligibility criteria and included contact tracing as one of the main components in their analysis. According to Mustafee et al., (2020), co-citation analysis provides insight into possible disciplinary silos as well as theoretical and methodological gaps in the literature. It enhances transdisciplinary research as it is useful in building a shared understanding of ideas and constructs relevant to a range of disciplines (Trujillo & Long, 2018).

Figure 2 presents the distribution of the reviewed research papers by year. It shows the number of papers on contact tracing through mining mobile-phone location data in a public health emergency such as the COVID-19 pandemic and its implications for public governance in South Africa. Given the recent nature of the pandemic, a significant number of articles (57 out of 72), representing 79.17% were published in 2020. A further 20.83% were published between 2010 and 2019.



	2010	2011	2014	2015	2016	2017	2018	2019	2020			
Papers	1	1	3	1	1	2	3	3	57			
Percentage	1.39	1.39	4.17	1.39	1.39	2.78	4.17	4.17	79.17			

Figure 2: Distribution of research papers by year

Data Extraction and Synthesis

Two researchers were independently engaged to extract the data from the selected research papers, based on the following criteria.

- Does the paper discuss the challenges associated with contact tracing while mining mobile-phone location data in a public health emergency context such as COVID-19 in South Africa?
- Does the paper address the implications of this contact tracing technology for public health governance?

The data extracted by the two researchers were compared, and where there were discrepancies they were discussed and resolved through mutual consensus. The data were subsequently synthesized using the core themes that were pre-defined in the research papers. Thematic analysis was crucial in examining the challenges associated with contact tracing while mining mobile-phone location data in a public health emergency such as the COVID-19 pandemic and its implications for public governance in South Africa.

Findings And Results

This section presents a detailed discussion on the data extracted from the reviewed research papers. It synthesizes the literature by putting forward different situation contexts. Table 2 highlights the use of location data mining technology and contact tracing. It lists all 72 usable articles emerging from the selection process.

Table 2: Mapping of reviewed papers on the use of location data mining technology and contact tracing.

Study	*Location data mining technology and public health emergencies*	*Contact tracing and data mining for COVID-19*
Abbas & Michael (2020)	✓	
Abbruzzo et al. (2020)		✓
Alamo et al. (2020)		✓
Alkhatib (2020)		✓
Allan (2020)	✓	
Arakpogun et al. (2020)	✓	
Bauer (2016)	✓	
Beaunoyer et al. (2020)		✓
Q. Chen et al. (2020)		✓
Cho et al. Yu (2020)		✓
Chowdhury et al. (2020)	✓	
Cleary (2020)	✓	
Couture et al. (2020)	✓	
Das & Dutta (2020)	✓	
Dave (2020)		✓
David (2020)	✓	
Department of Co-operative Governance and Traditional Affairs (2020)	✓	
Department of Health (2020)	✓	
Dlamini et al. (2019)		✓
Dubov & Shoptaw (2020)	✓	✓
Etoori et al. (2020)	✓	
Farrahi et al. (2014)		✓
Glaeser et al. (2020)	✓	
Govender (2019)	✓	
Guinchard (2020)		✓
Han et al. (2011)		✓
Hanrahan et al. (2019)		✓
Hellewell et al. (2020)		✓
Herland et al. (2014)	✓	
Househ et al. (2017)	✓	
I.Y.F. Huang (2020)		✓
Y. Huang et al. (2020)		✓

Study	*Location data mining technology and public health emergencies*	*Contact tracing and data mining for COVID-19*
Klaaren et al. (2020)		✓
Klopfenstein et al. (2020)		✓
Khemani (2020)	✓	
Khwela (2020)	✓	
Kuraitis et al. (2020)		✓
Lavazza & Farina (2020)		✓
T. Li et al. (2020)	✓	
Lian et al. (2020)	✓	
Little et al. (2018)	✓	
Luciano (2020)		✓
Mantas (2017)	✓	
Moses (2020)	✓	✓
Nanni et al. (2021)	✓	
Naseer et al. (2020)	✓	
Osman et al. (2020)	✓	
Pentland (2010)	✓	
Parodi & Liu (2020)	✓	✓
Park et al. (2020)	✓	
Pepper & Botes (2020)	✓	
Qaffas et al. (2020)	✓	
Ranchordas (2020)	✓	
Ristevski & Chen (2018)	✓	
Ryan (2020)	✓	
Sacks et al. (2015)		✓
Schepers & Novazi (2020)		✓
Schiff et al. (2020)	✓	
Seco et al. (2020)	✓	
Seddighi et al. (2020)	✓	
Sharma & Bashir (2020)		✓
Sweidan (2020)		✓
Taberner et al. (2020)	✓	
Teo et al. (2020)	✓	
Trujillo & Long (2018)	✓	
Voigt (2020)		✓

Study	*Location data mining technology and public health emergencies*	*Contact tracing and data mining for COVID-19*
Wang et al. (2020)	✓	
Waseem & Chen (2020)		✓
Yang et al. (2020)	✓	
Yen et al. (2020)		✓
Yu et al. (2020)		✓
Zinn & Lochner (2014)	✓	

Table 3 presents each reviewed paper's mapping in relation to contact tracing and data mining for COVID-19 in South Africa and its challenges. Table 4 presents the implications of contact tracing and data mining for public governance. Finally, recommendations are made to address the problems arising as a result of these challenges.

Table 3: Mapping of reviewed papers on contact tracing, data mining and its challenges in South Africa

Study	*Contact tracing and data mining in South Africa*	*Challenges of contact tracing and data mining in South Africa*
Cleary (2020)		✓
Dave (2020)	✓	
Department of Co-operative Governance and Traditional Affairs (2020)	✓	
Department of Health (2020)	✓	
Dlamini et al. (2019)	✓	
Etoori et al. (2020)	✓	
Farrahi et al. (2014)	✓	
Govender (2019)	✓	
Hanrahan et al. (2019)		✓
Klaaren et al. (2020)		✓
Khwela (2020)	✓	
Kuraitis et al. (2020)	✓	
Little et al. (2018)		✓
Osman et al. (2020)		✓
Pentland (2010)	✓	
Pepper & Botes (2020)	✓	
Schepers & Novazi (2020)		✓
Sweidan (2020)	✓	
Voigt (2020)	✓	
Waseem & Chen (2020)		✓
Zinn & Lochner (2014)		✓

Table 4: Mapping of reviewed papers on the implications of contact tracing and location data mining for public governance

Study	*Enforcement of quarantine and ethical challenges*	*Exposure to security risks*	*Aligning government action plan*
Alkhatib (2020)	✓		
Couture et al. (2020)	✓		✓
Dubov & Shoptaw (2020)			✓
Glaeser et al. (2020)		✓	
Guinchard (2020)	✓		
Parodi & Liu (2020)			✓
Sacks et al. (2015)	✓		
T. Li et al. (2020)		✓	
Wang et al. (2020)			✓
Yen et al. (2020)	✓		✓

THE USE OF LOCATION DATA MINING TECHNOLOGY AND CONTACT TRACING

Contact tracing by mining mobile phone location data is a sound intervention to control the spread of infectious disease like COVID-19 (Hellewell et al., 2020). It has already been implemented in countries like Taiwan, China and South Korea. According to Dubov and Shoptaw (2020), contact tracing using location-tracking capabilities can accelerate the identification of newly diagnosed patients, instantly informing past contacts about their risk of infection and supporting social distancing efforts. It also aids data flow to various databases designated for COVID-19 work. However, intensive effort and cooperation from the public health sector is required to reach and monitor all contacts (Dubov & Shoptaw, 2020). The government also needs to align its action plans to combat and manage COVID-19 with contact tracing. Given the high infection rates and asymptomatic individuals' significant contribution to transmission, traditional (i.e., person-to-person) efforts to halt the pandemic by contact tracing and isolation are not possible (Dubov & Shoptaw, 2020). The alternative approach of widespread lockdowns and quarantine measures may also not be sustainable (Dubov & Shoptaw, 2020).

Using mobile phone location capabilities for swift identification and isolation of cases and exposure is a promising way to reduce transmission of COVID-19. Mining location data using mobile phones enables contact tracers to mine useful information that can assist public health officials to identify priority areas for intervention, to isolate infected individuals, and to identify those who may have come into contact with infected people and quarantine them to receive medical attention. According to Dubov and Shoptaw (2020, p. 7), "technology can scale up traditional epidemiological methods and offer a way to relax restrictive lockdown without sacrificing the protection of citizens." How, then, can mining location data be used to enhance data gathering to manage COVID-19 without infringing individual privacy and other ethical and legal considerations? The following section discusses the use of location data mining technology and public health emergencies.

The use of location data mining technology and public health emergencies

Data mining plays a critical role in public health emergencies (Herland et al., 2014). It is generally used to obtain information that is systematically employed to identify the efficiencies and inefficiencies in a system so that improvements can be made and the cost of health care can be reduced (Han et al., 2011). From a public health perspective, data mining is an essential mechanism as it supports contact investigation through smartphone technologies, complementing manual contact tracing (Yang et al., 2020). Manual contact tracing commences with diagnosed individuals reporting to a healthcare facility or department, which then assesses the risk and asks the individual to identify their known contacts prior to accessing a health facility (Trujillo & Long, 2018). The contacts are then notified of their potential exposure to the disease that the diagnosed individual may be infected with, with notification either done in person or telephonically.

In contrast, digital contact tracing uses data mined from electronic data that provides pertinent demographic and location data (Ristevski & Chen, 2018). Health care officials then use this information to trace individuals exposed to those diagnosed with public health emergencies such as COVID-19 (Bauer, 2016). Digital mining of location data is an effective mechanism to augment traditional methods of contact tracing. It helps to identify an individual's mobility trends over time, thereby enabling public health specialists and epidemiologists to map COVID-19 trends and geographical distribution (Househ et al., 2017). Moreover, it provides real-time information on mobility and identifies hotspots, making it appropriate for a rapid response from health departments (Mantas, 2017). More importantly, real-time information gathered via digital contact tracing-enabled technologies helps governments to consider post-pandemic easing of regulations as they use the information to make decisions regarding the disease's progression and undertake a cost-benefit analysis of mobility restrictions (Qaffas et al., 2020). The rise of GPS-enabled technologies has assisted the gathering of location data, as it has increased the availability of large amounts of data in real-time (Taberner et al., 2020). GPS-enabled devices provide location data that can be used to speed up interventions related to public health emergencies (Lian et al., 2020). Moreover, through this technology, location data can be mined from diverse types of users such as students, professionals, retailers, government workers, company workers, and home helpers to name but a few. The locations that they visit, such as shopping malls, places of worship, parks, and sports grounds, can be easily traced as well as the time that they spend at each of the geographical locations (Abbruzzo et al., 2020).

All these data can be mined from a large GPS dataset, aggregated, and analyzed to provide rich insight into the transmission of a disease such as COVID-19 at the community level as a broad range of users' outdoor movements are tracked and captured onto databases (Yu, et al., 2020).

The intersection of technology and public health emergencies is thus enhanced as critical points of connection are identified by intervening agencies, such as governments, research institutions, academia, civil society, and the private sector, working collaboratively to address emergencies (Seddighi et al., 2020). This multi-agency approach is necessary as scientific solutions such as vaccines are explored and the spread is mitigated against to minimize infections and mortality across geographical regions (Y. Huang et al., 2020). The following section discusses contact tracing and location data mining and their implications for public governance.

Contact tracing and data mining for COVID-19

As part of the national response to the COVID-19 crisis, governments in Europe, Asia, and other countries across the globe are considering using mobile phones and apps for a variety of purposes (Dubov & Shoptaw, 2020). This includes contact tracing by mining the mobile phone locations of symptomatic patients to curtail the spread of the virus and analyzing mobile phone location data from service providers to ascertain residents' compliance with lockdown rules. For example, Dubov and Shoptaw (2020) note that Chinese citizens are expected to report their current symptoms and travel history using the Alipay Health code app. The app will display a color-based QR-code indicating their health status. Users with a green code may travel freely and those with a yellow code are advised to stay indoors for seven days, while users with a red code are instructed to quarantine for 14 days. China was able to reduce the spread of COVID-19 and ease lockdown restrictions through this app. The app is used in the neighborhood as well as at various checkpoints (highways or train stations) to track travel. People are required to show their QR-codes at a checkpoint before they are allowed to travel.

Similarly, in Norway, users of a smartphone app called the "Smittestopp" otherwise known as "stop infection" (Naseer et al., 2020) receive alerts if they have been in close proximity to another Smittestopp user who has been infected with COVID-19 (David, 2020). The app keeps records of users who have been exposed to the coronavirus and sends signals to another user of the app. This is followed by a text message advising on the steps to take to limit further infection. However, the identity of the COVID-19 infected person is not revealed. Only the date on which the Smittestopp user was in close contact with another Smittestopp user who has been infected by the coronavirus is made known (Naseer et al., 2020). According to David (2020), this app was temporarily suspended following a Norway data protection regulator report that there are only a few coronavirus cases in the country.

In Singapore, the government released an app called "TraceTogether" and encouraged citizens to install it (Abbas & Michael, 2020). It enables digital contact tracing using Bluetooth signals between mobile phones in close proximity. The technology also enables contact tracers to establish the proximity of "TraceTogether" users who may have been infected with COVID-19 and quickly get in touch with them (Y. Huang et al., 2020). The app developers claim that users' privacy is protected as it retains the data for 21 days and thereafter deletes the oldest record and adds the latest day's data while avoiding collecting location data (Abbas & Michael, 2020). Nikkei Asian Review's report showed that more than 70% of respondents supported this app (Y. Huang et al., 2020).

The Australian government developed a digital contact tracing app called COVIDSafe (Seco et al., 2020). According to Abbas and Michael (2020), its development was based on Singapore's TraceTogether app. It automatically tracks contacts between users of the COVIDSafe app using blue trace protocol and enables the health authorities to alert other users who may have come in contact with confirmed cases. Like the TraceTogether app, COVIDSafe does not reveal confirmed cases' identity but notifies those who may have been exposed to take immediate precautions. According to Seco et al. (2020), while more than four million Australians are reported to have downloaded the COVIDSafe app as of May 2020, no information is available on how many have enabled it or continue to keep it enabled.

In Rwanda, contact tracing remains a priority to speed up testing for COVID-19. The Rwanda Utilities Regulatory Authority (RURA) has assembled a team that uses phone data profiles to trace people who had contact with COVID-19 patients (Allan, 2020). The team uses movement analytics to track other phones that were in close proximity to the infected person (Moses, 2020). It then undertakes deeper data analysis, and the information gathered helps the COVID-19 command center to trace the individuals and contact them for testing (Moses, 2020). Contact tracing has been effective in Rwanda because the people who tested positive for COVID-19 and those with whom they were in contact generally had mobile phones (Moses, 2020). Thus Moses (2020) notes that there is the possibility of missing contacts without mobile phones.

Contact Tracing and Data Mining in South Africa

Strategies to trace cases as well as their contacts have been adopted in South Africa for various purposes including crime control (Dlamini et al., 2019; Govender, 2019; Zinn & Lochner, 2014) and also to control the spreading of infectious diseases like Tuberculosis (TB), HIV/AIDS and COVID-19 (Hanrahan et al., 2019; Klaaren et al., 2020; Little et al., 2018). Contact tracing entails identifying, assessing, and apprehending or quarantining persons exposed to the virus or accomplices in a crime. While in public health, contact tracing techniques are used to gain in-depth understanding of a virus' behavior to curb its spread (Klaaren et al., 2020), in criminology, they serve to track and investigate criminals' behavior, and apprehend and convict them (Dlamini et al., 2019). In both cases, contact tracing can be achieved through physical approaches, technology-aided approaches, or a combination of both to mine data for surveillance and follow-ups on cases and case-contacts.

Physical or manual tracing of contacts, which involves household visits, manual recording of details of persons of interest, and timely physical follow-ups have been widely applied in South Africa (Hanrahan et al., 2019). To improve efficiency, these techniques are supplemented with technology, mostly the telephone. For instance, Little et al. (2018) report the use of phone calls for scheduling an appointment and tracking household members who were not present during household visits. Similarly, amidst the current global pandemic, manual contact tracing for COVID-19 cases and their contacts is carried out at designated testing centers and laboratories across South Africa (Klaaren et al., 2020; Voigt, 2020). However, these conventional approaches have been ruled ineffective, inaccurate, and costly in terms of time and funds (Etoori et al., 2020; Farrahi et al., 2014; Pentland, 2010). Conventional contact tracing practices are heavily based on individual self-reporting that can be severely biased (Farrahi et al., 2014).

Advances in technology present new opportunities to avoid such biases. Likewise, the demand for timely and highly accurate information brought about by the severity of infectious diseases such as COVID-19 has forced public health stakeholders in South Africa as elsewhere to rethink their practices for contact tracing. The country thus amended the regulations for contact tracing, making provision for the creation of an electronic database and the aggregation of personal information of persons infected or suspected to be infected or to have come into contact with COVID-19 positive cases (Klaaren et al., 2020; Pepper & Botes, 2020). Klaaren et al. (2020) note that the tracing database links a range of data warehouses to the Council for Scientific and Industrial Research (CSIR), a public institution, for purposes of research. The database contains personal information such as the name, identity number, cellphone number, COVID-19 results, and information on both known and suspected contacts. This data is generated from public and private testing facilities and laboratories, places of accommodation, and electronic communication service providers.

There have been several initiatives to develop contact tracing applications at the global and national levels, with the WHO pioneering a global app for symptoms diagnosis and tracing of contacts to support African and other developing countries (Dave, 2020). In South Africa, a smartphone application, named Covi-ID, developed in partnership between the government and the University of Cape Town, is the first official application to assist in tracking those that have tested positive and those who could have come into contact with them (Schepers & Novazi, 2020). The government has also approached technology companies to identify and develop technologies to assist in crisis response. Several applications have been developed, including the COVIDConnect app, a free information service through WhatsApp and SMS launched by the Minister of Health to augment manual tracing (Voigt, 2020). The South African COVID-19 tracing app uses Bluetooth technology and geolocation data to track and trace those in contact with a confirmed positive case. Among the offerings on the COVIDConnect platform are the COVID Alert SA app and a notification system that uses Bluetooth technology instead of GPS to notify an individual if they have been close to a positive COVID-19 case (Department of Health, 2020). These initiatives are offered on a voluntary, opt-in basis for cases and their contacts' information on the tracing database. In contrast, the new regulations have obliged mobile phone companies to promptly provide customer information on location or movement of a positive case and its contacts for surveillance purposes (Department of Co-operative Governance and Traditional Affairs, 2020).

In accordance with the provisions of the Regulation of Interception of Communications and Provision of Communication-Related Information Act 70 of 2002, geographical data from cellular tower records and other data provided are likely to reproduce errors resulting from the wide-area coverage or data capturing processes of the operators (Department of Co-operative Governance and Traditional Affairs, 2020). Thus, it is critical to employ appropriate data mining strategies, including processes for data review, error correction, and analysis (Department of Co-operative Governance and Traditional Affairs, 2020; Klaaren et al., 2020). Moreover, the regulations that establish digital contact tracing by authorizing the use of individualized data for tracing of contacts go beyond the CSIR's initial intention of aggregating location data for analytic purposes to inform national crisis response strategies and policies. As in other parts of the world, this poses several challenges to contact tracing practices in South Africa.

Challenges of Contact Tracing for COVID-19 in South Africa

Tracing cases and their contacts for COVID-19 largely hinges on the use of personal information. Protection of the privacy of such information is regarded as a basic human right. While contact tracing is an important tool to combat the spread of COVID-19 or fight crime, its implementation is not without challenges. This section discusses the major challenges in regard to the application of contact tracing in South Africa.

Information disclosure has proven a challenge in tracking and tracing cases and their contacts. Osman et al. (2020) posit that social norms and cultural attitudes shape people's perceptions of contact tracing and their willingness to participate. In South Africa, fear of being isolated from their family and community has made people reluctant to test and provide information about themselves or their contacts (Cleary, 2020). In some cases, people have provided inaccurate or false information in an attempt to avoid being harassed, isolated, or taken to the designated centers for quarantine and treatment (Waseem & Chen, 2020). Moreover, the stigma and discrimination directed against those who have tested positive for COVID-19 and their contacts, especially their immediate family, discourages voluntary release of the requisite information for effective contact tracing. Gary Sweidan, South Africa's COVID-19 patient zero, has recounted the stigmatization and discrimination he and his family experienced, with family members being accused of being irresponsible by being in contact with him despite adhering to strict protocols to provide care (Sweidan, 2020). The fear, anxiety, discrimination, and stigma arising from widely disseminated COVID-19 misinformation have resulted in people not seeking healthcare or adopting behavior to curb the spread of infection (Cleary, 2020; Osman et al., 2020).

Furthermore, while contact tracing undoubtedly helps to curb the spread of COVID-19, the accompanying tracing database infringes the constitutional right to privacy and also evokes ethical dilemmas in medical professional practice (Klaaren et al., 2020). The right to privacy is the basis for protecting details of one's private life, such as medical status, address, and movement, from the public domain. However, contact tracing violates this. The provisions in South African law that enable cellular data to be accessed for anti-crime activities or public health management have been challenged by the courts as anti-privacy, citing suspicions of covert and unauthorized use of information (Pepper & Botes, 2020). This begs the question of what will stop the state from using information from contact tracing for other purposes outside the public health realm? In the case of COVID-19, measures such as notification of the purpose and storage of information, the duration for storing the information, a notice of when the data is destroyed/deleted from the database, and the appointment of a designated COVID-19 judge to oversee the contact tracing database have been put in place. However, with the postponement of the Protection of Personal Information Act 4 of 2013, which qualifies health information as special personal information and stipulates additional safeguarding measures for collecting, processing, and storing, privacy protection in South Africa remains in the hands of the common law and the constitution. Thus, in implementing contact tracing in the time of a pandemic, the challenge is balancing constitutional obligations to ensure the safety of all citizens from the effects of public health emergencies and to provide health services without prejudice.

Moreover, the role of technology in contact tracing is unclear and questionable given the sheer volume of contact tracing applications released globally. The question thus arises as to whether it is a critical supporter or a distractor (Kuraitis et al., 2020). In South Africa, Covi-ID, and COVIDConnect with the COVID Alert SA app are among the official applications, while private institutions such as schools and universities have come up with their own offerings. An example is the University of KwaZulu-Natal's smartGro app (Khwela, 2020). As in other countries, the myriad of applications raises the issue of the integration of the information from these sources while maintaining privacy. This exacerbates the data aggregation problem for any meaningful information to support decision making at the policy level. Likewise, the influx of COVID-19 tracing applications amplifies global concerns relating to the lack of privacy due to the lack of transparency in some applications on the collection and use of personal data (Kuraitis et al., 2020).

Contact Tracing, Location Data Mining and Implications for Public Governance

Contact tracing and location data mining are useful in mitigating against public health emergencies such as COVID-19. In many respects, the use of technology has enabled better management of the pandemic as governments collaborate with the private sector and other technology solutions providers to provide supportive mechanisms to curb the transmission of the virus (Alkhatib, 2020). Mining location data has enabled an on-time response from the government in terms of preventative measures for specific geographical regions as it draws insights from various datasets rich with information about people, their behavior and movement (Couture et al., 2020). Whilst this is laudable, it has implications for public governance. These are discussed below.

Enforcement of Quarantine Measures Can Raise Ethical Challenges

Geo-locational data can be used to enforce quarantine measures such as lockdowns aimed at reducing the spread of a public health emergency such as COVID-19 (Glaeser et al., 2020). Conversely, the use of digital contact tracing tools alongside location data mining mechanisms can be used to ease lockdown regulations in areas declassified as hotspots, that is, areas in which transmission and infection levels are low relative to other regions (Alkhatib, 2020). Rapid identification of cases and their isolation help to prevent contagion and support non-pharmaceutical interventions to prevent a rise in infections (Wang et al., 2020).

While digital contact tracing apps and location data mining tools are hailed as successful interventions to manage pandemics such as COVID-19, they rely on the public to report when they test positive for the virus (Sacks et al., 2015). Public announcement that one is a virus carrier can lead to stigmatization as people isolate themselves from the infected individual. The virus carrier may also suffer psychological trauma. Thus, whilst technology may solve one problem, it could result in other challenges that adversely impact public governance (Guinchard, 2020). For instance, in South Africa, like in other countries, contact tracing involves collecting private citizens' information that can be lost if not properly stored. From a human rights point of view, data loss violates individual confidential information privacy and raises an ethical dilemma that the government and its agencies must always prevent. This is an ongoing challenge as governments endeavor to strike a balance between effective mitigation of a pandemic and saving lives without creating situations that will infringe on citizens' civil liberties.

Exposure to Security Risks Due to Location Disclosure

The use of geolocation data might expose confidential information to publicly accessible databases that may compromise their security and predispose them to criminal activities such as theft (T. Li et al., 2020). From a public governance perspective, any public exposure to social ills is highly undesirable (Dubov & Shoptaw, 2020). Therefore, as contact tracing apps are used to provide pertinent data location, caution needs to be exercised to ensure that sensitive private information is not made public irresponsibly to the extent that it can compromise the safety and security of the public.

Aligning Governments' Action Plan and Contact Tracing Processes

It is essential that the government's action plans to combat and manage COVID-19 are aligned with contact tracing (Glaeser et al., 2020). Testing and contact tracing are highly dependent on control measures. If these measures do not align with contact tracing processes, some ill people may not be located and remain untreated (Wang et al., 2020). Whilst testing is a support rather than a substitute for contact tracing and location data mining, all these processes need to be aligned for effective management of public health emergencies (Yen et al., 2020). This calls for the coordination of all stakeholders involved in managing COVID-19 as misalignment can defeat the overall intention of saving lives (Parodi & Liu, 2020).

In summary, this section discussed the implications of contact tracing and location data mining for public governance. Whilst technology is useful in managing a public health emergency such as COVID-19, there are risks that need to be managed in order to ensure that civil liberties are not violated. Collaborative efforts are required among a range of stakeholders to ensure a coordinated effort to minimize the risk of the adverse effects that may occur through the use of technology.

Recommendations for Practice

The Data Collected Should be Used for Pandemic Containment Only

It is imperative that safeguards be built into location tracing to ensure that the data is not retained or used for any other purpose than epidemic containment. Therefore, access to and use of data should be limited and highly regulated, and any abuse of these conditions should be met with punitive penalties by the state (Alamo, Reina, & Millán, 2020).

Promote Data Privacy

Connected to the above point, the data collected must be protected from unauthorized access as well as data loss. Unauthorized access could involve access to data by public health officials not assigned to COVID-19 processes, as well as health insurance companies such as medical aids and medical schemes (Wang et al., 2020). One way of protecting data is to ensure that it is anonymized and shared only on request with designated and authorized public health officials (Sharma & Bashir, 2020). Another way is to encrypt it and have it stored on users' phones, especially if they tested positive and it has been requested (Chowdhury, Ferdous, Biswas, Chowdhury, & Muthukkumarasamy, 2020). All these aspects of privacy call for proper database management by government and all holders of geo-location data.

Promote the Privacy of Those Testing Positive for COVID-19

Contact tracing and data location mining can be invasive as they access and use people's confidential information (Sharma & Bashir, 2020). People must be tested before the information is captured and all those they had contact with are traced (Cho, Ippolito, & Yu, 2020). They may suffer stigma as they are quarantined as positive virus carriers and third parties may access their information. Every effort should be made to ensure that private information is not accessible to unauthorized third parties. Publicly available information should be limited to protect people's identities. Moreover, there should be a consent process to promote transparency on who is accessing data and the purpose for which they seek to use it.

Promote State-Citizen Partnerships and Collaboration

Contact tracing and location data mining are high stakes activities as far as privacy is concerned. This calls for state-citizen engagement on how they should be implemented (Nanni et al., 2020). Citizens should be part of decision-making processes on data collection, usage and resulting interventions (Klopfenstein et al., 2020). Their voice is represented by civil society organizations who continuously interact with the government authorities to ensure that civil liberties are not violated as per the Constitution of South Africa. Civil society should be represented in any decision-making body that manages a pandemic such as COVID-19 (Q. Chen et al., 2020). This will ensure that ordinary citizens' interests are represented and prioritized. On the other hand, the governing body is responsible for sharing frequent updates on the various processes regarding contact tracing and location data mining as well as the usage of that information (Khemani, 2020). Y. Huang, Sun, and Sui (2020) argue that governments are responsible for reporting the results obtained using digital mechanisms such as changes in infection trends and mortality rates, including when these mechanisms may be phased out.

Moreover, the inclusion of vulnerable and marginal populations should be taken into account, as the digital divide is a reality in many areas of South Africa (Beaunoyer, Dupéré, & Guitton, 2020). Digital technologies may not reach such populations. The government thus needs to be aware of the sections of the population that might be excluded from technology adoption (Das & Dutta, 2020). It is imperative to ensure that technology does not marginalize any population groups as this violates their civil rights (Arakpogun, Elsahn, Prime, Gerli, & Olan, 2020). Other possibilities must be explored, such as sharing information in other ways that accommodate those who do not have mobile phones. Furthermore, the information should be presented in a language that they understand.

Avoid Stigmatizing People Through Responsible Use of Technology-Enabled Intervention Mechanisms in Managing COVID-19

Technology has the potential to exacerbate inequalities in society, including the propagation of stigma (Dubov & Shoptaw, 2020). When people's movement is controlled, the purpose of contact tracing should be properly communicated so that it does not cause those that may not be aware of this digital technology mechanism to stigmatize others (Teo, Tan, & Prem, 2020). For instance, travelers are quarantined while undergoing testing and awaiting the results. Members of the public could misinterpret this preventive measure and assume that the travelers are COVID-19 carriers (Park, Choi, & Ko, 2020). As such, government authorities that use digital mechanisms should apply the preventative measures responsibly. No government wants to be seen to be promoting stigma in society (Ryan, 2020).

Leave No One Behind in Managing COVID-19

In the months since the first COVID-19 case was confirmed in South Africa, it has been shown that ICTs and mobile technology can assist in managing public health emergencies such as COVID-19. These virtual solutions have proven efficient in facilitating interaction between health care workers and the public as well as the collection and sharing of data across multiple agencies tasked with various responsibilities aimed at curbing the pandemic (Lavazza & Farina, 2020). While these efforts are laudable, it is imperative to keep in mind that not everybody may be reached via these technological mechanisms (Ranchordas, 2020). Who are we leaving behind by relying purely on technology and remote data collection? In our new way of working, we need to take a step back and consider how we reach those with no access to ICTs and places where contact tracing and location mining data are not possible (Luciano, 2020). Otherwise, we run the risk of widening inequalities due to technology use and further exacerbating the situation by neglecting populations in need of COVID-19 healthcare services.

Conclusion

Contact tracing and location data mining are useful digital mechanisms to manage epidemics (Schiff, Biddle, Borenstein, & Laas, 2020). As discussed in this paper, they present both opportunities and risks. They offer opportunities to improve public health delivery and enhance technology use in curtailing public health emergencies such as COVID-19. However, there is a risk of excluding certain sections of the population due to existing digital inequalities. Therefore, governments across the world need to work to minimize the digital divide so that every person can enjoy public health services, including those provided through a digital mechanism. This will ensure that digital mechanisms assist in tackling public health emergencies and promote the constitutional imperatives of ensuring equal access to health services, irrespective of socio-economic status.

Limitations and Suggestions for Future Research

This research was limited to a literature review as it was not easy to collect primary data due to the restrictions imposed by the South African government in response to the COVID-19 pandemic. Furthermore, the study focused on COVID-19, and other pandemics such as HIV/AIDS, Tuberculosis, and Ebola were not considered. The insights presented are thus limited to COVID-19 and do not capture learnings from past experiences of similar public health emergencies.

Future research should focus on collecting primary data to provide insights on contact tracing with reference to mining mobile phone location data. In addition, future research should further explore how app-based technology can enhance the effectiveness of contact tracing, with potential to optimize testing and tracing coverage and to minimize transmission whilst minimizing tracing delays. Moreover, it is important to develop contact tracing apps that are universally inter-operable and privacy-preserving.

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