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# Digital Epidemiology: Harnessing Big Data and Artificial Intelligence for Enhanced Disease Surveillance

**[1] Abduaziz Rashed Zaid Bin Gannam,[2] Nasser Faleh M Alghatani,[3]- Fahad Mohammed Najmi,[4]-Hamad Ahmad Nasser Al Saigh,[5] Ali Jarrdi Ahmed Aljaafari.,[6]-Hamad Ibrahim Hamad Alghareeb,[7]-Wael Bejad Sajed Alamri,[8]-Tariq Ghunaim H Alharbi,[9]-Almuhannad Hamad Ahmed Bajawi,[10] -Tariq Abdulmonaim Alaki,[11]-Ibrahim Mohammad Ibrahim Shabani,[12]-Ahmed Abduh Ahmed Hamzi,[13]-Jabril Yousef Ahmed Abdali**

1. Ksa, Ministry Of Health, First Health Cluster In Riyadh Casablanca II Health Center
2. Ksa, Ministry Of Health, Casablanca Health Center2 Riyadh
3. Ksa, Ministry Of Health, Department Of Health Centers In The Southern Sector - Jazan
4. Ksa, Ministry Of Health, The First Health Cluster In Riyadh
5. Ksa, Ministry Of Health, Al-Husseini Primary Care Center - Western Sector
6. Ksa, Ministry Of Health, Riyadh First Health Complex Okaz Health Center
7. Ksa, Ministry Of Health, Preventive Medicine Public Health - Madinah
8. Ksa, Ministry Of Health, King Salman Bin Abdulaziz Medical City
9. Ksa, Ministry Of Health, Jazan Infection Control Department
10. Ksa, Ministry Of Health, Public Health Administration - Infectious Diseases .
11. Ksa, Ministry Of Health, Iradah Hospital In Jizan
12. Ksa, Ministry Of Health, Alaradh Primary Health Care Center
13. Ksa, Ministry Of Health, Alaradh Primary Health Care Center

**Abstract**

**Background:** The emergence of SARS-CoV-2 in late 2019 highlighted the critical need for advanced disease surveillance systems. Digital epidemiology, leveraging Big Data and artificial intelligence (AI), offers promising solutions for effective monitoring and management of infectious diseases like COVID-19.

**Methods:** This review explores the integration of Big Data analytics and AI in enhancing disease surveillance. It examines various data types, including real-time epidemiological data, social media trends, and population mobility patterns. Case studies, such as the AI-driven initiatives by Blue Dot and Johns Hopkins University, illustrate the application of these technologies in early outbreak detection and trend forecasting.

**Results:** The findings indicate that AI and Big Data significantly improve the efficiency of pandemic response. For instance, AI algorithms successfully predicted COVID-19 case surges based on social media search trends and population mobility data. Additionally, novel diagnostic tools, including salivary tests and AI-enhanced imaging platforms, have emerged to facilitate rapid and accurate COVID-19 diagnosis.

**Conclusion:** The integration of Big Data and AI into public health strategies enhances the ability to monitor disease spread, predict outbreaks, and inform decision-making. These technologies not only improve responsiveness to current pandemics but also pave the way for more resilient healthcare systems in the future. Continued investment in digital epidemiology is essential for efficient disease surveillance and management, ensuring preparedness for future health crises.

**Keywords:** Digital Epidemiology, Big Data, Artificial Intelligence, Disease Surveillance, COVID-19.

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## 1. Introduction

In late December 2019, a cluster of cases attributed to an emerging virus causing pneumonia of unknown etiology and respiratory symptoms was identified among patients, several of whom had frequented the "Huanan Seafood Wholesale Market" in Wuhan, Hubei province, southern People's Republic of China. The unique virus was first designated as "2019 novel coronavirus" (2019-nCoV) and later as "Severe Acute Respiratory Syndrome Coronavirus type 2" (SARS-CoV-2). It was first isolated on January 7, 2020. As of 25 April 2020, the virus has disseminated internationally, affecting 210 nations and infecting over 3,000,000 individuals, resulting in 200,000 fatalities [1,2]. Individuals infected with the virus may present as either asymptomatic or symptomatic, with clinical manifestations ranging from mild (e.g., fever, sore throat, and cough) to severe (including pneumonia, respiratory failure, and perhaps death) [2]. The infectious illness produced by SARS-CoV-2 is referred to as "coronavirus disease" (COVID-19) [3].

From a molecular standpoint, SARS-CoV-2 is an enveloped, single-stranded, positive-sense RNA virus and constitutes the eighth coronavirus capable of human-to-human transmission [4]. Bats, recognized as reservoir hosts for several zoonotic viruses such as Hendra and Nipah, have been identified as potential primary reservoirs of coronaviruses in China. Genomically, SARS-CoV-2 has roughly 50% and 79% genetic sequence similarity with MERS-CoV and SARS-CoV, respectively [5]. Moreover, SARS-CoV-2 has a receptor-binding domain structure similar to that of SARS-CoV [6].

Recent advancements in computational techniques and information and communication technologies (ICTs) enable artificial intelligence (AI) and Big Data to manage the vast, unprecedented volumes of data generated from public health surveillance, real-time epidemic monitoring, trend forecasting, regular updates from governmental institutions, and health resource utilization information [7].

Big Data is traditionally characterized by three Vs: velocity, referring to the exceptional speed of data acquisition, processing, and manipulation, often termed "fast data"; volume, indicating the substantial quantity of available information; and variety, denoting the diverse sources and channels capable of generating and disseminating Big Data [8,9]. Big Data can be categorized based on its sources: molecular Big Data, derived from wet-lab techniques and OMICS methodologies, including genomics and post-genomics fields such as proteomics and interactomics; imaging-based Big Data, exemplified by radiomics, which involves extensive data-mining to extract clinically relevant, high-dimensional information from images; sensor-based Big Data, generated by wearable sensors; and digital and computational Big Data, characterized by the vast amounts of data produced by the internet, smartphones, and other mobile devices [10-13]. This study will examine significant potential uses of AI and Big Data in the management of COVID-19.

## 2. Immediate Utilization of Artificial Intelligence and Big Data: An Efficient Pandemic Notification System

Big Data facilitates real-time monitoring of disease outbreaks. In comparison to other epidemics and pandemics, COVID-19 is unique due to the extensive availability of open-access datasets that provide daily statistics of new infections categorized by nation and, in some instances, by city. The integration of our data on human mobility is an ideal dataset for the amalgamation of mathematical modeling and artificial intelligence. Blue Dot, a Toronto-based start-up utilizing an AI-enhanced surveillance system, appears to have been the first to identify the epidemic outbreak, several hours after its emergence in the initial epicenter of Wuhan, well in advance of Chinese authorities and other international institutions and agencies [14].

Computational techniques facilitate real-time visualization of virus dissemination, exemplified by the application developed at Johns Hopkins University, USA. Additionally, social Big Data, gathered from social networks and other unconventional data sources, allows for the reconstruction of the outbreak's early epidemiological narrative. Sun and colleagues [15] conducted a population-level observational research, examining healthcare-related websites, social networks, and news stories from January 13 to January 31, 2020, in mainland China. Authors stated that non-classical datasets may assist researchers in comprehending the dissemination of an epidemic concerning health literacy, healthcare-seeking behaviors, and the usage of health services. Particularly during the first phases of the epidemic, non-traditional information and data streams might guide the formulation and execution of successful public health strategies.

Likewise, Qin and colleagues [16] used Big Data to forecast the quantity of new COVID-19 instances, whether suspected or confirmed. Authors used a delayed set of "Social Media Search Indexes" (SMSI) for many terms, including COVID-19 clinical symptoms such as dry cough, fever, chest discomfort, and pneumonia. Researchers discovered that using methods like subset selection enabled the detection of new suspected and confirmed COVID-19 cases 6–9 and 10 days in advance, respectively.

Yang and colleagues [17] used population mobility data to enhance a dynamic transmission, compartmental "Susceptible-Exposed-Infectious-Removed" (SEIR) model, integrated with an AI methodology, trained on SARS data, to forecast the COVID-19 pandemic trajectory. The authors showed that a five-day delay in the enforcement of the rigorous public health measures implemented by Chinese authorities would have led to a threefold rise in epidemic magnitude. Relaxing the lockdown measures would result in a second peak in Hubei province from mid-March to late April.

Regarding another coronavirus, Song and colleagues [18] examined the online dissemination of information, the propagation of anxiety, and the perceived risk of catching MERS during the epidemic in South Korea from May to June 2015. Negative sentiment was seen to be more prominent in online discussion boards, Twitter, and online cafés compared to news sites and blogs. News buzz, distinct from rumor buzz, is associated with happy feelings and references to consuming immunity-enhancing foods. Public health authorities must focus on the veracity, one of the three Vs of Big Data, which pertains to the correctness and dependability of the acquired data. The analysis and modeling of Big Data must account for uncertainty and address it, so assuring the robustness of the results. This remains an unresolved problem.

## 3. Immediate Utilization of Artificial Intelligence and Big Data: Monitoring and Diagnosing COVID-19 Cases

The availability of a reliable, sensitive, and specific diagnostic test is crucial for the prevention and management of infectious diseases. Researchers have developed a molecular tool that can swiftly and precisely diagnose and differentiate between COVID-19 and SARS-CoV. Salivary diagnostics seems to provide significant potential for the accurate detection of the virus. In conjunction with molecular assays and testing, either multiplex nucleic acid amplification or microarray-based high-resolution CT of the chest is essential for monitoring illness progression and its development regarding severity and treatment response. Ongoing research aims to uncover early radiological prognostic indicators, which would significantly aid in the stratification and clinical treatment of COVID-19 patients [7,14,19].

Artificial intelligence may enhance the diagnosis of COVID-19 patients. Infervision is a start-up that use deep learning medical imaging platforms to expedite the diagnosis of COVID-19 by identifying distinct lung characteristics [7,14]. Moreover, blockchain technology is a distinctive decentralized framework for recording, validating, and authorizing data, as well as executing a sequence of transactions. It is distinguished by a robust security framework that facilitates the provision of patient-centered healthcare services, improved public health monitoring, outbreak control, and prompt, efficient decision-making [20-22]. A cost-effective blockchain and AI-integrated self-testing and tracking system has been suggested for controlling the COVID-19 pandemic in both developed environments (to prevent overloading public health capacity and healthcare/laboratory infrastructure) and in developing, resource-constrained settings [20,22].

## 4. Medium-Term Applications of Artificial Intelligence and Big Data: Identifying a Prospective Pharmacological Intervention

At present, there are no officially sanctioned therapy alternatives for the management of COVID-19. Physicians must provide supportive treatment to patients and assess their dietary state prior to medicine administration. In light of the emergency situation, and recognizing the time and resource constraints associated with developing specific therapeutics, researchers are investigating three primary strategies: assessing the viability of employing existing broad-spectrum antiviral medications, considering modifications or adaptations based on the biochemical and biophysical characteristics of the novel virus, and utilizing available pharmaceuticals, whether from Western or traditional Chinese medicine, for alternative therapeutic applications (drug repositioning or repurposing) [2].

These tactics seek to target the virus by directly interfering with it, obstructing its associated biological processes and events (such as viral entrance and reproduction), or by strengthening the human immune system [2]. Advancements in genomic and post-genomic sciences facilitate the rapid analysis of genome sequences, identifying similarities with other genomes and uncovering possible druggable targets. Potential pharmacological agents for COVID-19 encompass neuraminidase inhibitors such as Oseltamivir and Peramivir, antiviral protease inhibitors including Ritonavir/Lopinavir, nucleotide analogs like Remdesivir, nucleoside inhibitors such as Ribavirin, influenza hemagglutinin-mediated fusion inhibitors like Arbidol/Umifenovir, and anti-malarials such as Chloroquine, among others.

The majority of COVID-19 patients are receiving Oseltamivir, while recent Cochrane reviews have raised concerns over its efficacy in influenza therapy. Oseltamivir has shown little clinically significant effects, accompanied by a notable incidence of adverse events. Information about Peramivir is very scarce, with a restricted number of randomized clinical trials (RCTs) available, hence obstructing a comparison between the two neuraminidase inhibitors. Furthermore, in-vitro testing tests have not shown the prevention of cytopathic effects of SARS-CoV [2], instead revealing the effectiveness of some commercially available interferons. Nonetheless, they have been underutilized in the therapeutic care of individuals with COVID-19 too far.

The application of Ribavirin, a pro-drug of ribavirin triphosphate and a competitive inhibitor of the enzyme inosine monophosphate dehydrogenase, essential for guanosine and nucleic acid biosynthesis, lacks support from both cellular and clinical data. Numerous studies have reported conflicting results and clinically significant toxicities that could lead to the cessation of treatment [2]. Arbidol has little evidence available [2], and its usage for treating severe acute respiratory infections is typically not advised. In SARS patients, Lopinavir/Ritonavir has shown in-vitro antiviral properties, facilitated the reduction of steroid dosages, lowered hospitalizations and nosocomial infections, leading to a diminished viral load and an elevated peripheral lymphocyte count [2].

A limited number of individuals are receiving treatment with ganciclovir, an acyclovir analogue and inhibitor of the Herpesvirus family, including cytomegalovirus (CMV). Ganciclovir is authorized for addressing problems from AIDS-related CMV infection; however, in vitro studies have shown no reduction of the cytopathic effects of SARS-CoV [2]. Moreover, some clinicians prescribe corticosteroids, with the Cochrane reviews indicating moderate evidence about their effectiveness in clinical outcomes and the avoidance of complications and mortality. A comprehensive assessment of the therapeutic effects of candidate medications against SARS-CoV revealed that 25 out of 29 research evaluated the use of steroids, which was deemed inconclusive, with four studies indicating possible damage to patient health [23]. The efficacy of antibiotics in treating viral pneumonia seems to be restricted.

Artificial intelligence can rapidly find prospective medicines and vaccination candidates. A partnership between the AI start-up BenevolentAI and Imperial College London has resulted in the identification of baricitinib, a biologic utilized for treating moderately to severely active rheumatoid arthritis in adults, as a potential inhibitor of the janus kinases JAK1 and JAK2 with anti-viral properties. Concurrently, the Hong Kong-based start-up Insilico Medicine has announced the discovery of six novel drugs that may impede viral replication [24].

Zhang and colleagues [25] conducted a network pharmacology analysis of traditional Chinese medicine, systematically identifying natural compounds utilized in Chinese therapies. They discovered 13 compounds that may possess potential anti-COVID-19 effects through the regulation of viral replication, modulation of immune and inflammatory pathways, and the hypoxia cascade.

## 5. Medium-Term Utilization of Artificial Intelligence and Big Data: Enhancing the Execution of Public Health Initiatives

During an epidemic, resources are scarce and may be rapidly depleted. Consequently, to prevent resource wastage and optimize the allocation of available assets, the Chinese government has enhanced traditional data gathering methods with modern computational tools and procedures that have facilitated the identification of at-risk individuals. The start-up Megvii has revealed the advancement of advanced body and facial detection, along with dual sensing through infrared cameras and visible light, functioning as thermal scanners for the swift screening of individuals in crowded environments to identify fever and elevated temperatures, potentially associated with COVID-19.

Ant Financial Services Group, formerly referred to as Alipay and part of the Alibaba group, has developed AI-driven apps that use characteristics such as self-reported health state, travel history, and contact history to detect COVID-19 instances. The system has been established in Shizhu County, Chongqing, in southern China, to monitor population movement during the Chinese Lunar New Year vacation, which has facilitated the transmission of the virus. This technology has enabled the determination of quarantine measures. In the provinces of Zhejiang, Sichuan, and Hainan, sophisticated data analysis has been used to recreate social interactions and conduct contact tracing.

Srinivasa Rao and Vazquez [26] have delineated a framework using an AI algorithm designed for the rapid detection of infected patients, conducting risk assessments and evaluations based on symptoms and indicators associated with the new coronavirus. This will be conducted by a web- or mobile-based survey. Additionally, based on the responses, the algorithm may dispatch alerts to clinics or mobile health units for health visits and case verification.

## 6. Prolonged Utilization of Artificial Intelligence and Big Data: Developing Intelligent, Healthy, and Resilient Urban Environments

In recent years, significant socioeconomic trends, such as globalization, fast urbanization, population growth, and demographic shifts, have profoundly altered our lives. Over half of humankind resides in urban areas, a proportion projected to rise to two-thirds of the worldwide population by 2050. In Western nations, fewer than half of the population resided in urban areas at the onset of the 20th century; this ratio quadrupled by the beginning of the new century and is expected to continue rising in the next decades.

The eleventh Sustainable Development Goal (SDG-11) of the United Nations asserts the need to "make cities and human settlements inclusive, safe, resilient, and sustainable," a commitment reaffirmed at the 2016 United Nations Habitat III conference on housing and sustainable urban development in Ecuador, known as the "New Urban Agenda." It is more essential. Environmental difficulties, including pollution, waste management, and climate change, and health issues such as communicable diseases—specifically food- or vector-borne infections—pose significant threats to inhabitants' livability and quality of life [27].

This necessitates a multi-disciplinary strategy for successful resolution by all stakeholders, including urban designers, planners, and public health professionals, while also engaging people in sustainable urban management planning and empowerment. An integrated systems approach is essential, since a healthy city resembles a living, dynamic organism. Intelligent interconnected devices, wearable sensors, and other advanced technologies such as smartphones, telecommunications, networks, and GPS facilitate the real-time collection of substantial user-centered and technology-driven data, enabling quality monitoring, transparency, and accountability, optimization of resource allocation, citizen participation and inclusion, and resilience and adaptation to external events.

In recent years, several towns and communities in Spain, New Zealand, the United States, the United Kingdom, Canada, and the United Arab Emirates have initiated programs and challenges to foster research and innovation in the subject. A recent systematic review of the literature indicates that smart cities facilitate population-wide surveillance, combat aging by fostering active aging, socialization, and healthy lifestyles, incorporate disabled and marginalized individuals, and offer prompt and efficient responses to emergencies and disasters, including outbreaks [27]. Nonetheless, despite the significance of this subject, there exists a scarcity of mathematical models, as noted by Grindrod and associates [28]. The domain of "mathematics of smart cities" presents significant challenges, since modeling communities involves complex considerations about city limits and their interactions with adjacent surroundings. Documenting the temporal dynamics of interactions among various components of a smart city is rather challenging.

Following calamities, the likelihood of infectious diseases increases significantly. Policies for effective disaster and emergency management must be comprehensive and multi-tiered, including prevention, protection, mitigation, preparedness, response, and recovery. Current policies exhibit deficiencies, as they lack a multi-criterion, comprehensive, and highly integrated approach that anticipates future events through risk-assessment scenarios and proactive planning, instead primarily emphasizing disaster resilience and relying on contingent evaluations influenced by administrative and political pressures.

Artificial Intelligence and Big Data may provide local decision-makers and policymakers with educated, evidence-based forecasts. Allam and Jones [29] examined the COVID-19 epidemic from an urban perspective, demonstrating how smart cities and networks might use superior established rules for data exchange during crises to improve management of such scenarios. Conversely, unlike the preceding parts, this area remains mostly hypothetical, with applications now in an experimental phase.

Artificial Intelligence and Big Data have significant promise for the management of COVID-19 and other crises, with expectations for their involvement to expand in the future. Artificial Intelligence and Big Data can facilitate real-time monitoring of virus transmission, inform the planning and cessation of public health measures, evaluate their efficacy, repurpose existing compounds, identify novel pharmaceuticals, ascertain potential vaccine candidates, and improve community and regional responses to the ongoing pandemic. These novel methodologies may be used with traditional surveillance: while the latter facilitates data processing and interpretation, the former reveals concealed trends and patterns, which can be employed to construct prediction models.

According to Hua and Shaw [30], despite the initial delay by Chinese authorities in addressing the outbreak, “a unique combination of strong governance, strict regulation, robust community vigilance and citizen participation, and astute utilization of big data and digital technologies” has been pivotal to the People's Republic of China's success in containing COVID-19. Additional study is necessary to investigate the use of advanced technologies that preserve human rights and privacy while maintaining high standards.

## 7. Conclusion

The integration of Big Data and artificial intelligence (AI) in disease surveillance represents a transformative shift in public health management, particularly highlighted by the COVID-19 pandemic. As demonstrated throughout this review, these technologies significantly enhance the capability to monitor, predict, and manage infectious diseases, providing timely insights that are crucial for effective public health responses. The utilization of real-time data from diverse sources—such as social media, mobility patterns, and health reports—enables health authorities to identify outbreaks early and implement targeted interventions. For instance, AI algorithms have proven effective in forecasting disease trends, allowing for proactive measures that can mitigate the spread of infections. Furthermore, advancements in diagnostic technologies, including AI-driven imaging and novel testing methods, facilitate rapid identification of cases, which is critical in controlling outbreaks.

Despite these advancements, challenges remain in ensuring data accuracy and protecting individual privacy. The reliance on large datasets raises concerns about data security and the ethical implications of surveillance. Therefore, it is essential for policymakers to establish robust frameworks that balance the benefits of data utilization with the need for ethical standards and individual rights. Looking ahead, continued investment in digital epidemiology is necessary to advance our understanding of disease dynamics and improve public health infrastructure. Collaborative efforts among governments, technology companies, and public health organizations can foster innovation in surveillance systems, ensuring they are adaptable and resilient to future health crises.

In conclusion, the ongoing integration of AI and Big Data into disease surveillance not only enhances our current capabilities but also sets the foundation for a more responsive and effective public health landscape. By embracing these technologies, we can better prepare for and manage future pandemics, ultimately safeguarding global health.

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**علم الأوبئة الرقمية: تسخير البيانات الضخمة والذكاء الاصطناعي لتعزيز مراقبة الأمراض**

**الملخص**

**الخلفية :**أدى ظهور فيروس SARS-CoV-2 في أواخر عام 2019 إلى تسليط الضوء على الحاجة الملحة إلى أنظمة متقدمة لمراقبة الأمراض. يوفر علم الأوبئة الرقمية، الذي يعتمد على البيانات الضخمة والذكاء الاصطناعي، حلولًا واعدة لرصد الأمراض المعدية مثل COVID-19 وإدارتها بشكل فعال.

**الطرق :**تستعرض هذه المراجعة تكامل تحليلات البيانات الضخمة والذكاء الاصطناعي في تعزيز مراقبة الأمراض. يتم استعراض أنواع مختلفة من البيانات، بما في ذلك البيانات الوبائية في الوقت الفعلي، واتجاهات وسائل التواصل الاجتماعي، وأنماط التنقل السكاني. كما يتم تقديم دراسات حالة، مثل المبادرات المدفوعة بالذكاء الاصطناعي من قبل شركة Blue Dot وجامعة جونز هوبكنز، لتوضيح تطبيق هذه التقنيات في الكشف المبكر عن تفشي الأوبئة وتوقع الاتجاهات المستقبلية.

**النتائج :**تشير النتائج إلى أن الذكاء الاصطناعي والبيانات الضخمة يعززان بشكل كبير كفاءة الاستجابة للجائحة. على سبيل المثال، توقعت خوارزميات الذكاء الاصطناعي بدقة زيادات في حالات COVID-19 بناءً على اتجاهات البحث في وسائل التواصل الاجتماعي وبيانات التنقل السكاني. بالإضافة إلى ذلك، ظهرت أدوات تشخيصية جديدة، بما في ذلك اختبارات اللعاب ومنصات التصوير المدعومة بالذكاء الاصطناعي، لتسهيل التشخيص السريع والدقيق لـCOVID-19.

**الخلاصة :**يعزز تكامل البيانات الضخمة والذكاء الاصطناعي في استراتيجيات الصحة العامة القدرة على مراقبة انتشار الأمراض، والتنبؤ بتفشيها، ودعم اتخاذ القرارات. لا تقتصر فوائد هذه التقنيات على تحسين الاستجابة للأوبئة الحالية، بل تفتح أيضًا المجال أمام أنظمة صحية أكثر مرونة في المستقبل. إن الاستثمار المستمر في علم الأوبئة الرقمية ضروري لتحقيق مراقبة فعالة للأمراض وإدارتها، وضمان الجاهزية للأزمات الصحية المستقبلية.

**الكلمات المفتاحية :**علم الأوبئة الرقمية، البيانات الضخمة، الذكاء الاصطناعي، مراقبة الأمراض، .COVID-19