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Epidemiological Surveillance Innovative Applications for Community and Public Health: A Systematic Review

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ABSTRACT

The paper explores the transformative impact of digital media on epidemiological surveillance. We are aiming to highlight innovative technologies such as Artificial Intelligence (AI), Internet of Things (IoT), Blockchain, and Wearable Devices role in collecting surveillance data. Through predictive modeling, image recognition, and Geographic Information Systems (GIS), the integration of digital tools has revolutionized disease detection, outbreak prediction, and resource allocation aiding in overall data surveillance system. Cases including Arogya Setu, BlueDot, and HealthMap illustrate the efficacy of AI-driven surveillance during the COVID-19 pandemic. Challenges persist, necessitating a holistic approach encompassing technological advancement, regulatory frameworks, and ethical considerations to optimize the benefits of digital surveillance while safeguarding privacy and equity

KEYWORDS: Epidemiological surveillance, Artificial Intelligence (AI), Internet of Things (IoT) and Blockchain Technology

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I. INTRODUCTION

Epidemiological surveillance means systematic health data collection and analysis, and dissemination and this data is used to inform public health decision-making, forms the cornerstone of disease control efforts. Traditional methods of epidemiological data collections include surveys, interviews, medical records, and community assessments. The history of epidemiological surveillance includes significant interventions such as mass vaccination campaigns, establishment of disease control programs, and creation of surveillance systems. These interventions aimed to combat endemic diseases like smallpox through initiatives such as the smallpox eradication campaign in the 1960s [1]. The CDC's Epidemic Intelligence Service (EIS) was pivotal in investigating outbreaks and expanding surveillance beyond vector-borne diseases. However, challenges like the Tuskegee study scandal and mishandling of the swine flu epidemic in 1976 tarnished the CDC's reputation. The emergence of AIDS in the 1980s prompted a resurgence in the CDC's relevance, despite budget cuts and political obstacles. Additionally, in Brazil's São Paulo state, initiatives dating back to the late 19th century, such as mass vaccination campaigns and the creation of health departments and institutes, laid the foundation for effective surveillance efforts. The establishment of the National Epidemiological Surveillance System in the 1970s underscored the importance of notification and response to communicable diseases. Challenges in the 21st century, including pandemics like H1N1 and COVID-19, highlight the ongoing need for robust epidemiological surveillance systems in public health [1]. This literature review aims to explore the cutting-edge applications of such technologies in community surveillance, highlighting their significance in bolstering early detection, improving data accuracy, and ultimately safeguarding public health. Through an in-depth examination of current research, this review seeks to elucidate the pivotal role of technology in advancing epidemiological surveillance practices.

II. METHODS

Inclusion and Exclusion Criteria

We decided on articles published in peer-reviewed journals only, and those studies that focused on the application of innovative technologies in community-based epidemiological surveillance were selected. Most of the studies that were published within the last five years are considered a priority; however, in the criteria, about ten-year-old articles were included to extract some important information. Articles that were available in the English language were selected. Our exclusion criteria were designed so that non-peer-reviewed publications such as conference abstracts, editorials, and opinion pieces would be discarded. We avoided articles that did not explicitly address the use of technology in community surveillance. Articles needing more detail on methodology or results were promptly discarded.

Search Strategy:

A comprehensive search was conducted using electronic databases, including PubMed and Scopus. Our primary vital terms were "digital health," "community surveillance," "epidemiological surveillance," "innovative technologies," "wearable biosensors," "real-time data analytics," and "artificial intelligence" were used in various combinations to identify relevant articles. Boolean operators (AND, OR) were utilized to refine search results and ensure inclusivity. We used MeshTerms like ((Epidemiological et al. OR Digital Innovation Digital et al. OR Innovations in Community Surveillance)). While selecting articles, we reviewed titles first, and then after the screening, we selected studies and excluded irrelevant papers. After selecting papers, we read abstracts, and further studies were discarded. Full-text articles meeting inclusion criteria were retrieved and further evaluated for eligibility.

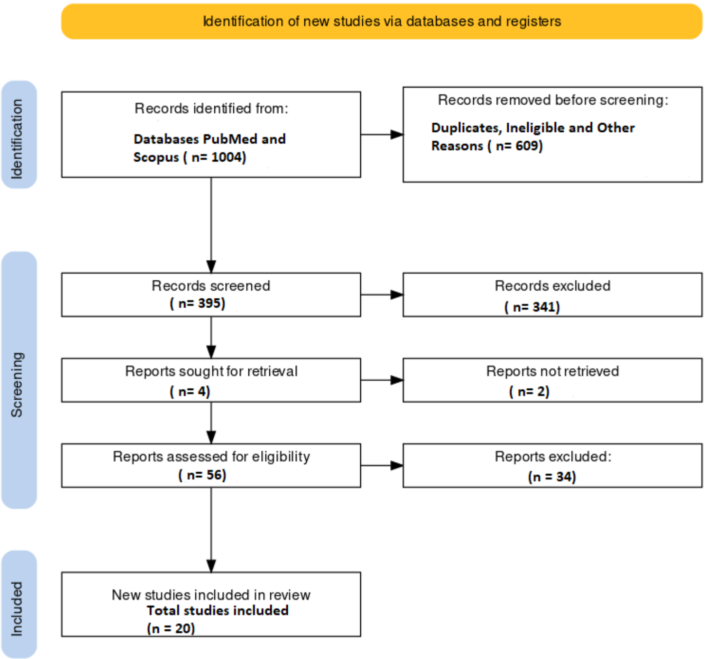

Figure 1. Flowchart for PRISMA

III.RESULTS

Table 1. Summary of findings

Author Name	Year of Publication	Findings and Results
Anjaria, P., Asediya, V., Bhavsar, P. P., Pathak, A., Desai, D., & Patil, V.	2023	AI-based technological advances can reduce pandemic-related disparities and broaden medical access. They enable equitable vaccine distribution, combating issues like vaccine hesitancy and unequal access. However, challenges include potential false results and data privacy concerns. Policy implications stress data security, responsible use, research investment, and addressing ethical concerns like bias and discrimination. Future research should refine algorithms, improve vaccination records, and enhance disease detection.
Association of Health Care Journalists	2023	Passive surveillance relies on voluntary reporting, while active surveillance involves systematic searching for cases. Passive surveillance detects patterns but lacks a clear denominator, while active surveillance provides a denominator for assessing incidence or prevalence. Systems like VAERS are passive, while VSD is active, offering clearer data for adverse event monitoring.

Barata, R. B.	2022	The narrative review explores the historical evolution of epidemiological surveillance, initially conceived to combat communicable diseases. It highlights the establishment of the CDC in the United States as a global benchmark and outlines the development of surveillance systems in São Paulo, Brazil. It concludes by distinguishing epidemiological surveillance from monitoring and health surveillance.
Donelle, L., Comer, L., Hiebert, B., Hall, J., Shelley, J., Smith, M. J., Kothari, A., Burkell, J., Stranges, S., Cooke, T., Shelley, J. M., Gilliland, J., Ngole, M., & Facca, D.	2023	The scoping review examines the use of digital technologies for public health surveillance during the COVID-19 pandemic. It identifies various technologies utilized globally and highlights factors impacting their efficacy, including uptake, technological capacity, and legal frameworks. The findings underscore the importance of evaluating digital surveillance's value and mitigating potential harms.
Environmental tracking for public health surveillance	2013	Study titled with Environmental Tracking for Public Health Surveillance, delves into the integration of satellite imagery and data for disease surveillance, tracing its development from the 1970s to the present. It explores methods for assessing environmental factors impacting public health and emphasizes the importance of interdisciplinary collaboration. This comprehensive resource targets professionals in public health, spatial data analysis, Earth observation, and medical research.
Centre of Disease Control	2018	GIS plays a pivotal role in field investigations, aiding in situational awareness, boundary establishment, sampling plans, and population estimation. Utilizing publicly available data like US Census and health outcome data, GIS assists in assessing population at risk and identifying epidemic patterns across space and time. Collaboration with GIS experts enhances field team capacity.
Hayman, D. T. S., Adisasmito, W., Almuhairi, S., Behravesh, C. B., Bilivogui, P., Bukachi, S. A., Casas, N., Becerra, N. M. C., Charron, D., Chaudhary, A., Zanella, J. R. C., Cunningham, A. A., Dar, O., Debnath, N., Dungu, B., Farag, E., Gao, G. F., Khaitsa, M. L., Machalaba, C., . . . Koopmans, M.	2023	The One Health High-Level Expert Panel advocates for integrated surveillance systems in their article "Developing One Health surveillance systems." Recognizing the interconnectedness of human, animal, and environmental health, they stress the need for holistic approaches to disease surveillance. Their framework encompasses both traditional pathogen-focused surveillance and monitoring of drivers of disease emergence for effective prevention and mitigation.
Huang, J., Li, J., Li, Z., Zhu, Z., Shen, C., Qi, G., & Yu, G.	2022	The article "Detection of Diseases Using Machine Learning Image Recognition Technology in Artificial Intelligence" has been retracted. It aimed to apply machine learning-based image processing in childhood disease detection, demonstrating promising results in identifying white blood cells. However, due to undisclosed reasons, the article has been retracted, raising concerns about its validity and reliability.
Jpiersol	2023	Digital apps have revolutionized public health surveillance by enabling real-time data collection, analysis, and dissemination. These apps enhance accessibility, accuracy, and timeliness of information, empowering both individuals and health authorities to monitor and respond to health threats efficiently. Embracing digital tools is essential for advancing public health surveillance in an increasingly interconnected world.
Kanchan, S., & Gaidhane, A.	2023	The National Library of Medicine (NLM) website previews improvements to PubMed Central (PMC) for October 2024. PMC, as part of NLM, offers access to scientific literature. It's crucial to note that inclusion in NLM databases doesn't imply endorsement. A study discussed social media's role in public health, highlighting its benefits and challenges ethically, professionally, and socially. The impact of platforms like Twitter, YouTube, and Facebook on health information dissemination and health-

		related behaviors was explored. The research also touched upon relevant guidelines and policies from medical associations and authorities.
Nsubuga, P., White, M. E., Thacker, S. B., Anderson, M. A., Blount, S. B., Broome, C. V., Chiller, T. M., Espitia, V., Imtiaz, R., Sosin, D., Stroup, D. F., Tauxe, R. V., Vijayaraghavan, M., & Trostle, M.	2006	Public health surveillance involves systematic data collection, analysis, and dissemination to prevent and control diseases. It empowers decision-makers by providing timely evidence for effective management. Developing countries and donors increasingly recognize its importance for resource allocation and program evaluation. Competent epidemiologists and surveillance staff are essential for rational planning and intervention.
Olawade, D. B., Wada, O. J., David-Olawade, A. C., Kunonga, E., Abaire, O. J., & Ling, J.	2023	The narrative review in Frontiers in Public Health discusses the emerging role of artificial intelligence (AI) in enhancing public health. AI applications include spatial modeling, risk prediction, misinformation control, and disease forecasting. While AI offers significant potential, challenges like infrastructure limitations and ethical concerns hinder universal implementation. The COVID-19 pandemic accelerated AI adoption in public health, aiding in forecasting, contact tracing, and rapid testing.
Otoum, S., Al Ridhawi, I., & Mouftah, H. T.	2021	This comparative study evaluates AI-driven intrusion detection techniques for critical infrastructures, utilizing machine learning, deep learning, and reinforcement learning. Results demonstrate the efficacy of Q-learning-based IDS in detecting malicious behavior. The research highlights the significance of robust intrusion detection systems in safeguarding cyberphysical systems, particularly in the context of increasing data traffic and security concerns.
Radin, J. M., Wineinger, N. E., Topol, E. J., & Steinhubl, S. R.	2020	Finding suggested an example with integrating Fitbit data significantly enhances state-level influenza-like illness predictions, with strong correlations observed between Fitbit-derived metrics and CDC-reported ILI rates. These findings underscore the potential of wearable technology for real-time disease surveillance, facilitating timely public health interventions to mitigate infectious disease spread.
Sahu, K. S., Majowicz, S. E., Dubin, J. A., & Morita, P. P.	2021	The article discusses the potential of utilizing Internet of Things (IoT) data sources for public health surveillance. It highlights the advantages of IoT data, such as high volume and frequency of data collection, real-time availability, and minimal acquisition effort. The authors summarize existing literature on IoT as a surveillance tool and discuss challenges in incorporating IoT data into public health surveillance systems. They emphasize the need for leveraging IoT data to meet the evolving needs of surveillance in public health.
Tulchinsky, T. H., & Varavikova, E. A.	2014	The study emphasizes the pivotal role of epidemiology and health monitoring in shaping public health policy and management. Utilizing data systems and research methods, it underscores the importance of informed decision-making, efficient health information systems, and accountability in achieving optimal population health and cost-effective healthcare delivery.
Xu, Y., Liu, X., Cao, X., Huang, C., Liu, E., Qian, S., Liu, X., Wu, Y., Dong, F., Qiu, C., Qiu, J., Hua, K., Su, W., Wu, J., Xu, H., Han, Y., Fu, C., Yin, Z., Liu, M., . . . Zhang, J.	2021	The review article highlights the profound impact of artificial intelligence (AI) on various fields, including fundamental sciences like mathematics, medical science, physics, and more. AI, coupled with machine learning techniques, facilitates data analysis, prediction, and decision-making, accelerating research and enabling novel applications across disciplines. The paper offers insights into AI's potential to address scientific challenges and outlines emerging research trends, aiming to guide researchers and foster advancements in fundamental sciences.
Asadzadeh, A., Samad-Soltani, T., & Rezaei-Hachesu, P.	2021	Virtual and augmented reality (VR/AR) offer innovative solutions for managing infectious disease outbreaks like COVID-19. VR simulates

		infection scenarios and aids in skill development, telehealth, and drug discovery. AR enhances communication and visualization. While VR is more prevalent, both have potential across entertainment, clinical, business, and educational domains. Leveraging these technologies could significantly improve emergency responses and mitigate pandemic impacts."
Gasser, U., Ienca, M., Scheibner, J., Sleigh, J., & Vayena, E.	2020	The article discusses the utilization of digital public health technologies for combating the COVID-19 pandemic and easing lockdown measures. It highlights the ethical and legal challenges surrounding the deployment of such tools and presents a typology of primary digital health applications, including contact tracing and symptom monitoring. The paper aims to provide guidance for policymakers and decision-makers on the ethical development and utilization of these technologies.
Kumar, P. S., Ramasamy, M., & Varadan, V. K.	2022	Remote monitoring and digital health systems are vital in healthcare. Demand for precise, easy-to-use biosensor technology is rising. Such systems offer crucial insights during clinical events. Wearable, implantable, and ingestible biosensors cater to diverse clinical needs. This chapter outlines disease priorities, system components, and transitions between biosensor types.

Table 2. Basic type of surveillance system

Surveillance Type	Description
Indicator	A measurable factor enabling decision makers to objectively estimate the magnitude of a health issue and monitor intervention effects (e.g., new cases of diarrhea, proportion of fully immunized children, percentage of high school students smoking) **Error! Reference source not found.**.
Active Surveillance	Involves staff regularly contacting healthcare providers or the population to gather health information, providing accurate but costly data.
Passive Surveillance	Health jurisdiction receives reports from hospitals, clinics, or other sources, offering relatively inexpensive coverage but with challenges in data quality and timeliness due to reliance on various institutions for data submission **Error! Reference source not found.**
Routine Health Information System	A passive system where regular reports on diseases and programs are submitted by public health staff, hospitals, and clinics.
Health Information and Management System	A passive system gathering routine reports on financial, logistic, and administrative processes involved in public health and clinical systems, serving surveillance purposes **Error! Reference source not found.**.
Categorical Surveillance	Active or passive system which focuses on specific diseases or behaviors, useful for program managers but potentially inefficient due to multiple forms and challenges in resource allocation and data reconciliation.
Integrated Surveillance	Utilizes a combination of active and passive systems to gather information on multiple diseases or behaviors, aiming for a single infrastructure; though efficient, may lead to duplication and inefficiency if disease-specific systems are maintained.
Syndromic Surveillance	Active or passive system using clinical features for case definitions rather than clinical or laboratory diagnosis, offering rapid but less specific data which may require further investigation; useful in resource-limited settings but may mask epidemics.
Behavioral Risk Factor Surveillance System (BRFSS)	An active system of repeated surveys measuring behaviors causing disease or injury (e.g., tobacco use, unprotected sex), providing timely measures of program effectiveness for both communicable and noncommunicable disease interventions **Error! Reference source not found.**.

Principal of Public Health Surveillance system

The primary aim of surveillance is to collect data at the national or international level to understand pattern changes of diseases or problems related to healthcare. This information is then used to guide intervention strategies in less time and at less cost [6]. For instance, swift responses to acute infectious disease epidemics like SARS necessitate surveillance systems offering rapid early warning data from clinics and laboratories The design and implementation of this system are specific to public health objectives and required actions. While driving data, its crucial to ensure that data is flexible and adaptable to make changes, and simple stable system is needed which is continues without any chance of breakdown. The slow progression of chronic diseases such as hypertension or certain metabolic disorders and health-related behaviors such as smokers warrants less frequent monitoring, typically on an annual basis or even less frequently. Surveillance systems that measure the population effects of programs, such as tuberculosis control, may yield information only every one to five years through demographic and health surveys. The choice of surveillance or health information system should align with the type, frequency, and urgency of actions required, ensuring optimal support for public health initiatives [2].

Current State of Epidemiological Surveillance and role of Digital Media Revolutionizing Surveillance in the Digital Age

The penetration of the internet in modern life is now prominent and has transformed surveillance functions about public health issues. The market share of social networks has been the largest, and each person has an average of eight social accounts. This data, whose primary purpose is not to scrutinize, has become a crucial aspect of digital public health surveillance (DPHS). The utilization of digital platforms enables real-time information on disease dynamics and the ability to speed up reactions to growing health issues. Through digital data, infodemiology and infoveillance become two possible approaches for research and surveillance to be part of public health. Inaccurate data is still a persistent issue, but digital surveillance systems have been regarded as making many breakthroughs as they have been as reliable as the traditional methods; thus, a new age in public health monitoring and intervention has approached. As the concept of digital media in public health surveillance boards progresses, the potential of digital media in promoting public health is increasingly seen. Thus, it is being implemented to design more effective and responsive health interventions in the digital age [7].

Innovations of Emerging Technologies in AI

The most straightforward public health planning tool is epidemiological surveillance, which spans the process of sensing, analyzing, and distributing health information to new disease outbreaks. AI-based surveillance is another powerful mechanism in healthcare security, as AI algorithms can scan and analyze data streams, including electronic health records, social media, and news sources [8]. AI systems supply workable know-how to public health bodies, leading to intelligent and corrective actions for emerging health difficulties. AI-driven surveillance has become 100 times superior over conventional methods, and its superiority lies in its capacity to anticipate future outbreaks, enabling pro-active interventions and experts of these systems continually refine their predictive capabilities through adaptive learning, a feature absents in static traditional approaches [9].

For example, Arogya Setu" app, a collaboration between the Indian Government and various stakeholders, including the National Informatics Centre (NIC), offers real-time contact tracing and self-assessment during critical times like the COVID-19 pandemic. With over 210 million downloads, its AI-driven system provides accurate perceptions while aiding both individuals and health authorities in combating the virus and saving lives. Similarly, Canada's "BlueDot" is another AI based platform that effectively issued early warnings about COVID-19 by analyzing diverse data sources, influencing global pandemic response strategies. "HealthMap," based in Boston, Massachusetts, monitors disease outbreaks in real-time using data from social media and health reports, aiding proactive interventions. The most famous AI based software BioSense" by the CDC employ machine learning to detect disease outbreaks promptly, improving public health outcomes [8].

AI-based surveillance system needs meticulous attention to regulatory frameworks safeguarding data privacy and restraining its misuse. It's crucial to focus on advancing algorithms, improving vaccine distribution systems, and setting up real-time surveillance methods. These are key areas of research that we need to prioritize. Ensuring robust data security measures is essential for building trust in AI-powered medical advancements. Collaboration among policymakers, health professionals, and stakeholders can address these gaps and challenges linked with AI use epidemiological surveillance [8].

Predictive Modeling Technology

Predictive modeling in healthcare encompasses various applications where mostly there is use of artificial intelligence and machine learning algorithms to forecast outcomes, trends, and behaviors. Predictive models can analyze historical epidemiological data, environmental factors, population demographics, and various variables to estimate the likelihood of future disease outbreaks. Early warning signs are predicted and public health authorities can implement proactive measures that helps mitigating the spread of diseases while allocating resources effectively. Predictive models have become so efficient as they are being now used in individual patient data to stratify the risk of developing certain diseases or experiencing adverse health events, develop tailor interventions, preventive measures, and treatment plans to improve patient outcomes and reduce healthcare costs. Predictive modeling expedites drug discovery by analyzing molecular structures and clinical data. It optimizes resource allocation in healthcare by forecasting patient demand and bed occupancy. In chronic disease management, it monitors patient data, predicts complications, and enables personalized interventions for improved outcomes [11].

Image Recognition for Disease Detection

Image recognition for disease detection in epidemiological surveillance works by utilizing machine learning algorithms to analyze medical images such as X-rays, MRI scans, or microscopy images. These algorithms are trained on a large dataset of labeled images to identify patterns and features indicative of various diseases or health conditions. Once trained, the system can automatically analyze new images, flagging any abnormalities or potential signs of disease for further review by healthcare professionals [11]

Geographic Information Systems (GIS)

Geographic Information Systems (GIS) integrate spatial data, geographical mapping, and data visualization techniques to analyze and visualize patterns, trends, and relationships in disease outbreaks. GIS platforms aggregate and analyze epidemiological data, demographic information, and geographic coordinates to monitor disease incidence, prevalence, and spatial distribution in real-time. By mapping disease hotspots, transmission pathways, and vulnerable populations, GIS helps public health authorities identify high-risk areas, allocate resources, and implement targeted interventions to control disease spread. GIS-based epidemic models simulate the spread of infectious diseases within populations by incorporating spatial, temporal, and demographic factors. By predicting disease transmission dynamics, population movements, and intervention effects, GIS enables public health officials to evaluate different control strategies, optimize resource allocation, and mitigate the impact of epidemics [12].

Blockchain Technology in Public Heath Surveillance

Blockchain technology offers a decentralized and immutable platform for secure data sharing and collaboration among stakeholders in disease surveillance networks. Blockchain ensures the integrity and immutability of surveillance data by cryptographically linking individual data blocks in a tamper-resistant and transparent manner. By recording data transactions on a distributed ledger, blockchain prevents unauthorized modifications or tampering with surveillance data, thereby enhancing data integrity and trustworthiness. Blockchain facilitates interoperability and data standardization by providing a common framework for data exchange and collaboration across disparate surveillance systems and organizations. By establishing consensus mechanisms and smart contracts, blockchain enables seamless integration and sharing of surveillance data while maintaining data privacy and security [13].

NextGen Public Health surveillance _Internet of Things (IoT)

While IoT data has proven its utility in various health sectors, its full potential in public health surveillance remains largely untapped. The 2020 Riyadh Declaration, prompted by the pandemic, emphasized the necessity for scalable and sustainable digital health technologies, particularly highlighting the importance of health intelligence. There's a burgeoning interest in harnessing IoT data for constructing public health indicators across different levels.

IoT data presents an opportunity to overcome existing surveillance limitations. With its high-frequency data collection and widespread use of devices like smartphones, wearables, and smart-home technologies, IoT offers data sources with greater usability. Presently, billions of smartphones and wearable device users worldwide contribute to this data ecosystem effortlessly. Moreover, IoT data boasts features like high granularity, objectivity, and validity, with minimal effort and cost from both users and researchers. Additionally, IoT enables near real-time data collection, significantly reducing the time gap between health events and intervention. Assessing IoT's current attributes through Groseclose et al.'s framework for public health surveillance reveals several advantages and challenges. IoT excels in features like high-frequency data collection, potential for syndromic surveillance, ease of data collection, and diverse data types. However, challenges such as lack of representativeness within a single data source, involvement of private entities as data owners, technological requirements for data management, and data privacy concerns pose significant hurdles to adoption [14].

One significant challenge lies in accessing and analyzing the vast amounts of IoT data being generated. While some companies offer research-oriented data sources, others publish studies from their own devices, creating barriers to data fusion. Technical hurdles include energy optimization, hardware compatibility, security, and data connectivity. However, recent advancements in algorithm development show promise in addressing these challenges. IoT data holds potential in detecting aberrations and early signs of diseases. Wearables like Fitbit and Oura ring have demonstrated the ability to detect early signs of COVID-19 infection, potentially weeks before symptoms appear. These anomalies in IoT data could predict future outbreaks and facilitate early intervention, contributing significantly to disease prevention and control efforts [14].

Wearable Devices

Technology-on-wearables has brought a sea change in health surveillance by allowing the continuous recording of vital signs and lifestyle patterns. Smartwatches and fitness trackers track heartbeats, sleeping patterns, and physical activities. That is why medical professionals can evaluate the early signs of the disease and provide appropriate treatment. Distant patient monitoring gives care away from the clinic, highlighting individuals with chronic conditions. More sophisticated sensors detect minute changes that suggest a disease is developing, and such data impact the way each patient benefits from personalized interventions and care. Telemedicine integration makes it easy to reach a broader population, especially those living in underserved and remote areas. Aggregate data from wearables is being used for public health surveillance and directed towards interventions and policies. These innovations in medicine hope to improve the health care dispatch and population health management [15].

Environmental Sensors

A clear, exciting advancement in environmental sensor technology guarantees innovative opportunities for monitoring chemical contamination and other environmental hazards. These sensors comprise intelligent air quality sensors capable of real-time monitoring air pollutants such as particulate matter (PM) and odorous organic compounds (VOCs). Water quality sensors are fitted in water bodies, monitoring pollution indicators like pH, dissolved oxygen, and specific contaminants in lakes, rivers, and groundwater sources.

The sensors used in these soil contamination detectors show whether pesticide and heavy metal content in soil samples are at dangerous levels. The primary purpose of biological sensors is to use organisms to detect toxins and pathogens in air, water, and soils with very high sensitivity. The growth of remote sensing technologies such as satellite imagery and UAVs is crucial in obtaining comprehensive environmental data because they have the necessary coverage to monitor large and inaccessible areas. With the advent of the Internet of Things, sensors and devices are pre-connected and transmitting data over the Internet. In environmental management, we can do real-time observation to promote sustainable resource utilization and minimize environmental degradation. These revolutionary technologies are key factors that gave us an understanding of the environment and its dangers to humans and assisted in preserving ecosystems [16].

Navigating the Complexities of Digital Surveillance

Effective implementation of digital surveillance is a beneficial concept since its existence depends on many factors, each having a unique role in determining the results. The appropriation of surveillance technologies among people in the populations concerned is the most critical factor; this depends on availability, safety issues, and government intervention. Navigability lies in technological power, and technical glitches are expected. They pose implications like implementation defects and interpretation errors. So, governments need to build capacities and systems for continuous review. For that purpose, there has to be upgraded validity and accuracy of surveillance data to be able to apply effective public health responses, and this has to do with eliminating sampling biases, and that is clear in terms of disparities in access. In the development process, the legal frameworks perform the primary function of protecting privacy and ethics; therefore, agreement on the harmonization of these issues is appropriate, especially at the time of technological innovations. Infrastructure for the utilization of technology includes both technological and institutional aspects, decision support systems, funding, health response mechanisms, and the public. Furthermore, the step of being cautious about techno-solutionism expresses the necessity of taking mechanical solutions along with trust in the public health approach together, which has a successful track record, is economically effective, and is doable under limited resources [17].

Future of digital surveillance

The ongoing research projects mainly increase the precision and efficiency of monitoring systems using more advanced data collection methods and practical algorithms, as well as solving privacy issues with the help of encryption and anonymization methods. Going forward, interdisciplinary collaborations aim to utilize cutting-edge technologies such as machine learning, blockchain, and edge computing in surveillance systems, which could mean massive progress in real-time monitoring, predictive insights, and automatic responses. With the moving of the digital environment, ethical concerns, transparency, and inclusivity directed the path of digital monitoring, and in the end, this kind of approach was more robust and more socially responsible [18]. Continuously, some technologies are emerging for digital surveillance, which holds the potential for transformative applications that have not yet been anything close to their potential. Quantum computing provides digitization potential beyond any capabilities and offers the ability to redesign cryptographic methods that secure surveillance data. In addition, the further development of biometric identification, such as facial recognition and step analysis, could be used to make better and faster tracking of individuals in surveillance systems. Augmented reality (AR) technology along with AI will be the order of the day as it promises increased surveillance data and intelligence over physical areas, which will help raise the level of situational awareness for operators [19]Small-scale biometric sensors allow for the seamless measurement of vital signs, gestures, and physiological parameters, facilitating security applications [20]. The increased amount of edge computing means that all the data can be processed and analyzed close to its source, with reduced latency and enhanced real-time decision capabilities in the distributed surveillance network. Data analytics combined with machine learning and big data are helping develop predictive models that can forecast potential threats and identify situations of abnormal behavior, reducing the chances of threats in surveillance environments. Cutting-edge drone innovations have delivered considerable benefits to aerial surveillance activities in terms of flexibility, range, and autonomy, which explains why they are a preferred option by many for monitoring large areas and hard-to-reach territories [17].

IV. CONCLUSIONS

From the above research, we concluded that digital surveillance, propelled by cutting-edge technologies, offers unprecedented opportunities for advancing public health. While AI, IoT, and Blockchain promise real-time insights and proactive interventions, their implementation requires careful navigation of ethical, legal, and technical challenges. The COVID-19 pandemic underscores the urgency of harnessing digital tools for rapid response and disease control. Moving forward, sustained investment in research, infrastructure, and capacity building is essential to realize the full potential of digital surveillance in promoting global health security and equity.

REFERENCES

I. Barata RB. Epidemiological surveillance: A brief history and the experiences of the United States and the state of São Paulo. Faculdade de Ciências Médicas da Santa Casa de São Paulo, Departamento de Saúde Coletiva, São Paulo, SP, Brazil. [Internet]. Available from: https://www.scielo.br/j/ress/a/C6yQYYMw6WgdjQ78ZrgxBpr/?format=pdf&lang=en

II. Tulchinsky TH, Varavikova EA. Measuring, monitoring, and evaluating the health of a population. In Elsevier eBooks, 2014; p. 91–147. https://doi.org/10.1016/b978-0-12-415766-8.00003-3

III. Association of Health Care Journalists. Active vs. passive surveillance | Association of Health Care Journalists. [Internet]. 2023 [cited 2023 Nov 9]. Available from: https://healthjournalism.org/glossary-terms/active-vs-passive-surveillance

IV. Hayman DTS, Adisasmito W, Almuhairi S, Behravesh CB, Bilivogui P, Bukachi SA, et al. Developing One Health surveillance systems. One Health. 2023;17:100617. https://doi.org/10.1016/j.onehlt.2023.100617

V. Nsubuga P, White ME, Thacker SB, Anderson MA, Blount SB, Broome CV, et al. Public Health Surveillance: a tool for targeting and monitoring interventions. Disease Control Priorities in Developing Countries - NCBI Bookshelf. [Internet]. 2006. Available from: https://www.ncbi.nlm.nih.gov/books/NBK11770/

VI. Jpiersol. What is public health surveillance? School of Public Health. [Internet]. 2023 June 23. Available from: https://publichealth.tulane.edu/blog/public-health-surveillance/

VII. Kanchan S, Gaidhane A. Social media role and its Impact on Public Health: A Narrative review. Cureus. 2023. https://doi.org/10.7759/cureus.33737

VIII. Anjaria P, Asediya V, Bhavsar PP, Pathak A, Desai D, Patil V. Artificial intelligence in Public Health: Revolutionizing epidemiological surveillance for pandemic preparedness and equitable vaccine access. Vaccines. 2023;11(7):1154. https://doi.org/10.3390/vaccines11071154

IX. Xu Y, Liu X, Cao X, Huang C, Liu E, Qian S, et al. Artificial intelligence: A powerful paradigm for scientific research. The Innovation. 2021;2(4):100179. https://doi.org/10.1016/j.xinn.2021.100179

X. Olawade DB, Wada OJ, David-Olawade AC, Kunonga E, Abaire OJ, Ling J. Using artificial intelligence to improve public health: a narrative review. Frontiers in Public Health. 2023;11. https://doi.org/10.3389/fpubh.2023.1196397

XI. Huang J, Li J, Li Z, Zhu Z, Shen C, Qi G, et al. Detection of diseases using machine learning image recognition technology in artificial intelligence. Computational Intelligence and Neuroscience. 2022;2022:1–14. https://doi.org/10.1155/2022/5658641

XII. Geographic Information System Data | Epidemic Intelligence Service | CDC. [Internet]. 2018. Available from: https://www.cdc.gov/eis/field-epi-manual/chapters/GIS-data.html

XIII. Otoum S, Al Ridhawi I, Mouftah HT. Preventing and controlling epidemics through blockchain-assisted AI-enabled networks. IEEE Network. 2021;35(3). https://doi.org/10.1109/MNET.011.2100014

XIV. Sahu KS, Majowicz SE, Dubin JA, Morita PP. NextGen Public Health Surveillance and the Internet of Things (IoT). Frontiers in Public Health. 2021;9. https://doi.org/10.3389/fpubh.2021.756675

XV. Radin JM, Wineinger NE, Topol EJ, Steinhubl SR. Harnessing wearable device data to improve state-level real-time surveillance of influenza-like illness in the USA: a population-based study. The Lancet Digital Health. 2020;2(2):e85–e93. https://doi.org/10.1016/s2589-7500(19)30222-5

XVI. Environmental tracking for public health surveillance. Routledge & CRC Press. [Internet]. n.d. Available from:

https://www.routledge.com/Environmental-Tracking-for-Public-Health-Surveillance/Morain-Budge/p/book/9780415584715

XVII. Donelle L, Comer L, Hiebert B, Hall J, Shelley J, Smith MJ, et al. Use of digital technologies for public health surveillance during the COVID-19 pandemic: A scoping review. DIGITAL HEALTH. 2023;9:205520762311732. https://doi.org/10.1177/20552076231173220

XVIII. Gasser U, Ienca M, Scheibner J, Sleigh J, Vayena E. Digital tools against COVID-19: taxonomy, ethical challenges, and navigation aid. The Lancet Digital Health. 2020;2(8):e425–e434. https://doi.org/10.1016/s2589-7500(20)30137-0

XIX. Asadzadeh A, Samad-Soltani T, Rezaei-Hachesu P. Applications of virtual and augmented reality in infectious disease epidemics with a focus on the COVID-19 outbreak. Informatics in Medicine Unlocked. 2021;24:100579. https://doi.org/10.1016/j.imu.2021.100579

XX. Kumar PS, Ramasamy M, Varadan VK. Transforming healthcare technologies with wearable, implantable, and ingestible biosensors and digital health. In: Varadan VK, editor. Miniaturized Biosensing Devices. Springer; 2022. p. 177–204. https://doi.org/10.1007/978-981-16-9897-2_8