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AI Applications in Public Health: A Review of Epidemic Monitoring, Epidemiological Analysis, and Health Management

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Abstract

This review explores AI's applications in public health, focusing on epidemic monitoring, epidemiological analysis, and health management, alongside key challenges and future directions. In epidemic monitoring, AI enables early detection and prediction: social media data powers systems like WHO's EARS (analyzing multilingual COVID-19 narratives with superior precision); AI processes news articles to spot outbreak signals (while addressing misinformation); mobility data analysis via GPT/GCNs improves disease spread forecasting; and anomaly detection (e.g., Siamese neural networks on ECG data) identifies unusual healthcare patterns signaling outbreaks. For epidemiological analysis, AI advances understanding of disease dynamics: Gaussian Mixture models cluster COVID-19 cases to reveal hotspots; causal inference techniques (aided by XAI) uncover disease-risk factor links; multi-factor AI models personalize risk stratification (e.g., HIV prevention, cardiac plaque assessment); and BRBFNs/neural networks model transmission (e.g., COVID-19, TB) to optimize controls. In health management, AI enhances care delivery: deep learning aids early diagnosis (e.g., graph networks for cervical cancer, retinal analysis for glaucoma); AI integrates multi-omics/clinical data for personalized treatments (e.g., oncology biomarkers, stroke outcome prediction); RPM systems (sensors, voice chatbots) enable remote monitoring; and AI-driven platforms boost public health education (e.g., adolescent behavior interventions). Challenges include data privacy (needing robust cybersecurity), algorithmic bias (requiring diverse datasets/audits), and ethical concerns (upholding equity/transparency). Future directions involve AI in drug development, workforce training, and fostering multidisciplinary collaboration to unlock AI's full potential for equitable public health improvement.

Key words: artificial intelligence; public health; epidemiology; health management

Introduction

Artificial intelligence (AI) is rapidly transforming various sectors, and public health is no exception. Its potential to revolutionize epidemic monitoring, epidemiological analysis, and health management is garnering increasing attention. From early detection of outbreaks to personalized treatment recommendations, AI offers unprecedented opportunities to improve population health outcomes. However, realizing this potential requires careful consideration of the challenges associated with data privacy, algorithmic bias, and ethical implementation. This review aims to provide a comprehensive overview of AI applications in public health, focusing on three key areas: epidemic monitoring, epidemiological analysis, and health management.

First, we will explore AI-driven epidemic monitoring, examining how AI can enhance early warning systems using social media data, analyze news articles for outbreak detection, predict disease spread through mobility data analysis, and identify outbreaks through anomaly detection in healthcare data. This section will highlight the potential of AI to accelerate outbreak response and mitigate the impact of epidemics.

Next, the review will delve into the role of AI in epidemiological analysis. This includes identifying disease clusters and spatial-temporal patterns, assisting in causal inference studies, enabling personalized risk assessment, and modeling disease transmission dynamics. This section showcases how AI can provide deeper insights into disease dynamics and risk factors, informing targeted interventions.

The third section will focus on AI in health management, exploring its applications in diagnostic tools for disease screening, personalized treatment recommendations, remote patient monitoring, and public health education. This part illustrates how AI can improve healthcare delivery, enhance patient outcomes, and promote healthier behaviors.

Finally, the review will address the challenges and future directions of AI in public health, including data privacy concerns, algorithmic bias, ethical considerations, and future research needs. By addressing these challenges, we can pave the way for responsible and effective implementation of AI in public health, maximizing its benefits while minimizing potential risks. This review seeks to provide a balanced perspective on the transformative potential of AI in public health, emphasizing both its opportunities and the critical need for careful planning and ethical oversight.

AI-Driven Epidemic Monitoring: Early Detection and Prediction

The application of artificial intelligence (AI) is revolutionizing epidemic monitoring through early detection and prediction capabilities. AI-driven systems are being deployed across diverse data streams, from social media to healthcare records, to provide timely and accurate insights into emerging health threats.

One crucial area is the development of AI-driven early warning systems that leverage the wealth of data available on social media platforms. The underlying assumption is that online user behavior, including search queries and social media posts, can serve as leading indicators of an impending epidemic [1]. As Arslan and Benke [1] point out, individuals often seek information about medical symptoms online, making social media a valuable resource for tracking disease incidence, as demonstrated during the COVID-19 pandemic. The World Health Organization (WHO) developed the Early Artificial Intelligence–Supported Response with Social Listening (EARS) platform to analyze COVID-19 narratives from web-based conversations in multiple languages [2]. The machine learning algorithm used in EARS demonstrated superior precision and recall compared to traditional Boolean search filters, highlighting AI's effectiveness in processing vast amounts of digital social data during an infodemic [2]. Beyond infectious diseases, Convolutional Neural Networks (CNNs) are also being utilized to analyze social media data for patterns indicative of mental health conditions, enabling early detection and personalized interventions [6].

Complementing social media analysis, AI algorithms also play a vital role in outbreak detection by rapidly processing and synthesizing information from news articles and online reports. The digital age has transformed news dissemination, making it faster and more accessible [4]. AI algorithms can sift through these diverse sources, identifying unusual patterns, keywords, or events that may signal the start of an outbreak. These systems analyze content, location, and time of reports to provide early warnings, enabling public health officials to respond more effectively. It is worth noting that the proliferation of online news also brings the challenge of misinformation, which AI can also help to detect [4].

Furthermore, AI is increasingly employed to predict disease spread by analyzing mobility data, recognizing that human movement patterns are critical drivers of epidemic dynamics. By integrating AI with mobility data, researchers can develop more accurate and timely predictions of disease transmission [7]. For instance, Riccardo Corrias et al. [6] explored the use of General Purpose Transformers (GPT) and Graph Convolutional Networks (GCNs) for next-place prediction, a key factor in estimating human mobility patterns and managing disease spread. Their findings suggest that these AI methods hold significant potential to surpass current approaches in mobility prediction [6].

Finally, AI-based anomaly detection in healthcare data is crucial for early outbreak identification. These systems utilize machine learning algorithms to analyze vast amounts of healthcare data, including electronic health records and diagnostic test results, to identify unusual patterns or deviations from the norm that might indicate the emergence of a disease cluster or public health threat. Siamese neural networks, for example, can use ECG data from mobile devices to serve as both a medical test and biometric identifier, potentially flagging anomalies in cardiac health outside of traditional healthcare settings [7]. Moreover, anomaly detection techniques can identify unusual measurements and consumptions, intrusions, and electrical data [8]. Durgesh Samariya et al. [9] developed a framework that detects anomalies in healthcare data and provides explanations for why they are considered anomalies by detecting outlying aspects.

AI in Epidemiological Analysis: Understanding Disease Dynamics and Risk Factors

AI is revolutionizing epidemiological analysis, providing powerful tools to understand disease dynamics and identify critical risk factors. This extends beyond traditional statistical methods, enabling researchers to uncover complex relationships and patterns within large, heterogeneous datasets.

One significant application lies in identifying disease clusters and spatial-temporal patterns. AI algorithms can analyze geographical and temporal data to pinpoint areas with unusually high disease incidence, revealing potential hotspots and informing targeted interventions. For example, unsupervised Gaussian Mixture models have been successfully employed to cluster COVID-19 cases in South Africa, exposing location-specific virus dynamics during the first and second waves of the epidemic [10]. This granular level of analysis allows for the quantification of cluster severity, progression, and the identification of potential drivers of transmission. Similarly, AI-powered software like MATCH-AI can model subdistrict tuberculosis (TB) prevalence, identifying potential disease hotspots and potentially improving the effectiveness of active case finding efforts [11]. These spatial-temporal insights are crucial for resource allocation and focused public health responses.

Building upon the identification of patterns, AI is also being leveraged for AI-assisted causal inference in epidemiological studies. Moving beyond simple correlations, these techniques aim to elucidate the underlying causal mechanisms driving disease patterns [12]. Determining cause-and-effect relationships is paramount for designing effective public health interventions. AI techniques, including causal discovery methods, enable researchers to analyze large observational datasets to identify potential causal links between risk factors and health outcomes [13]. Explainable AI (XAI) techniques further enhance this process by providing insights into the reasoning behind AI's conclusions, improving trust and interpretability [14]. By articulating causal models that accurately describe the phenomena under investigation, AI can better predict the outcomes of potential interventions, leading to more effective public health strategies.

The insights gained from causal inference can then be applied to AI for personalized risk assessment and stratification. Recognizing that individuals have varying susceptibilities and responses to disease, AI algorithms can analyze a multitude of factors – epidemiological, behavioral, socioeconomic, and even molecular – to tailor risk assessments and interventions [15]. In HIV prevention, AI can analyze large datasets to personalize risk reduction strategies based on individual circumstances [15]. In cardiology, AI-enhanced software applied to cardiac CT scans can identify high-risk coronary plaques, even when non-obstructive, leading to more accurate and personalized risk assessments [16]. The integration of multi-omics data, such as metabolomics and microbiomics, with machine learning holds promise for even more refined risk assessments, as demonstrated by potential applications in early COVID-19 diagnosis and patient management [17]. Furthermore, in early breast cancer, AI techniques are being integrated with histopathological and molecular biomarkers to refine risk stratification and personalize treatment decisions [18].

Finally, AI plays a critical role in AI-driven modeling of disease transmission dynamics. These models provide valuable insights into how infectious diseases spread and how control measures can be optimized. For instance, Bayesian-regularization backpropagation networks (BRBFNs) have been used to predict the transmission dynamics of COVID-19, leveraging fractional numerical methods [19]. Similarly, AI and neural networks have been used to develop geospatial models of TB transmission, enabling detailed assessment and analysis of disease spread and the development of targeted prevention strategies [20]. These sophisticated models can integrate various factors, including interpersonal contacts, place of residence, and modes of transport, providing a more comprehensive understanding of disease dynamics and informing the development of effective control strategies [20].

AI in Health Management: Improving Healthcare Delivery and Patient Outcomes

AI is rapidly reshaping health management, offering innovative solutions to enhance healthcare delivery and improve patient outcomes across various domains. This includes revolutionizing diagnostic processes, personalizing treatment strategies, enabling remote patient monitoring, and transforming public health education.

AI-powered diagnostic tools are at the forefront of this transformation, promising earlier and more accurate disease detection [21]. By leveraging sophisticated deep learning algorithms, these tools can analyze complex medical images, clinical data, and other relevant information to assist healthcare professionals in identifying diseases at their nascent stages. For instance, AI is being utilized to develop automated diagnostic systems for cervical cancer screening, with studies demonstrating remarkable accuracy in classifying cervical cell types using graph convolution networks [22]. Similarly, AI systems are showing promise in the early detection of lung cancer through the analysis of chest X-ray and CT images, aiding in the identification of subtle pulmonary nodules [57, 58]. The application of AI extends to ophthalmology, where algorithms can analyze retinal photographs and synthesize risk factors to identify individuals at high risk of glaucoma [23]. Furthermore, AI is being deployed in cardiovascular disease screening for women, leveraging extensive datasets to facilitate risk assessment and enable tailored preventive interventions [24].

Beyond diagnostics, AI is also revolutionizing personalized treatment recommendations and precision medicine. By harnessing the power of big data, AI algorithms can dissect the complexities of diseases and individual patient characteristics [25]. In oncology, AI can analyze diverse data types, including genomics, transcriptomics, proteomics, radiomics, and digital pathology images, to pinpoint novel biomarkers for tumor screening, detection, diagnosis, and prognosis prediction. This ultimately paves the way for tailored treatment strategies and improved clinical outcomes [42, 46, 51]. AI-assisted tumor characterization, encompassing automated image interpretation and tumor segmentation, enhances diagnostic processes by providing a precise and detailed assessment of individual clinical profiles [26]. The impact of AI is also being felt in cardiovascular medicine, where it is increasingly applied to improve diagnosis, prognosis, risk prediction, stratification, and treatment planning [27]. Machine learning models, such as logistic regression, random forest, and deep learning models, are employed to analyze electronic health records, imaging data, and omics data to identify individuals at high risk of developing cardiovascular diseases [27]. In stroke outcome research, AI approaches hold the potential to compute single-patient predictions in the acute, subacute, and chronic stages, considering a multitude of factors, including demographic, clinical, electrophysiological, and imaging data [28].

The integration of AI into remote patient monitoring (RPM) and telehealth has further transformed healthcare delivery, particularly in the wake of the COVID-19 pandemic [43, 50]. These technologies facilitate easy access to patient data and enable the delivery of high-quality care at a reduced cost [29]. Intelligent Remote Patient Activity Tracking Systems, for example, can monitor patient activities and vital signs using attached sensors, employing machine learning models to track activities like running, sleeping, walking, and exercising, along with vitals such as body temperature and heart rate [29]. Moreover, AI-driven voice technology, such as voice chatbots, is being implemented to enhance telehealth solutions, enabling automatic acute care triaging and chronic disease management, including remote monitoring and preventive care [30]. Studies have demonstrated that multi-vital AI-based software platforms can strongly correlate vital parameters and ECG measures, further supporting the use of remote monitoring technology in patient care [31].

Finally, AI is playing an increasingly important role in public health education and behavior change interventions. Digital learning platforms are being reimagined to promote healthier behaviors and lifestyles [32]. These platforms can enhance behavior change communication by increasing engagement in public health education initiatives [32]. A framework has been proposed for leveraging AI to improve digital health behavior change interventions (DHBCI) for adolescent risky behaviors, focusing on measuring and modeling adolescent engagement, optimizing existing interventions, and generating novel approaches [33].

Challenges and Future Directions

The integration of artificial intelligence (AI) into public health presents a transformative opportunity, yet it simultaneously introduces a complex array of challenges that must be addressed to ensure responsible and effective implementation. These challenges span data privacy and security, algorithmic bias and fairness, ethical considerations, and the need for ongoing research and development.

Data privacy and security are paramount when deploying AI in public health. The extensive collection, storage, and analysis of sensitive patient data inherent in AI applications create significant vulnerabilities to privacy breaches and potential misuse [61, 62]. As the role of private entities, corporations, healthcare providers, and public bodies in handling patient health information expands, so too does the risk of privacy violations and data security compromises [34]. Furthermore, advancements in re-identification algorithms can undermine traditional de-identification methods, further jeopardizing patient confidentiality [34]. To mitigate these risks, robust cybersecurity measures, clearly defined ethical guidelines, and comprehensive legal frameworks are essential [35].

Beyond data protection, ensuring fairness and mitigating bias in AI algorithms is crucial. AI algorithms can inadvertently perpetuate and even amplify existing health disparities if trained on biased data or designed without careful consideration of equitable outcomes [36]. For instance, a diagnostic tool trained predominantly on data from a specific demographic group may exhibit reduced accuracy when applied to individuals from other populations, potentially leading to misdiagnosis or unequal access to appropriate care [37]. Evidence suggests that AI specialists themselves recognize the presence of bias in their development projects, often stemming from a lack of fair data, comprehensive guidelines, or sufficient knowledge [38]. The potential for biased AI systems to result in unfair user interactions and information distribution necessitates proactive strategies to mitigate bias. These strategies include employing diverse and representative datasets, conducting rigorous algorithm audits, and establishing clear ethical guidelines to ensure equitable AI integration in public health [69, 63, 71].

Ethical considerations are at the forefront of responsible AI implementation in public health. A constellation of ethical principles, including equity, bias mitigation, privacy, security, safety, transparency, confidentiality, accountability, social justice, and individual autonomy, demand careful consideration [39]. The multifaceted ethical challenges surrounding AI and machine learning in healthcare encompass privacy and data security, algorithmic bias, transparency, clinical validation, and professional responsibility [40]. Identifying and addressing these ethical concerns is crucial for establishing comprehensive guidelines that promote responsible AI implementation in public health [39].

Looking ahead, the future of AI in public health holds significant promise, but realizing this potential requires addressing critical research needs and overcoming existing limitations. AI can dramatically accelerate the discovery of new chemicals and materials, impacting areas such as drug development and precision oncology [41]. Furthermore, the integration of AI into health workforce training programs can enhance the quality, consistency, and personalization of education [42]. However, realizing these benefits necessitates addressing ethical concerns related to privacy and data ownership, as well as technical constraints such as limited computational resources [43]. Fostering innovation, encouraging multidisciplinary collaboration, and promoting open data science are crucial steps toward fully harnessing the power of AI to improve public health outcomes [43].

Conclusion

In summary, this review has highlighted the transformative potential of AI across various facets of public health, from revolutionizing epidemic monitoring and deepening epidemiological analysis to optimizing health management strategies. AI-driven systems are enhancing early warning systems, identifying disease clusters, personalizing risk assessments, and improving healthcare delivery, ultimately contributing to better population health outcomes. Addressing the challenges surrounding data privacy, algorithmic bias, and ethical implementation is paramount to ensure that AI is deployed responsibly and equitably.

As we look to the future, the continued advancement and integration of AI in public health holds immense promise. By fostering innovation, promoting multidisciplinary collaboration, and prioritizing ethical considerations, we can unlock the full potential of AI to create a healthier and more equitable world. This requires a proactive approach to research and development, focusing on addressing existing limitations and exploring new opportunities for AI to improve public health outcomes. The journey towards a future where AI seamlessly supports and enhances public health initiatives is one that demands continuous learning, adaptation, and a steadfast commitment to ethical principles.

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