



Bio surveillance Systems for Health Safety: Innovations in Tracking Disease Outbreaks and Threats using Real-Time Data

¹- Ahmed Khalid Alharbi,²- Turki Nawaf Abdullah Alrashdi,³-Mohammed Ali Masoud Alhajri,⁴- Abdulaziz Eid Alharbi,⁵-Rumi Muteb Mufarrij Alshammari,⁶- Maslat Tami Aldossari,⁷-Mohammad Abdullah Alharthei,⁸-Mohammed Yahya Ali Makrashi,⁹-Bandar Abdul Salam Al Mansour,¹⁰- Ahmed Mohammed Ali Khairi,¹¹- Mansour Ahmed Yami,¹²-Ahmed Hadi Jafari

¹ Ksa, Ministry Of Health

² Ksa, Ministry Of Health, Irada Mental Health Complex Hail

³ Ksa, Ministry Of Health, Al-Farshah General Hospital

⁴ Ksa, Ministry Of Health, Phc Al Muntazah, Buraydah

⁵ Ksa, Ministry Of Health, Irada Mental Health Complex Hail

⁶ Ksa, Ministry Of Health, Suliy General Hospital

⁷ Ksa, Ministry Of Health, Khodera Damad Primary Health Care Tb Unit

⁸ Ksa, Ministry Of Health, Al-Arda Hospital Jazan Health Cluster

⁹ Ksa, Ministry Of Health, Prince Sultan Military Medical City

¹⁰ Ksa, Ministry Of Health, Jazan Health Complex

¹¹ Ksa, Ministry Of Health, El-Hadror Primary Health Care Center

¹² Ksa, Ministry Of Health, Jazan Health Cluster Alfakrah Phc

Abstract

Background: Infectious disease outbreaks in war zones pose significant public health challenges, compounded by the destruction of healthcare infrastructure and the displacement of populations. This narrative review synthesizes research on the intersection of technology and infectious disease response in conflict-affected areas, highlighting innovative methodologies for tracking and managing disease outbreaks.

Methods: A systematic literature search was conducted across electronic databases, including PubMed, Web of Science, and Scopus, employing a combination of keywords related to infectious diseases, technological integration, and war zones.

Results: The findings reveal critical obstacles such as insufficient healthcare access, disrupted disease monitoring, and the ethical dilemmas surrounding data privacy. However, advancements in epidemiological surveillance, including mobile health (mHealth) technologies and genomic sequencing, present promising avenues for enhancing disease tracking and response efforts. Additionally, innovative tools like drones and artificial intelligence (AI) offer novel methodologies for real-time monitoring and predictive analytics.

Conclusions: The study concludes that while these technologies can significantly improve outbreak management and healthcare delivery, challenges related to ethical governance, data security, and resource constraints must be addressed. Collaborative efforts among governments, humanitarian organizations, and local communities are essential for optimizing the deployment of technological solutions in conflict settings. The integration of these strategies can enhance public health outcomes and bolster resilience against future epidemics in war-torn regions.

Keywords: Infectious diseases, War zones, Epidemiological surveillance, Technological integration, Public health interventions

1. Introduction

Outbreaks of infectious illnesses in war zones represent a convergence of humanitarian crises and public health emergencies, necessitating innovative remedies [1]. Such conflicts exacerbate vulnerabilities in healthcare infrastructure, disrupt monitoring and response actions, and increase susceptibility to disease transmission [2]. Addressing the challenges of infectious illnesses in these contexts requires a holistic multidisciplinary strategy that integrates technical advancements with traditional public health and humanitarian strategies [3]. This paper addresses the intersection of technology and infectious disease response in war zones, highlighting the obstacles, creative solutions, and policy implications for future interventions. This analysis examines how the detrimental impact of war on healthcare infrastructure leads to diminished access to healthcare services and resources.

Migrations exert heightened strain on healthcare systems, exacerbate inequities, and disrupt disease monitoring and response efforts [4]. Prompt and effective intervention in infectious disease outbreaks is crucial to prevent escalation and mitigate disease transmission. Nonetheless, the hazards faced by healthcare professionals and humanitarian groups in war zones represent significant impediments to delivering essential health services and reacting effectively [5-7]. This analysis examines the complexities of safeguarding frontline responders operating in dynamic environments to provide life-saving treatments. Innovations in epidemiological surveillance have revolutionized the monitoring and control of illnesses, offering insights into real disease dynamics and transmission patterns. Similarly, mobile health (mHealth) technology has transformed healthcare delivery via remote monitoring, telemedicine consultations, and personalized therapies [8,9].

This study examines how these technologies are being adapted and used in war zones to enhance monitoring capabilities and healthcare access. Genomic sequencing methods have emerged as a powerful instrument for rapid pathogen identification and monitoring, facilitating customized medicine and focused therapeutic alternatives. Currently, challenges related to the standardization of protocols and ethical concerns around data sharing and privacy remain pertinent.[10] This paper examines the implications of integrating genomic sequencing into infectious disease response strategies in war zones and the potential for improving patient outcomes. Surveillance technology, including drones and artificial intelligence, is offering novel methods for monitoring conflict dynamics and forecasting disease outbreaks [11]. While such technologies provide the potential to enhance readiness and response, ethical considerations around monitoring and data privacy must be addressed with care.[12] Finally, this study offers policy recommendations about the use of technology in response strategies to infectious illnesses in war zones, emphasizing the need for surveillance systems, diagnostic tools, and capacity development. This study examines transparent governance structures and stakeholder involvement to promote responsible technology usage, safeguard individual rights, and ensure optimum resource allocation. This review seeks to elucidate the challenges, innovations, and policy implications of technology integration in addressing infectious diseases in conflict zones, thereby guiding future research agendas and informing decision-making to improve public health outcomes in these complex environments.

2. Methods

This review used a systematic methodology to identify and compile pertinent material about the correlation between technology and infectious disease responses in war zones. A thorough search method was used to identify the relevant research using electronic databases including PubMed, Web of Science, and Scopus. Various combinations of keywords and Medical Subject Headings related to infectious disease outbreaks, war zones, and technological integration were used in many permutations to enhance literature retrieval.

3. Analysis of distinct problems presented by infectious disease epidemics in war zones

Infectious disease epidemics in conflict zones represent a complex challenge that intertwines the devastation of war with public health crises.[13] This paper summarizes the unique challenges posed by such epidemics, including degraded health infrastructure, refugee assistance services, restricted access to

healthcare, the disintegration of social and governmental systems, and an elevated risk of disease transmission. Understanding and addressing difficulties is essential for formulating responses and mitigation plans in conflict-affected regions [14]. Conflict zones are inherently vulnerable to epidemic breakouts due to inadequate health systems, population displacements, and the deterioration of essential services [15]. When infectious illnesses coincide with war, their impact intensifies, resulting in increased morbidity, death, and socio-economic instability.[16] This study aims to examine the specific challenges encountered in managing infectious disease outbreaks during periods of war and their effects on public health interventions and humanitarian initiatives. The healthcare infrastructure in war zones is often severely weakened, characterized by destroyed hospitals, a scarcity of medical supplies, and a limited number of skilled health professionals.[17] This impairment significantly restricts the ability to identify, diagnose, and treat infectious infections effectively.

Secondly, the closure of medical facilities diminishes access to services, exacerbating the burden of illnesses among the impacted population. Refugee camps and informal settlements remain congested due to the large influx of residents resulting from violence. Such settings facilitate the fast spread of infectious illnesses, exacerbated by tight quarters, inadequate sanitation, and restricted access to clean water [18,19]. Displaced individuals are often very vulnerable, lacking access to healthcare and facing significant risks of hunger and infectious infections. In war zones, impediments to accessing healthcare services arise from security concerns, bureaucratic constraints, and physical barriers such as checkpoints or barricades. Humanitarian organizations struggle to coordinate aid and medical assistance for impacted populations, so exacerbating the disparity between the affluent and the impoverished and facilitating the undetected and untreated spread of illnesses [20-23]. Challenges in disease monitoring, prevention, and control arise from the inadequacies of social and governmental institutions in war zones [24,25]. Poor governance, instability, and relocation disrupt public health initiatives and impede the implementation of preventative strategies, such as vaccination campaigns and vector control.[26] Furthermore, skepticism towards institutions results in disinformation and inadequate responses to community disease prevention initiatives. Conflicts create conditions conducive to the development of infectious illnesses, exacerbated by overpopulation, hunger, and inadequate sanitation [27].

Disruption of health services, together with immigration and emigration within a certain community, promotes the fast dissemination of infections that may lead to localized or widespread epidemics [28,29]. Furthermore, the deployment of weaponry, the movement of wildlife, and the degradation of infrastructure may contribute to the emergence of novel disease vectors or exacerbate current health threats [30]. Disease outbreaks in war zones are complex and exacerbated by the many vulnerabilities associated with armed conflicts and public health crises. Addressing these issues requires a comprehensive strategy that integrates humanitarian assistance, health interventions, and conflict resolution efforts. Strengthening health systems, enhancing disease monitoring, and ensuring equitable healthcare access are essential to mitigate the effects of infectious illnesses in war zones [31-33]. Collaboration among governments, humanitarian groups, and local communities is essential for addressing the unique problems posed by infectious disease epidemics in war zones, therefore safeguarding the health and quality of life of the afflicted populations.

4. Significance of prompt and efficient intervention to avert escalation and diminish the proliferation of illnesses

Epidemics of infectious illnesses, initiated by established pathogens or novel viruses, may arise within days or weeks, spreading both domestically and internationally, leading to significant morbidity, death, and social upheaval [34]. Swift and effective responses are essential to manage outbreaks at their inception and prevent the escalation of these incidents into larger epidemics or pandemics.[35] This paper examines the essential elements of quick response mechanisms in disease management and prevention of transmission. The promptness of reaction is essential in curtailing the transmission of illnesses caused by infectious organisms.[36] Timely detection, diagnosis, and action may diminish transmission rates and mitigate the effects of epidemics. Rapid reaction enables the execution of containment strategies including quarantine, isolation, contact tracing, and vaccination, which are crucial for avoiding further transmission [37]. Delayed reactions result in a rapid increase in cases, the deterioration of the healthcare system, and exacerbation of

the problem. Effective response methods need cooperation across several disciplines and sectors, including public health authorities, healthcare providers, researchers, lawmakers, and communities. Robust surveillance systems facilitate the prompt identification of epidemics and emerging dangers [38].

Early warning systems, when integrated with data analysis and modeling, provide insights into disease patterns and facilitate the formulation of proactive solutions [39]. Prompt patient identification, isolation, and treatment need access to rapid and reliable diagnostic testing [40]. Advancements in molecular diagnostics, point-of-care testing, and surveillance technologies enhance the capacity to promptly identify and control diseases. Non-pharmaceutical treatments, including social distancing, mask-wearing, hand cleanliness, and travel restrictions, may diminish transmission rates and disease proliferation, particularly in the absence of targeted medicines or vaccines. Vaccines are crucial for preventing infectious illnesses and alleviating their impact on individuals [41]. Timely deployment of vaccines, along with efficient vaccination programs, may enhance herd immunity and limit the transmission of diseases. The clarity and promptness of communication with the public are essential for fostering trust, promoting adherence to preventative actions, and dispelling misconceptions.[42]

Effective risk communication tactics mitigate fear, panic, and stigmatization resulting from disease epidemics. Resource constraints, often linked to financing, staff, and infrastructure, might hinder the escalation of response initiatives, particularly in low-resource environments [43,44]. Decentralization of activities and lack of coordination among local and national players may undermine responses and create gaps in monitoring, communication, and action. Prevention and public health habits are affected by social and economic inequities, cultural customs, and political inclinations, hence complicating disease control efforts [45]. The intricate and evolving characteristics of infectious illnesses, often marked by the introduction of new pathogens and increasing antibiotic resistance, complicate the prediction and response to epidemics.[40] A prompt and effective reaction is the essential preventative strategy against the escalation and management of infectious illnesses [46]. Emphasizing monitoring, fast diagnoses, public health measures, vaccination campaigns, and communication strategies enables all stakeholders to enhance preparedness and resilience against epidemics. Addressing hurdles such as resource constraints, coordination issues, and socioeconomic factors is essential for enhancing responsiveness and safeguarding global health security.[47] Collaborative efforts across sectors and borders are essential for addressing evolving threat situations and safeguarding vulnerable populations from the impact of diseases.[48]

5. Consequences of conflict-induced devastation on healthcare infrastructure

In war zones, devastation extends beyond physical violence to include sabotage of essential infrastructure, such as healthcare facilities and supplies. The continued interruption of health care in these regions exacerbates the suffering of the people already impacted by the effects of conflict [49,50]. Conflict consequences extend beyond the immediate devastation of medical institutions, and also include the loss of essential infrastructure, including highways, water supply systems, and electrical grids.[51] Consequently, the majority of current healthcare institutions are compromised, with inadequate resources and unable to meet the increasing demand for medical treatment.[52] Moreover, population migration exacerbates the strain on already burdened healthcare systems, leading to overpopulation and resource depletion.[52] The limited accessibility of healthcare services due to conflict-induced devastation leads to several issues for the affected population. Geographical limitations and disruptions in transportation networks impede patients' access to healthcare services, particularly in distant regions. Moreover, financial constraints exacerbate disparities in healthcare access, disproportionately affecting impoverished areas.

Furthermore, the collapse of healthcare infrastructure leads to a decline in the quality of service provided, resulting in detrimental health risks to the impacted population. The devastation caused by wars often results in severe shortages of medical supplies, equipment, and personnel, consequently hindering the provision of essential healthcare services. The incineration of pharmaceutical warehouses and production facilities disrupts supply lines and exacerbates shortages of essential pharmaceuticals. The exodus of healthcare practitioners from crisis zones further depletes the already limited pool of trained staff, consequently exacerbating the healthcare system's capacity to meet the demands of impacted

populations.[53] Addressing the issues of restricted health infrastructure access in conflict-affected regions requires a comprehensive strategy including humanitarian assistance, infrastructure rehabilitation, and capacity development.[54]

The enhancement and reinforcement of healthcare infrastructure is a crucial investment aimed at bolstering resilience in future conflicts and catastrophes.[55] Furthermore, programs designed to ensure equitable distribution of medical resources and staff, particularly in underserved regions, are essential for universal healthcare access.[56] Furthermore, it is essential to establish a strong rapport among local stakeholders, international organizations, and humanitarian entities to enhance coordination efforts for optimal effect in conflict-affected areas.[57] The devastation inflicted by conflict on health infrastructure is a substantial obstacle to achieving universal healthcare in such regions. Comprehensive measures must be implemented to address the intricate issues of restricted access to healthcare services, including infrastructure rehabilitation, resource mobilization, and capacity-building programs.[58] By concentrating on the resilience and sustainability of health systems in conflict zones, stakeholders may mitigate the impact of conflict-related devastation on healthcare access and enhance the health status of impacted communities.[58]

6. The displacement of residents and the disintegration of community organizations impede monitoring and response initiatives

Population displacement has emerged as a pervasive worldwide phenomena attributable to events such as war, natural catastrophes, and economic conditions.[59] The dissolution of communal institutions simultaneously undermines social cohesion and support networks [60]. These events have significant public health ramifications, particularly with disease monitoring and response.[59] Recognizing the connections between population displacement, the breakdown of community organizations, and the impact of these factors on the efficacy of public health initiatives is essential for formulating suitable measures to manage the related risks.[60] Population displacement complicates monitoring by dispersing individuals over many places, resulting in fragmented data gathering and incomplete epidemiological profiles.[61] Moreover, displaced communities may lack access to healthcare services and have an increased risk of infectious illnesses, complicating monitoring efforts.[62]

The fundamental collapse of community structures disrupts conventional methods of information transmission and hinders the surveillance systems intended for implementation via community engagement [63]. Nevertheless, the detection and monitoring of disease outbreaks occur belatedly, resulting in delayed reaction measures and an increased likelihood of disease proliferation [64]. Destruction of community institutions impedes response mechanisms due to diminished trust in authorities and obstructs the dissemination of critical health information [65]. Poor communication channels and cultural obstacles hinder the delivery of healthcare treatments to displaced people, hence increasing the risk of disease transmission. Furthermore, the inflow of displaced individuals into host towns strains the existing healthcare infrastructure and resources, hence complicating response operations [59]. The politicization of humanitarian assistance in war or unstable settings may impede the delivery of essential services, exacerbating public health problems. The resolution to the issues arising from population relocation and the disintegration of community structure involves a synthesis of efforts related to surveillance augmentation, community participation, and resource mobilization.[62]

Innovative technologies, like mobile health apps and geospatial mapping, may enhance epidemiological monitoring by facilitating real-time data gathering and analysis among geographically distributed populations.[63] Engaging with local community leaders and stakeholders is essential for building trust, fostering engagement, and tailoring response strategies to the specific needs of impacted communities.[64] Moreover, robust healthcare systems that effectively adapt to shifts in population dynamics are essential investments to alleviate the effects of displacement on public health. The migration of people and the disruption of community institutions pose significant obstacles to monitoring and response efforts in public health [66]. Addressing these difficulties requires a comprehensive strategy that amalgamates technology innovation, community engagement, and the fortification of the health system [67]. Comprehending the

complex interplay between population dynamics and public health outcomes allows policymakers and practitioners to devise strategies that mitigate the impact of displacement on surveillance and response systems, thereby safeguarding the health and welfare of vulnerable displaced populations.[68]

7. Security issues faced by healthcare professionals and humanitarian organizations in crisis zones

In war zones, healthcare professionals and relief groups encounter significant obstacles, since the provision of essential services is often obstructed by ongoing instability. In unstable circumstances, individuals and organizations committed to alleviating suffering and improving health face various security challenges that jeopardize their safety, well-being, and capacity to assist.[69] This paper examines the security conditions faced by healthcare professionals and organizations operating in war zones, highlighting the unique aspects of their operational environment and the need to develop suitable risk mitigation techniques.[69]

8. Security vulnerabilities

Incidents of violence against healthcare and humanitarian workers include direct physical assaults, including targeted attacks, shootings, bombings, and assaults [70]. These incidents pose a danger to human lives and impede the delivery of important healthcare services to vulnerable populations.[71] The abduction of healthcare and humanitarian personnel in war zones remains a persistent threat, driven by factors including ransom demands, political leverage, and ideological motives.[72] The abduction of personnel not only inflicts direct harm but also engenders dread and uncertainty among humanitarian groups.[73] The looting of medical facilities, equipment, and supplies during war deprives healthcare professionals of vital resources required for effective care delivery [70]. Moreover, looting undermines the confidence between humanitarian organizations and local people, exacerbating tensions and obstructing humanitarian access.[71] Bureaucratic obstacles, checkpoints, roadblocks, and entrance rejections by armed factions consistently hinder healthcare personnel and assistance organizations from reaching individuals in need. These impediments diminish the efficacy of humanitarian assistance and exacerbate the humanitarian crisis in conflict-affected regions. Seventy Employment in combat zones causes significant psychological harm to healthcare and humanitarian personnel, manifesting as stress, anxiety, depression, and post-traumatic stress disorder.[71] Exposure to violence, personal dangers, and moral difficulties are the primary factors contributing to psychological discomfort among first responders.[72] The cumulative impact of these stresses jeopardizes the personal well-being of specific personnel and undermines the efficacy of humanitarian activities.[73]

9. Alleviating security threats and augmenting protective measures

Security training and readiness: Healthcare professionals and humanitarian assistance people in crisis zones should get general security training programs to develop skills in risk assessment, conflict management, and personnel safety.[74] Establishing a positive rapport with both the local community and armed groups is essential for daily security operations and access to humanitarian interventions. Discussion, negotiation, and arbitration would alleviate stress and promote understanding.[75] Operational modifications such as mobile clinics, remote healthcare delivery, and decentralized assistance distribution locations may mitigate hazards associated with fixed healthcare facilities and supply chains [75]. At the international level, it is imperative to emphasize advocacy efforts and diplomatic mediation to ensure the safety of healthcare workers and humanitarian organizations in conflict zones, accompanied by adherence to humanitarian principles and international humanitarian law. The challenges to health professionals and humanitarian organizations in conflict-affected regions are complex and extend beyond the denial of essential services and supplies [76]. These issues need a comprehensive response that includes the development of security training, community involvement, policy modifications, and worldwide lobbying, as shown in Figure 1. The focus on safeguarding frontline responders and enhancing security protocols will bolster the resilience and efficacy of humanitarian operations in some of the most unstable regions globally.



Figure 1. Mitigating security threats and augmenting protective measures.

10. Progress in epidemiological surveillance

Monitoring epidemiology is a systematic process including the structured gathering, analysis, interpretation, and dissemination of health-related data to enhance disease monitoring and management. Historically, surveillance mostly relied on manual data-collecting techniques, which were notably slow, labor-intensive, and susceptible to inaccuracies.[77] Conversely, recent technical breakthroughs provide novel methods for enhancing the speed, efficacy, and scope of monitoring. Satellite imagery: Satellite photography has emerged as a crucial tool for epidemiological surveillance, facilitating the collection of data on environmental factors, demographics, and disease vectors.[78] The high-resolution satellite imagery facilitates the monitoring of land use, vegetation trends, and aquatic systems—crucial markers of disease transmission. Satellite imagery has been used to track the proliferation of vector-borne illnesses such as malaria and dengue fever by identifying the locations of mosquito breeding places [79].

Additionally, satellite data may be integrated with geographic information systems to provide prediction models of disease occurrences and identify high-risk locations for targeted treatments. Drones, or unmanned aerial vehicles (UAVs), provide a cost-effective and adaptable method for collecting spatial data in remote or hazardous locations. Drones may be used in several health monitoring applications, including aerial surveys, crowd management, and sampling, among others.[72] Drones equipped with thermal imaging cameras may detect the heat signatures of animal reservoirs of zoonotic illnesses while fixed-wing drones provide more efficient coverage of extensive geographic regions compared to conventional ground-based surveys.[70] Furthermore, they may be rapidly deployed during emergencies, providing real-time information that informs decision-making in disease epidemics or natural disasters.[74]

Epidemiological surveillance is now used in AI algorithms to enhance the automation of data processing, pattern recognition, and forecasting of illness patterns.[80] Machine learning approaches, such as neural networks and deep learning, are adept at processing substantial volumes of intricate data derived from many sources, including electronic health records, social media, and sensor networks.[81] By doing real-time analysis of these data streams, AI systems may identify anomalous symptom patterns or clusters indicative of a potential new illness or pandemic.[81] Moreover, AI-driven prediction models empower public health organizations to allocate resources effectively and implement targeted treatments promptly to mitigate the spread of infectious illnesses [82].

Despite the tremendous benefits of emerging technology for epidemiological monitoring, certain obstacles must be addressed. These include issues related to data protection, data reconciliation, technological proficiency, and the legislative environment. Moreover, equitable distribution of technological resources and engagement of local populations is crucial for the legitimacy and sustainability of surveillance systems.[78] Future research should prioritize multidisciplinary collaborations, capacity-building initiatives, and the creation of tools and platforms that facilitate the integration of satellite imagery, drones, and artificial intelligence into surveillance operations.[79]

Consequently, the integration of satellite images, drones, and AI, when executed well, may transform epidemiological monitoring, establishing precise and credible foundations for disease prevention and management [81]. By using these emerging technologies, public health authorities may enhance their capacity to identify, monitor, and mitigate dangers from infectious illnesses, therefore preserving lives and safeguarding public health [82].

11. Conclusions

Infectious disease epidemics in war zones pose significant challenges to public health and humanitarian initiatives, necessitating innovative approaches to monitoring, diagnosis, and intervention. Conflict dynamics, healthcare infrastructure, and technology developments all play a role in influencing infectious disease outcomes in these contexts. The migration of populations complicates disease monitoring and response, necessitating adaptive techniques to address evolving demographic patterns and provide equitable healthcare. Technological advancements in surveillance, mobile health, genetic sequencing, and monitoring systems offer potential enhancements for infectious disease response in war zones. However, integration challenges persist, and healthcare professionals and humanitarian organizations must effectively handle security threats, ethical issues with data privacy and monitoring, and resource limitations.

Governments and international organizations need to invest in robust epidemiological monitoring systems, using modern technologies like UAVs, AI, BVLOS, and big data analytics. Capacity-building initiatives should focus on training healthcare professionals and humanitarian responders in technology-based tools and techniques for monitoring, diagnosis, and response. Ethical governance frameworks must be established to regulate the ethical use of technology in conflict environments, ensuring data privacy, security, and transparency. Implementing these policy proposals will empower stakeholders to optimize technological potential in addressing infectious diseases in war zones, while mitigating human suffering and bolstering global health security.

References

1. Schmid B, Raju E. Humanitarian crisis and complex emergencies: burden of disease, response, and opportunities for global health. In: Handbook of global health. Cham: Springer International Publishing. 2021. pp. 2437–72.
2. Bloom DE, Cadarette D. Infectious disease threats in the twenty-first century: strengthening the global response. *Front Immunol*. 2019;10:549.
3. Khatri RB, Endalamaw A, Erku D, et al. Preparedness, impacts, and responses of public health emergencies towards health security: a qualitative synthesis of evidence. *Arch Public Health*. 2023;81:208.
4. Lohrmann R. Migrants, refugees and insecurity. Current threats to peace? *Int Migr*. 2000;38:3–22.
5. Acter T, Uddin N, Das J, Akhter A, Choudhury TR, Kim S. Evolution of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) as coronavirus disease 2019 (COVID-19) pandemic: a global health emergency. *Sci Total Environ*. 2020;730:138996.
6. Søvold LE, Naslund JA, Kousoulis AA, et al. Prioritizing the mental health and well-being of healthcare workers: an urgent global public health priority. *Front Public Health*. 2021;9:679397.
7. Ladner JT, Grubaugh ND, Pybus OG, Andersen KG. Precision epidemiology for infectious disease control. *Nat Med*. 2019;25:206–11.
8. El-Rashidy N, El-Sappagh S, Islam SR, El-Bakry HM, Abdelrazek S. Mobile health in remote patient monitoring for chronic diseases: principles, trends, and challenges. *Diagnostics*. 2021;11:607.
9. Bissonnette L, Bergeron MG. Infectious disease management through point-of-care personalized medicine molecular diagnostic technologies. *J Pers Med*. 2012;2:50–70.
10. Anhalt-Depies C, Stenglein JL, Zuckerberg B, Townsend PA, Rissman AR. Tradeoffs and tools for data quality, privacy, transparency, and trust in citizen science. *Biol Conserv*. 2019;238:108195.
11. Mohsan SA, Zahra QU, Khan MA, Alsharif MH, Elhaty IA, Jahid A. Role of drone technology helping in alleviating the COVID-19 pandemic. *Micromachines*. 2022;13:1593.

12. Lyon D. Surveillance, snowden, and big data: capacities, consequences, critique. *Big Data Soc.* 2014;1:205395171454186.
13. Tambo E, Olalubi O, Chengho C, et al. Ebola outbreaks public health emergencies in Fragile conflicts zones and displaced populations in Africa. *Int J Trop Dis Health.* 2017;26:1–5.
14. Wallensteen P. International response to crises of democratization in war-torn societies. In: Peter Wallensteen: A Pioneer in Making Peace Researchable: With a Foreword by Jan Eliasson and a Preface by Raimo Väyrynen. Cham: Springer International Publishing. 2021; pp. 355–374.
15. Ekezie W, Adaji EE, Murray RL. Essential healthcare services provided to conflict-affected internally displaced populations in low and middle-income countries: a systematic review. *Health Promot Perspect.* 2020;10:24–37.
16. Ostrach B, Singer M. Syndemics of war: malnutrition-infectious disease interactions and the unintended health consequences of intentional war policies. *Ann Anthropol Pract.* 2012;36:257–73.
17. Witter S, Wurie H, Chandiwana P, et al. How do health workers experience and cope with shocks? Learning from four fragile and conflict-affected health systems in Uganda, Sierra Leone, Zimbabwe and Cambodia. *Health Policy Plan.* 2017;32(suppl_3):iii3–iii13.
18. Rahier JF, Ben-Horin S, Chowers Y, et al. European evidence-based Consensus on the prevention, diagnosis and management of opportunistic infections in inflammatory bowel disease. *J Crohns Colitis.* 2009;3:47–91.
19. Cutter SL, Boruff BJ, Shirley WL. Social vulnerability to environmental hazards. In: *Hazards Vulnerability and Environmental Justice.* United Kingdom: Routledge. 2012; pp. 143–160.
20. Mendola D, Busetta A. Health and living conditions of refugees and asylum-seekers: a survey of informal settlements in Italy. *Refug Surv Q.* 2018;37:477–505.
21. Wilson ME. Travel and the emergence of infectious diseases. *Emerg Infect Dis.* 1995;1:39–46.
22. Owoaje ET, Uchendu OC, Ajayi TO, Cadmus EO. A review of the health problems of the internally displaced persons in Africa. *Niger Postgrad Med J.* 2016;23:161–71.
23. Collier J, Kienzler H. Barriers to cardiovascular disease secondary prevention care in the West Bank, Palestine—a health professional perspective. *Confl Health.* 2018;12:1–3.
24. Bjerneld M, Lindmark G, Diskett P, Garrett MJ. Perceptions of work in humanitarian assistance: interviews with returning Swedish health professionals. *Disaster management & response: DMR: an official publication of the Emergency Nurses Association.* 2004;2:101–8.
25. Beyrer C, Villar JC, Suwanvanichkij V, Singh S, Baral SD, Mills EJ. Neglected diseases, civil conflicts, and the right to health. *Lancet (London, England).* 2007;370:619–27.
26. Lam E, McCarthy A, Brennan M. Vaccine-preventable diseases in humanitarian emergencies among refugee and internally-displaced populations. *Hum Vaccines Immunother.* 2015;11:2627–36.
27. Bodrud-Doza M, Shammi M, Bahlman L, Islam AR, Rahman MM. Psychosocial and socio-economic crisis in Bangladesh due to COVID-19 pandemic: a perception-based assessment. *Front Public Health.* 2020;8:341.
28. Ozaras R, Leblebicioglu H, Sunbul M, et al. The Syrian conflict and infectious diseases. *Expert Rev Anti Infect Ther.* 2016;14:547–55.
29. Morganstein JC, Fullerton CS, Ursano RJ, Donato D, Holloway HC. *Pandemics: health care emergencies. Textbook of Disaster Psychiatry.* 2017;2:270–84.
30. Fidler DP. Return of the fourth horseman: emerging infectious diseases and international law. *Minn. L. Rev.* 1996;81:771.
31. Moore CW. *The Mediation Process: Practical Strategies for Resolving Conflict.* John Wiley & Sons; 2014.
32. Palagyi A, Marais BJ, Abimbola S, Topp SM, McBryde ES, Negin J. Health system preparedness for emerging infectious diseases: a synthesis of the literature. *Glob Public Health.* 2019;14:1847–68.
33. Blanchet K, Sisténich V, Ramesh A, et al. An evidence review of research on health interventions in humanitarian crises.
34. World Health Organization. *Managing Epidemics: Key Facts About Major Deadly Diseases.* World Health Organization; 2018.

35. World Health Organization. WHO Guidelines on Tularaemia: Epidemic and Pandemic Alert and Response. World Health Organization; 2007.
36. Patz JA, Githeko AK, McCarty JP, Hussein S, Confalonieri U, De Wet N. Climate change and infectious diseases. *Climate Change and Human Health: Risks and Responses*. 2003;2:103–32.
37. Adhikari SP, Meng S, Wu YJ, et al. Epidemiology, causes, clinical manifestation and diagnosis, prevention and control of coronavirus disease (COVID-19) during the early outbreak period: a scoping review. *Infect Dis Poverty*. 2020;9:1–2.
38. Chung SC, Marlow S, Tobias N, et al. Lessons from countries implementing find, test, trace, isolation and support policies in the rapid response of the COVID-19 pandemic: a systematic review. *BMJ Open*. 2021;11:e047832.
39. Noreen N, Dil S, Niazi SU, et al. Coronavirus disease (COVID-19) pandemic and Pakistan; limitations and gaps. *Global Biosecurity*. 2020;1:1–1.
40. Erraguntla M, Zapletal J, Lawley M. Framework for Infectious Disease Analysis: A comprehensive and integrative multi-modeling approach to disease prediction and management. *Health Informatics J*. 2019;25:1170–87.
41. Roy S, Arshad F, Eissa S, et al. Recent developments towards portable point-of-care diagnostic devices for pathogen detection. *Sens Diagn*. 2022;1:87–105.
42. Bell D, Nicoll A, Fukuda K, et al. Non-pharmaceutical interventions for pandemic influenza, national and community measures. *Emerg Infect Dis*. 2006;12:88–94.
43. Kolobova I, Nyaku MK, Karakusevic A, Bridge D, Fotheringham I, O'Brien M. Burden of vaccine-preventable diseases among at-risk adult populations in the US. *Human Vacc Immunother*. 2022;18:2054602.
44. Kesale AM, Mwakasangula E, Muhanga M, Mahonge C. Leveraging governance strategies adopted by health facility governing committees in response to COVID-19 outbreak at the local level in Tanzania: A qualitative study. *PLOS Global Public Health*. 2022;2:e0001222.
45. Brownson RC, Fielding JE, Maylahn CM. Evidence-based public health: a fundamental concept for public health practice. *Annu Rev Public Health*. 2009;30:175–201.
46. Craven M, Sabow A, Van der Veken L, Wilson M. Not the last pandemic: Investing now to reimagine public-health systems. *McKinsey Report*. 2020;1:1–12.
47. Quinn SC, Kumar S. Health inequalities and infectious disease epidemics: a challenge for global health security. *Biosecurity and Bioterrorism: Biodefense Strategy, Practice, and Science*. 2014;12:263–73.
48. Reissman DB, Watson PJ, Klomp RW, Tanielian TL, Prior SD. Pandemic influenza preparedness: adaptive responses to an evolving challenge. *J Homel Secur Emerg Manage*. 2006;3:12–18.
49. Bennett BT. Understanding, Assessing, and Responding to Terrorism: Protecting Critical Infrastructure and Personnel. John Wiley & Sons; 2018.
50. de Jong JT, Berckmoes LH, Kohrt BA, Song SJ, Tol WA, Reis R. A public health approach to address the mental health burden of youth in situations of political violence and humanitarian emergencies. *Curr Psychiatry Rep*. 2015;17:1–0.
51. Feder J, Komisar HL, Niefeld M. Long-term care in the United States: an overview: a complex system of public and private funding often leaves elderly persons at risk of financial catastrophe and inadequate care. *Health affairs (Project Hope)*. 2000;19:40–56.
52. Rejeb A, Rejeb K, Simske S, Treiblmaier H. Humanitarian drones: a review and research agenda. *Internet Things*. 2021;16:100434.
53. Bowsher G, Papamichail A, El Achi N, et al. A narrative review of health research capacity strengthening in low and middle-income countries: lessons for conflict-affected areas. *Global Health*. 2019;15:1–3.
54. Sandifer PA, Walker AH. Enhancing disaster resilience by reducing stress-associated health impacts. *Front Public Health*. 2018;6:425313.
55. Altizer S, Dobson A, Hosseini P, Hudson P, Pascual M, Rohani P. Seasonality and the dynamics of infectious diseases. *Ecology Lett*. 2006;9:467–84.
56. Harvey P. International humanitarian actors and governments in areas of conflict: challenges, obligations, and opportunities. *Disasters*. 2013;37:S151–70.

57. Van Minh H, Pocock NS, Chaiyakunapruk N, et al. Progress toward universal health coverage in ASEAN. *Global health action*. 2014;7:25856.
58. Jamal Z, Alameddine M, Diaconu K, et al. Health system resilience in the face of crisis: analysing the challenges, strategies and capacities for UNRWA in Syria. *Health Policy Plan*. 2020;35:26–35.
59. Nel P, Righarts M. Natural disasters and the risk of violent civil conflict. *Int Stud Q*. 2008;52:159–85.
60. Mayer M. The onward sweep of social capital: causes and consequences for understanding cities, communities and urban movements. *Int J Urban Reg Res*. 2003;27:110–32.
61. Tizzoni M, Bajardi P, Poletto C, et al. Real-time numerical forecast of global epidemic spreading: case study of 2009 A/H1N1pdm. *BMC Med*. 2012;10:1–31.
62. Spiegel PB, Checchi F, Colombo S, Paik E. Health-care needs of people affected by conflict: future trends and changing frameworks. *Lancet (London, England)*. 2010;375:341–5.
63. Khanna RC, Cicinelli MV, Gilbert SS, Honavar SG, Murthy GV. COVID-19 pandemic: lessons learned and future directions. *Indian J Ophthalmol*. 2020;68:703–10.
64. Ansell C, Boin A, Keller A. Managing transboundary crises: Identifying the building blocks of an effective response system. *J Conting Crisis Manage*. 2010;18:195–207.
65. Hanefeld J, Mayhew S, Legido-Quigley H, et al. Towards an understanding of resilience: responding to health systems shocks. *Health Policy Plan*. 2018;33:355–67.
66. Silove D, Ventevogel P, Rees S. The contemporary refugee crisis: an overview of mental health challenges. *World Psychiatry*. 2017;16:130–9.
67. Okunade BA, Adediran FE, Balogun OD, Maduka CP, Adegoke AA. Capacity building in Nigeria's healthcare sector: a review of skill development and mentorship initiatives. *World J Adv Res Rev*. 2023;20:906–23.
68. Saleem S. Power, politics, and public health: understanding the role of healthcare expenditure in shaping health outcomes in Pakistan for policy enhancement. *Politica*. 2023;2:58–72.
69. Achumba IC, Ighomereho OS, Akpor-Robaro MO. Security challenges in Nigeria and the implications for business activities and sustainable development. *J Econ Sustain Dev*. 2013;4:79–99.
70. Kallström A, Häkkinen M, Al-Abdulla O, Juusola H, Kauhanen J. Caught in crossfire: health care workers' experiences of violence in Syria. *Med Confl Surviv*. 2021;37:34–54.
71. Madhav N, Oppenheim B, Gallivan M, Mulembakani P, Rubin E, Wolfe N. *Pandemics: risks, impacts, and mitigation. Disease Control Priorities: Improving Health and Reducing Poverty*. 3rd edition. 2017.
72. Chinwokwu EC, Michael CE. Militancy and violence as a catalyst to kidnapping in Nigeria. *Int J Police Sci Manage*. 2019;21:17–35.
73. Thomas R. Caring for those who care—aid worker safety and security as a source of stress and distress: a case for psychological support?. In: *Workplace Violence*. Willan. 2012. pp. 121–140.
74. Jiang L, Probst TM. The relationship between safety–production conflict and employee safety outcomes: testing the impact of multiple organizational climates. *Work & Stress*. 2015;29:171–89.
75. Clements A. *Humanitarian Negotiations with Armed Groups: The frontlines of diplomacy*. Routledge; 2019 Nov 26.
76. McNabb SJ, Chungong S, Ryan M, et al. Conceptual framework of public health surveillance and action and its application in health sector reform. *BMC Public Health*. 2002;2:1–9.
77. Brownson RC, Hoehner CM, Day K, Forsyth A, Sallis JF. Measuring the built environment for physical activity: state of the science. *Am J Prev Med*. 2009;36:S99–123.e12.
78. Chala B, Hamde F. Emerging and re-emerging vector-borne infectious diseases and the challenges for control: a review. *Front Public Health*. 2021;9:715759.
79. Kalluri S, Gilruth P, Rogers D, Szczur M. Surveillance of arthropod vector-borne infectious diseases using remote sensing techniques: a review. *PLoS Pathog*. 2007;3:1361–e116.
80. VoPham T, Hart JE, Laden F, Chiang YY. Emerging trends in geospatial artificial intelligence (geoAI): potential applications for environmental epidemiology. *Environ Health*. 2018;17:1–6.
81. Malik YS, Sircar S, Bhat S, et al. How artificial intelligence may help the Covid-19 pandemic: pitfalls and lessons for the future. *Rev Med Virol*. 2021;31:1–11.

82. Badidi E. Edge AI for early detection of chronic diseases and the spread of infectious diseases: opportunities, challenges, and future directions. Future Int. 2023;15:370.

أنظمة المراقبة البيولوجية لسلامة الصحة: الابتكارات في تتبع تفشي الأمراض والتهديدات باستخدام البيانات في الوقت الفعلي

الملخص

الخلفية: تشكل تفشي الأمراض المعدية في مناطق النزاعات تحديات كبيرة للصحة العامة، تزداد تعقيدًا بسبب تدمير البنية التحتية للرعاية الصحية ونشر السكان. تستعرض هذه المراجعة السردية الأبحاث حول تقاطع التكنولوجيا واستجابة الأمراض المعدية في المناطق المتأثرة بالصراعات، مع التركيز على المنهجيات المبتكرة لتتبع وإدارة تفشي الأمراض.

الطرق: تم إجراء بحث منهجي في قواعد البيانات الإلكترونية، بما في ذلك PubMed وWeb of Science وScopus، باستخدام مجموعة من الكلمات الرئيسية المتعلقة بالأمراض المعدية، والتكامل التكنولوجي، ومناطق النزاعات.

النتائج: كشفت النتائج عن عقبات حاسمة مثل قلة الوصول إلى الرعاية الصحية، وتعطيل مراقبة الأمراض، والمآزق الأخلاقية المتعلقة بخصوصية البيانات. ومع ذلك، فإن التقدم في مراقبة الأوبئة، بما في ذلك تقنيات الصحة المتنقلة (mHealth) والتسلسل الجينومي، يوفر مسارات واعدة لتحسين تتبع الأمراض وجهود الاستجابة. بالإضافة إلى ذلك، تقدم الأدوات المبتكرة مثل الطائرات بدون طيار والذكاء الاصطناعي (AI) منهجيات جديدة للمراقبة في الوقت الفعلي والتحليلات التنبؤية.

الخلاصة: خلصت الدراسة إلى أن هذه التقنيات يمكن أن تحسن بشكل كبير من إدارة التفشي وتقديم الرعاية الصحية، ولكن يجب معالجة التحديات المتعلقة بالحكم الأخلاقي، وأمن البيانات، والقيود على الموارد. تعتبر الجهود التعاونية بين الحكومات والمنظمات الإنسانية والمجتمعات المحلية أساسية لتحسين نشر الحلول التكنولوجية في مناطق النزاعات. يمكن أن يعزز دمج هذه الاستراتيجيات من النتائج الصحية العامة ويقوي القدرة على مواجهة الأوبئة المستقبلية في المناطق المتأثرة بالحروب.

الكلمات المفتاحية: الأمراض المعدية، مناطق النزاعات، مراقبة الأوبئة، التكامل التكنولوجي، تدخلات الصحة العامة.