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REVIEW

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Urbanization and emerging vector-borne threats: Diagnostic frontiers and public health implications

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ABSTRACT

Quick urban growth has greatly influenced the worldwide increase of vector-borne diseases (VBDs), altered their patterns, and broadened their geographical distribution. Cities with high population density, poor sanitation, and ecological changes caused by climate have established favorable circumstances for disease carriers like mosquitoes to flourish. Recent instances of dengue, chikungunya, Zika, and West Nile virus highlight the increasing public health challenge, particularly in swiftly developing areas. Clinical microbiologists are essential in monitoring, identifying, and controlling these infections using advanced diagnostic methods, molecular techniques, and real-time reporting systems. The combination of digital technologies such as GIS mapping, genomic sequencing, and AI-driven predictions of outbreaks enhances early warning abilities. Despite advancements in technology, obstacles such as inadequate infrastructure, lack of funding, and the necessity for trained staff continue to exist, especially in resource-poor environments. Enhancing cooperative networks and integrating One Health approaches will be crucial for efficient control of vector-borne diseases (VBD). This review emphasizes the various responsibilities of clinical microbiologists and stresses the importance of collaborative actions to address vector-borne diseases amid increasing urban development.

KEYWORDS

Vector-borne diseases (VBDs); Clinical microbiology; Disease surveillance; Public health microbiology

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Introduction

Urbanization, which refers to the increasing proportion of a population in urban areas, is a defining feature of 21st-century development. More than 55% of the world's population lived in cities in 2021, and forecasts point to a rise to 68% by 2050. Rapid and unplanned urbanization can result in issues like substandard housing, poor hygiene, and inadequate waste disposal, even if urban expansion can spur economic development and enhance access to services. These factors contribute to ideal conditions for the reproduction of disease vectors, particularly mosquitoes, which raises the danger of vector-borne diseases (VBDs) [1].

More than 17% of all infectious illnesses are vector-borne diseases, which are spread by vectors such as mosquitoes, ticks, and sandflies and result in more than 700,000 fatalities each year. There has been a notable rise in diseases like dengue, chikungunya, Zika, and malaria in urban regions, particularly in areas where cities are growing quickly. The accumulation of stagnant water in metropolitan waste, greater human-vector contact as a result of high population density, and the adaptation of vectors like Aedes aegypti to urban conditions are all factors that have contributed to this increase [2].

In this situation, clinical microbiologists' role becomes critical. Their proficiency in pathogen detection, disease surveillance, and outbreak response is critical for the early detection and management of vector-borne diseases (VBDs). Clinical microbiologists can contribute to the creation of focused interventions and policies to lessen the spread of these diseases by combining laboratory results with public health programs [3].

The goal of this brief review is to examine the relationship between urbanization and the incidence of vector-borne diseases, with a focus on the essential function that clinical microbiologists play in monitoring and control initiatives. This review aims to emphasize the significance of interdisciplinary approaches in tackling the health consequences of urbanization by analyzing contemporary issues and methods [4].

Urbanization as a Driver of Vector-Borne Diseases

Urban slums, which are defined by overcrowding, substandard housing, and restricted access to clean water and sanitation, are perfect breeding places for vectors. Due to an unreliable water supply, locals frequently store water in open containers in these environments, which unintentionally provide breeding grounds for mosquitoes like Aedes aegypti, the main carrier of the dengue, chikungunya, and Zika viruses. Furthermore, inadequate waste disposal and blocked drainage systems promote the build-up of stagnant water, which in turn promotes mosquito breeding. In Mumbai, for example, the combination of monsoon rains and inadequate urban infrastructure has resulted in a significant rise in malaria and dengue cases, with hospitals reporting serious cases requiring intensive care. According to health campaigners, the increase is due to the city's subpar waste management and sanitation infrastructure, which promotes mosquito breeding [5].

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Climate change intensifies the difficulties brought about by urban growth. Increasing global temperatures and changes in precipitation patterns affect the spread of vectors and the dynamics of disease transmission. Higher temperatures can speed up the life cycles of mosquitoes, leading to a rise in their numbers and more contact between humans and these insects. Additionally, severe weather events like floods and droughts can disturb ecosystems and compel vectors to adjust to city settings. For instance, the spread of Aedes mosquitoes into new areas has been associated with changes in habitats caused by climate, resulting in outbreaks of illnesses such as dengue and Zika in urban regions that were not previously impacted. (Figure 1), illustrates the multifactorial impact of urbanization on the epidemiology of vector-borne diseases in rapidly growing cities [6].

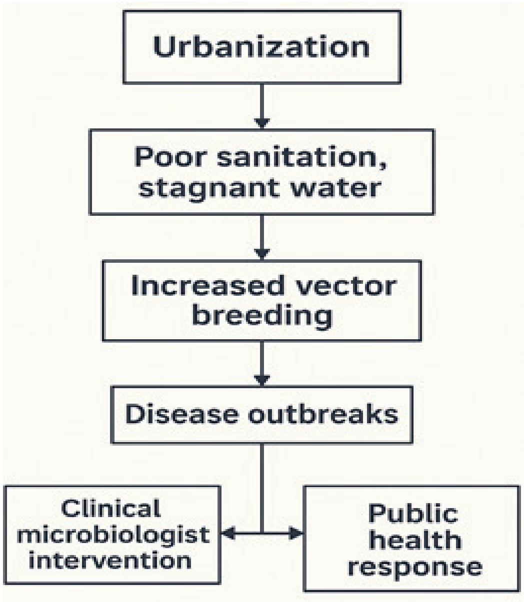

Figure 1. Schematic showing how urban slums, poor water management, and climate change drive vector-borne disease transmission.

Case study

Megacities like Mumbai and Rio de Janeiro have witnessed a surge in dengue cases, highlighting the interplay between urbanization and VBDs. In Mumbai, rapid urban growth has led to the proliferation of informal settlements with poor sanitation. The accumulation of stagnant water in these areas provides breeding sites for Aedes aegypti. Despite efforts by the Municipal Corporation of Greater Mumbai to implement vector control measures, including thermal fogging and public awareness campaigns, dengue outbreaks persist annually. Similarly, Rio de Janeiro faces challenges in controlling dengue due to its dense population and inadequate waste management. The city's favelas, often lacking proper sanitation, become hotspots for mosquito breeding. Public health initiatives focusing on community engagement and environmental management are crucial in mitigating the spread of dengue in such urban settings [7, 8].

Traditionally considered a rural disease, malaria is reemerging in urban areas across Africa. Factors contributing to this trend include unplanned urban expansion, inadequate drainage systems, and the proliferation of urban agriculture, which creates standing water bodies suitable for Anopheles mosquito breeding. Additionally, climate change-induced alterations in rainfall patterns have expanded the habitats of malaria vectors into urban settings. The reemergence of malaria in cities underscores the need for integrated urban planning and targeted vector control strategies to address this evolving public health challenge. Urban heat islands (UHIs), characterized by elevated temperatures in metropolitan areas compared to surrounding rural regions, influence mosquito behavior and disease transmission. Higher temperatures can enhance mosquito development rates, biting frequency, and viral replication within vectors. A study in São Paulo revealed that areas with higher land surface temperatures and lower vegetation cover experienced increased dengue incidence. Laboratory experiments further demonstrated that Aedes aegypti mosquitoes exhibited accelerated development and higher reproductive rates at temperatures between 28°C and 32°C, conditions commonly found in UHIs [9, 10].

Epidemiology and Vector-Borne Disease Threats in Urban Areas

Recent outbreaks in urban areas

Recent years have witnessed notable outbreaks of VBDs in urban regions. In 2024, the Hawaii Department of Health confirmed the first case of Zika virus in Hawaii since 2019, identified on the island of Oahu. This case was travel-related, highlighting the role of human movement in disease spread. Additionally, Europe has experienced a rise in mosquito-borne diseases, with the European Centre for Disease Prevention and Control reporting an increase in locally acquired cases of dengue and West Nile virus infections within the EU/EEA [11]. The traditional geographic boundaries of many VBDs are shifting due to urban migration and increased travel. For instance, the West Nile virus, once confined to specific regions, has been detected in UK mosquitoes for the first time, indicating a northward expansion of the disease vector. Similarly, dengue fever, historically prevalent in tropical areas, has threatened mainland France, with 78 indigenous cases reported since May 1st, 2024. These shifts underscore the impact of human movement and urbanization on disease distribution [12].

Globalization and contemporary transportation have enabled the swift dissemination of pathogens along with their carriers. The growth of international air travel and sea trade eliminates geographic obstacles for insect disease carriers, allowing them to travel long distances in a short time. For instance, the Asian tiger mosquito (Aedes albopictus), an effective carrier of various arboviruses, has disseminated worldwide, in part because of global trade and travel [12, 13].

Furthermore, climate change worsens these issues by making conditions more suitable for vectors in areas that were formerly unwelcoming. Rising temperatures and changed rainfall patterns have broadened the living spaces of mosquitoes, resulting in a higher spread of illnesses such as dengue and Zika in city environments. Various vector-borne diseases have surged in urban settings due to changing ecological dynamics and human mobility (Table 1) [13, 14].

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Table 1. Key vector-borne diseases prevalent in urban areas and their clinical and diagnostic features.

Disease	Primary Vector	Symptoms	Urban Hotspots	Diagnostic Tools
Dengue	*Aedes aegypti*	Fever, rash, hemorrhage	Mumbai, Rio de Janeiro	RT-PCR, ELISA
Chikungunya	*Aedes aegypti/albopictus*	Joint pain, fever, rash	Delhi, Bangkok	RT-PCR, Serology
Zika	*Aedes aegypti*	Rash, fever, congenital defects	Miami, São Paulo	RT-PCR, IgM ELISA
Malaria	*Anopheles spp.*	Fever, chills, anemia	Lagos, Kinshasa	Microscopy, RDT, PCR
West Nile Virus	*Culex spp.*	Fever, encephalitis	New York City, Cairo	IgM ELISA, PCR

Clinical Microbiologists in Surveillance and Detection

Accurate diagnosis begins with the proper collection, labelling, and transport of clinical specimens. Clinical microbiologists establish standardized protocols to ensure specimen integrity, which is crucial for reliable results. Proper specimen handling under appropriate biosafety conditions is essential to protect laboratory personnel and maintain sample quality. Once specimens reach the laboratory, microbiologists employ various techniques to identify pathogens. Traditional methods like culture and microscopy are complemented by modern molecular diagnostics, enabling the detection of pathogens that are difficult to culture or require rapid identification [15].

Molecular and serological diagnostics

Molecular diagnostics, especially real-time polymerase chain reaction (RT-PCR), have transformed the identification of vector-borne disease (VBD) pathogens. RT-PCR provides excellent sensitivity and specificity, enabling the quick detection of viral nucleic acids in clinical specimens. This method has been crucial in identifying illnesses like dengue, Zika, and West Nile virus, frequently revealing infections prior to the measurable responses in blood tests. Figure 2 outlines the key responsibilities of clinical microbiologists in vector-borne disease (VBD) surveillance [16].

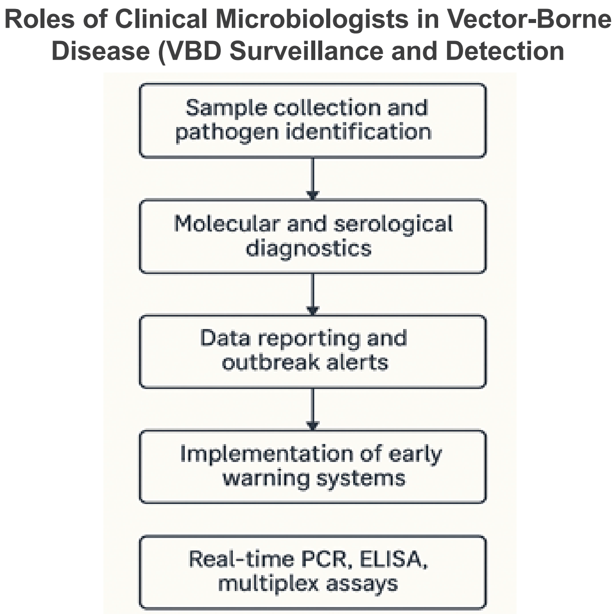

Figure 2. Clinical microbiologists' role in VBD surveillance, from sample collection to diagnostics and outbreak response

Serological tests, such as enzyme-linked immunosorbent assays (ELISA), identify antibodies in the host that respond to particular pathogens. ELISA is commonly utilized for monitoring purposes because it is economical and can handle a significant number of samples efficiently. For example, the ELISA method that focuses on the non-structural 1 (NS1) protein of the dengue virus is a common tool used for the early detection and monitoring of outbreaks [17].

Outbreak alerts

Clinical microbiologists play a critical role in reporting laboratory findings to public health authorities. Timely communication of diagnostic results facilitates prompt outbreak response and implementation of control measures. Laboratories often participate in surveillance networks, contributing data that inform public health strategies and policies. The integration of laboratory data into centralized surveillance systems enables real-time monitoring of disease trends. This collaborative approach enhances the ability to detect emerging threats and coordinate responses across different regions and sectors [18].

Laboratory-based early warning systems

Early warning systems rely on the continuous monitoring of laboratory data to identify unusual patterns indicative of potential outbreaks. Clinical microbiologists contribute by analyzing trends in test results, identifying anomalies, and alerting relevant authorities. Such systems are vital for the early detection of VBDs, allowing for swift public health interventions. The effectiveness of these systems depends on the accuracy and timeliness of laboratory diagnostics, underscoring the importance of robust laboratory infrastructure and skilled personnel [19].

Advanced diagnostic techniques

Advancements in diagnostic technologies have enhanced the capacity of clinical laboratories to detect multiple pathogens simultaneously. Multiplex PCR assays allow for the concurrent detection of various VBD agents in a single test, increasing efficiency and conserving resources. Similarly, multiplex ELISA platforms can screen for antibodies against multiple pathogens, facilitating comprehensive surveillance efforts. These high-throughput methods are particularly valuable during outbreaks when rapid and extensive testing is required. Clinical microbiologists play a central role in VBD surveillance through a range of responsibilities outlined in Table 2 [20].

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Table 1. Role of clinical microbiologists in urban VBD surveillance.

Activity	Description
Sample collection	Collection from suspected cases and vectors
Laboratory diagnostics	RT-PCR, ELISA, multiplex assays for pathogen identification
Data interpretation & reporting	Timely alerts to public health authorities
Outbreak investigation	Genomic tracking and hotspot mapping
Biosafety and QC	Ensuring laboratory safety and diagnostic accuracy
Policy advising	Informing vector control strategies and surveillance protocols

Quality control and biosafety in laboratories

Maintaining high standards of quality control is essential to ensure the reliability of diagnostic results. Clinical microbiologists implement rigorous quality assurance protocols, including the use of positive and negative controls, regular calibration of equipment, and participation in proficiency testing programs. Biosafety is another critical aspect, especially when handling infectious agents. Laboratories must adhere to biosafety guidelines to prevent laboratory-acquired infections and environmental contamination. Proper training, use of personal protective equipment, and facility design are integral components of a safe laboratory environment [21].

Integration of Digital Tools and Genomic Surveillance

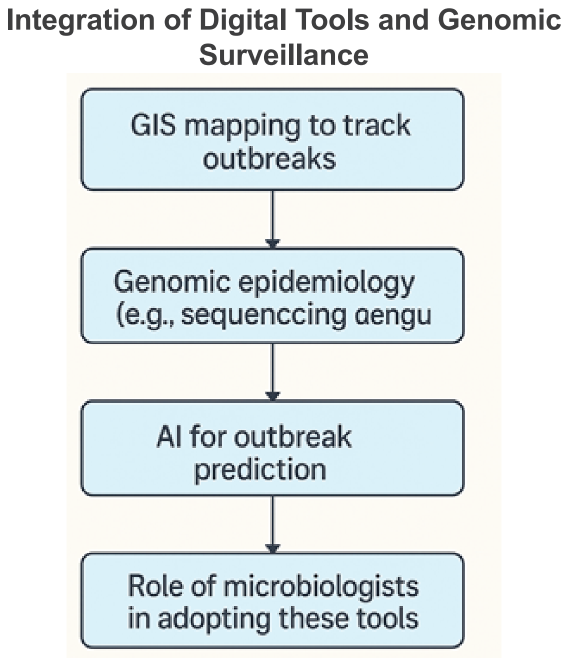
The advent of digital technologies has revolutionized the surveillance and management of vector-borne diseases (VBDs) in urban environments. Clinical microbiologists are at the forefront of this transformation, employing tools such as Geographic Information Systems (GIS), genomic epidemiology, and artificial intelligence (AI) to enhance disease tracking, prediction, and response [20].

GIS mapping for tracking

GIS technology enables the spatial visualization of disease incidence, facilitating the identification of hotspots and transmission patterns. In India, for instance, the PRISM-H platform integrates GIS with AI to predict dengue outbreaks by analyzing factors like rainfall, humidity, and vegetation. This system provides predictive analysis weeks in advance, allowing for proactive public health interventions [22].

Epidemiology for pathogen surveillance

Genomic sequencing has become an indispensable tool in understanding the evolution and spread of VBD pathogens. Platforms like Nextstrain offer real-time tracking of viral genomes, aiding in the identification of transmission chains and emerging variants. During the 2016 Zika outbreak in Florida, genomic analyses revealed multiple independent virus introductions and underscored the role of human movement in disease spread. Similarly, in Angola, genomic investigations of dengue virus serotype 2 provided insights into its introduction and dissemination patterns, informing targeted control measures. Figure 3 shows the integration of digital tools and genomic technologies in modern disease surveillance frameworks [23].



AI for outbreak prediction

Artificial intelligence enhances the predictive capabilities of disease surveillance systems. Tools like BlueDot analyze vast datasets, including climate patterns and travel data, to forecast disease emergence and spread. In Australia, AI algorithms have been utilized to analyze environmental and epidemiological data, improving the accuracy of arbovirus outbreak predictions [24].

Role of clinical microbiologists

Clinical microbiologists play a crucial role in integrating these digital tools into public health strategies. They are responsible for validating and interpreting data from genomic and AI-based systems, ensuring accurate disease surveillance. Their expertise bridges the gap between laboratory findings and actionable public health responses, facilitating timely interventions to curb the spread of VBDs [24, 25].

Collaboration with Public Health Authorities

Linking clinical data to public health

Timely and accurate laboratory data are essential for effective public health responses. Clinical microbiologists ensure the rapid identification and reporting of pathogens, facilitating prompt outbreak detection and response. Their expertise in diagnostic stewardship and data interpretation is vital for informing public health strategies and interventions [26].

Evidence-based support for vector control

Evidence-based data provided by clinical microbiologists underpin targeted vector control efforts. By analyzing trends in

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pathogen prevalence and resistance patterns, they guide the deployment of control measures such as insecticide application and community education programs. Their collaboration with public health authorities ensures that vector control strategies are scientifically grounded and contextually appropriate [27].

Informing policy and preparedness

Beyond immediate outbreak response, clinical microbiologists contribute to long-term public health planning and policy development. Their insights inform the creation of guidelines and protocols for disease prevention and control. In the realm of pandemic preparedness, their involvement is crucial for developing surveillance systems, laboratory capacity building, and emergency response frameworks. Collaborations with organizations like the Global Research Collaboration for Infectious Disease Preparedness (GloPID-R) exemplify their role in shaping global health policies [24, 27].

Challenges and Future Directions

Despite advancements, clinical microbiologists face significant challenges in effectively surveilling vector-borne diseases, especially in developing countries. Infrastructure gaps such as limited laboratory facilities, inadequate diagnostic tools, and insufficient biosafety measures hinder timely detection and response. Additionally, many regions struggle with shortages of trained personnel capable of utilizing advanced molecular and digital technologies. Funding constraints further exacerbate these issues, restricting continuous surveillance efforts and delaying outbreak interventions. Sustained investment is crucial to build resilient laboratory networks and upgrade diagnostic capacities [28, 29].

Looking ahead, establishing global microbiologist networks is vital for coordinated surveillance and rapid information sharing. Integrating the One Health approach, recognizing the interconnectedness of human, animal, and environmental health, will enhance comprehensive disease monitoring and control strategies. Collaborative efforts leveraging technology, training, and policy support can bridge current gaps, strengthening preparedness against the growing threat of vector-borne diseases in urbanized settings [30].

Conclusion

Urbanization has significantly reshaped the landscape of vector-borne diseases, amplifying their incidence and complexity in densely populated settings. Clinical microbiologists play a pivotal role in this evolving challenge by enabling accurate pathogen detection, integrating advanced diagnostic technologies, and collaborating closely with public health authorities. The adoption of digital tools and genomic surveillance further empowers timely outbreak prediction and response. However, addressing infrastructural and funding challenges, especially in developing regions, remains essential for effective disease control. Moving forward, strengthening global networks and embracing interdisciplinary approaches like One Health will be critical to enhance surveillance and mitigate the impact of vector-borne diseases in urban environments. Ultimately, clinical microbiologists stand at the forefront of safeguarding public health amid rapid urban growth and emerging infectious threats.

Disclosure statement

No potential conflict of interest was reported by the authors.

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