Review article

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Impact of climate change on vector-borne infectious diseases

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This thesis addresses the most significant vector-borne infectious diseases affecting humans and animals, which represent some of the major contemporary public health challenges. In recent years, these diseases have increasingly emerged in regions where they were not previously endemic. Over the past few decades, a clear association has been established between climate change and the geographic expansion and activity of vectors. The movement and behavior of disease vectors are becoming increasingly difficult to predict and control.

Keywords: vector-borne infectious diseases, climate change, disease vectors

Pregledni rad

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Uticaj promene klime na vektorski prenosive zarazne bolesti

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U ovom radu se govori o najznačajnijim vektorski prenosivim zaraznim bolestima ljudi i životinja, a koje nesumnjivo uzrokuju neke od najznačajnijih bezbednosnih problema današnjice. Ove bolesti u poslednje vreme imaju tendenciju da se pojavljuju u oblastima u kojima nije tipično da postoje. U poslednjih nekoliko decenija ustanovljeno da postoji veza između promene klime i kretanja vektora, odnosno prenosioca istih.

Ključne reči: vektorski prenosive zarazne bolesti, klimatske promene, prenosioci zaraznih bolesti

Introduction

Climate change, in addition to its extensive environmental and societal impacts, drives the redistribution of climatic zones, prompting wildlife to migrate from their traditional habitats into newly established regions. The high dispersal capacity of certain disease vectors, coupled with their ability to transmit pathogens beyond their endemic ranges, increases the likelihood of interactions with previously unexposed human and animal populations. These encounters may involve either newly introduced organisms or the endogenous microbiota of the vectors themselves. Such interactions between infected vectors and immunologically naïve hosts create ideal conditions for the emergence, replication, and dissemination of infectious agents. Given the potentially irreversible trajectory of climate change, the appearance of vector-borne diseases in regions where they were historically absent represents a critical public health concern. This necessitates rigorous evaluation of both the potential severity and probability of disease emergence, alongside the development of pragmatic and evidence-based control strategies.

Climate Change as an Indirect and Direct Cause of Human and Animal Susceptibility

Climate change refers to alterations in weather patterns that are directly linked to human activities, modifying the composition of the atmosphere and being recorded continuously over time, in contrast to natural climate variability, which occurs over longer periods[1]. The World Health Organization recognizes climate change as one of the most significant threats to human health[2]. Over the past several decades, climate change has emerged as the most serious global threat, affecting not only the natural environment and ecosystems but also socioeconomic and political structures worldwide. Addressing this issue requires coordinated and cooperative action from all nations. In 2015, under the United Nations Framework Convention on Climate Change (UNFCCC), an agreement was reached among 195 countries outlining their roles in combating global climate change, focusing on reducing greenhouse gas emissions and limiting global temperature rise to 1.5°C[3].

Climate change directly impacts health through long-term alterations in temperature and precipitation2, primarily influencing the transmission and spread of vector-borne diseases. Climate may affect the dynamics of transmission, the geographical distribution, and the recurrence of vector-borne infectious diseases. Beyond its direct effects on individual species, climate change can transform entire habitats and ecosystems[4]. Alterations in the natural environment can enhance the proliferation and dispersal of various vectors globally. The emergence of new viruses and pathogens represents a major potential threat. As these pathogens mutate, they may come into contact with susceptible populations, thereby increasing the potential for epidemic spread[5]. Conversely, the effects of climate on zoonoses transmitted by vectors remain particularly unclear and underexplored[6].

Vector-borne infectious diseases pose a substantial risk because their vectors—primarily arthropods—are highly sensitive to environmental changes. For example, arthropod body temperature is largely regulated by external conditions. The vectorial capacity of many harmful vector-borne pathogens reaches its peak at relatively high temperatures. If unmitigated, future climate change is likely to alter the duration of disease transmission seasons and shift the geographical distribution of species. The direct effects of climate change on habitats, combined with intensified anthropogenic pressures on the natural environment, significantly impact biodiversity, thereby influencing the occurrence and transmission of infectious diseases. Vector-borne pathogens may also indirectly affect human health by compromising food safety and quality, in addition to their established direct impacts through disease transmission via infected animals or vectors[2].

All levels of public health responsibility require accurate assessments of when and where climate change may trigger the emergence, re-emergence, or disappearance of vector-borne diseases. Predictive information is crucial for developing preparedness policies to address potential risks from vector-borne diseases in the near or distant future. Such predictions include, among other factors, the identification of climatic thresholds for vectors and pathogen transmission, the determination of when and where these thresholds occur, and, ultimately, the projection of future climatic boundaries using global or regional climate models[7].

The Influence of Diseases on Human and Animal Health

The ultimate goal in combating vector-borne diseases is the protection of human health, in addition to safeguarding animal health. Animal diseases contribute to increased mortality, reduced productivity, compromised quality of animal products, and ultimately, have direct and indirect impacts on human health. Human populations are considered at risk in regions where animal diseases are prevalent. Shared human and animal diseases can result in mortality as the most severe outcome in a substantial number of cases, as well as malnutrition, which is particularly characteristic of regions lacking adequate human health infrastructure[8].

Measurements and Strategies for Disease Control

Disease control remains one of the primary objectives in modern veterinary and public health practice. The principal strategy is the eradication of disease through the removal of sick and infected animals. Treatment of infected animals is generally reserved for specific, exceptional cases. Disease control relies on quarantine of affected and infectious animals, diagnostic testing, restriction of animal movement, and immunization in instances where vaccines are available and safe[9].

Prevention aims to avert the occurrence of a disease within a population where it is not yet present. Disease control, when implemented, encompasses interventions designed to reduce the incidence of disease and the number of infected individuals to levels deemed acceptable or economically, technologically, and ecologically insignificant. Eradication involves the complete elimination of a specific pathogen within a defined region or country. Key prerequisites for initiating an eradication program include: the disease's significant impact on the economy, ecology, and society; a thorough understanding of the disease's biology and epidemiology; and the availability of at least one effective intervention to prevent disease transmission[8].

Control of vectors—the transmitters of infectious agents—is critical for preventing the spread of pathogens to uninfected animals, humans, or disease-free regions. Decontamination of infected surfaces and materials is essential for interrupting the transmission of infection. Rigorous disinfection of contaminated areas can substantially reduce or halt the spread of zoonoses. Furthermore, harmonization of national and international regulations is crucial for the prevention and containment of zoonotic diseases[9].

Most Important Vectors and Significant Diseases Transmitted to Humans

During the final years of the previous century, a trend was observed in the emergence and spread of exotic diseases that had previously exhibited limited epizootiological and epidemiological potential. One of the earliest examples was West Nile fever. Initially considered a "localized" disease with low potential for rapid dissemination, it nevertheless spread from Africa to the Americas within a decade and subsequently reached global distribution. In the first decade of the current century, it became evident that globalization is a complex process encompassing economic, social, and climatic factors, all of which significantly influence the characteristics and distribution of exotic diseases and zoonoses, in part as a consequence of technological advancement[10].

Climate change has facilitated the expansion of vector species—including ticks, sandflies, and mosquitoes—that transmit zoonotic pathogens. Consequently, some vector-borne diseases are now appearing in regions where they were previously unrecorded, or occurring with greater frequency in areas where they were formerly sporadic. Additionally, alterations in the population dynamics of species serving as potential reservoirs necessitate continuous monitoring to mitigate the risk to human and animal health[11].

Climate Change and Ticks

Ticks, as one of the most representative vectors, spend the majority of their life cycle off-host within the environment. Their survival depends on the availability of suitable habitats and climatic factors, including temperature, humidity, and vegetation cover. Consequently, climate change directly influences the distribution, abundance, and host-seeking behavior of ticks[3]. Additionally, human activity contributes to the spread of tick populations through alteration of natural habitats and long-distance travel[12]. Over the past several decades, the expansion of tick distribution has been observed, indicating a favorable effect of climate change on their prevalence. Beyond increased abundance, climate-driven changes in habitat behavior also play a critical role in the occurrence of tick-borne diseases. Ticks serve as vectors for various pathogens, including zoonotic agents, affecting both humans and animals. The combined increase in tick prevalence and the geographic expansion of tick-borne zoonoses presents a substantial threat to public and animal health[3].

Climate is a key determinant of tick prevalence within specific regions, influencing interactions between ticks, their habitats, and pathogens. This effect facilitates the colonization of new areas by ticks and the transmission of associated pathogens. Climate change impacts ticks both directly and indirectly by affecting survival, reproduction, activity, and the suitability of human and animal habitats[3].

Changes in Geographical Distribution

Over recent decades, ticks have demonstrated a continuous expansion of their geographic range, including colonization of higher altitudes. This phenomenon is closely associated with rising environmental temperatures and altered precipitation patterns, which allow ticks to establish populations in newly available habitats. For example, *Ixodes ricinus* has expanded its range into regions of Europe where it was previously unrecorded. Similarly, climate change favors the establishment of exotic species; for instance, the Asian tick *Haemaphysalis longicornis* has become dominant in parts of the United States. Projections indicate a substantial global increase in tick distribution and intercontinental translocations[3].

Ticks exhibit distinct seasonal activity patterns that are influenced by environmental conditions suitable for habitat-seeking, including temperature, relative humidity, light intensity, and photoperiod. Warm climates accelerate diapause termination and egg hatching, thereby affecting tick phenology. In a 19-year study in New York, *Ixodes scapularis* emerged approximately three weeks earlier in warmer years compared with colder years. Similarly, tick activity in temperate regions has increased due to climate warming. Seasonal effects are more pronounced in exophilic species. For example, in Brazil, *Rhipicephalus microplus* spends a consistent 21–23 days on-host regardless of season, whereas off-host duration varies from 40–50 days in spring and summer to 70–120 days in autumn and winter. Ticks of the same species demonstrate adaptability to diverse climatic conditions, evident in behavioral studies of different populations. This adaptability is facilitated by evolutionary adaptations and modifications in gene expression within sensory systems[3].

Climate change is believed to enhance tick reproduction and development, reflected by increased tick densities in affected areas. In Russia, *Ixodes ricinus* populations have risen over the past 35 years in response to a 5°C increase in autumn and late-summer temperatures, underscoring temperature as the most critical factor for tick development. Elevated temperatures accelerate all life stages, from oviposition to host-seeking adults, inversely correlating with developmental duration. Consequently, global warming shortens the tick life cycle; for example, *Ixodes scapularis* completes a generation in 2 years in the USA compared with 3–4 years in Canada. Ticks also exhibit diapause mechanisms to survive adverse environmental conditions, which are modulated by temperature. When conditions become favorable, normal activity and development resume[3].

The Effect on Sensitive Habitats

When new tick species colonize previously uninhabited regions due to climate change, they induce complex ecological interactions within local communities. As a result, certain habitats may become more favorable, while others may be exploited. For example, *Rhipicephalus (R.) microplus*, primarily a parasite of domestic animals, invaded New Caledonia in 1942, leading to the adaptation of a deer species to its habitat. Initially, deer were considered suboptimal hosts; *R. microplus* required approximately 250 generations to fully adapt, resulting in isolated populations now established on both cattle and deer. Such adaptive processes are key mechanisms enabling ticks to persist in changing climates and maintain biodiversity3.

Most Important Diseases Transmitted by Ticks

Lyme Disease

Lyme disease (also referred to as borreliosis) is a bacterial zoonosis caused predominantly by *Borrelia burgdorferi*, transmitted via bites from infected *Ixodes* spp. ticks. These ticks undergo three developmental stages, completing their life cycle within 2–3 years depending on climatic conditions. Climate change has enhanced tick survival and habitat accessibility, leading to increased disease prevalence. In Canada, for instance, 40 cases were reported in 2004, increasing to 917 cases between 2009 and 2015, reflecting substantial growth. The geographic expansion of *Ixodes scapularis* northward, coupled with the proliferation of its primary host, the white-footed mouse, has driven this increase. Data from 2000–2017 in the USA similarly demonstrate higher incidence rates correlated with rising annual temperatures, particularly in the northeastern states3.

Tick-Borne Encephalitis

Tick-borne encephalitis is a viral zoonosis caused by a flavivirus. Humans act as incidental hosts, while small mammals serve as primary reservoirs. The virus affects the central nervous system and is distributed across Europe, the Caucasus, Kazakhstan, Russia, and China. Case numbers have increased in recent decades, even in regions previously unaffected3. Transmission is seasonal, primarily associated with *Ixodes ricinus* nymphs, and occurs via systemic, non-systemic, and transovarial routes. Climate change significantly influences tick survival, activity, reproduction, and ecological interactions, facilitating sustained transmission through increased habitat accessibility, higher tick densities, and overlapping activity of infected and uninfected nymphs and larvae3.

Crimean-Congo Hemorrhagic Fever (CCHF)

CCHF is a tick-borne zoonosis caused by a nairovirus, primarily transmitted to humans via bites from infected *Hyalomma* ticks, and also through contact with infected blood or bodily fluids3. Its global prevalence is rising, with recent epidemics reported across the Eastern Mediterranean. The disease has expanded into previously non-endemic regions, including Turkey, Greece, Iran, India, Georgia, and Spain. In Turkey, human cases increased from the first identification in 2002 to over 6,300 cases by 2012. Climate change and tick population dynamics jointly drive geographic expansion, increasing human exposure and pathogen transmission3.

Culex pipiens – Common House Mosquito

Culex pipiens is a widespread vector in Europe, including Serbia, inhabiting both rural and urban environments. It demonstrates high ecological adaptability and transmits numerous vector-borne pathogens, including West Nile virus (WNV)13. WNV persists in a natural cycle between mosquitoes and birds, while humans serve as incidental hosts14. Transmission to humans occurs via mosquito bites, blood transfusion, organ transplantation, or occupational exposure, with approximately 1 in 150 infected individuals developing neurological disease (meningitis, encephalitis, or poliomyelitis)15. Vector suppression remains the most effective preventive measure. Clinical presentations and transmission dynamics differ between Europe and North America, necessitating region-specific surveillance and control strategies16.

Aedes albopictus – Asian Tiger Mosquito

Aedes albopictus, originating from subtropical Southeast Asia, has expanded globally into temperate regions through climate change and human activity. It is a competent vector for several pathogens affecting human and animal health, including chikungunya, dengue, Japanese encephalitis, Zika, and Rift Valley fever viruses. In Europe, it is the primary transmitter of dengue and chikungunya viruses, with documented cases from 2007–2020 in Croatia, France, Italy, and Spain. In Serbia, *Aedes albopictus* has been recorded annually since 2009, with the first dengue case reported in 201513.

Anopheles hyrcanus – Malaria Mosquito

Anopheles hyrcanus, a Palearctic malaria vector, transmits *Plasmodium vivax*, one of the three deadliest human pathogens alongside tuberculosis and HIV/AIDS13. In Serbia, only imported malaria cases have been reported since 1974. Although it currently feeds outdoors and is not a primary European malaria vector, expansion into higher latitudes, combined with modified human activities and increased exposure, could enhance its role in malaria transmission in temperate regions13.

Phlebotomus papatasi – Sandfly, Vector of Leishmaniasis and Papataci Fever

Sandflies (*Phlebotomus* spp.) transmit *Leishmania* parasites, the causative agents of leishmaniasis, as well as other pathogens. Increased human, animal, and goods movement has elevated the risk of leishmaniasis in Serbia13. The disease, primarily tropical/subtropical, was first reported during World War II, with major epidemics in 1945 and 1953. Although considered eradicated since 1968, recent endemic transmission among dogs in Vojvodina indicates potential reemergence13.

Tracking and Monitoring of Disease Vectors

Vector surveillance employs active and passive methods13. Active monitoring involves collecting eggs, larvae, and adults in the environment using various techniques, while passive monitoring engages citizens in data collection. Serbia implemented its first passive system via a mobile application in 2018, later integrating with the European Mosquito Alert system in 2020, involving 26 countries. Surveillance can be transversal (one-time collections across multiple sites) or longitudinal (repeated collections at the same site over months or years), providing data on vector presence, distribution, seasonality, and abundance13.

Vector Suppression

Current vector control faces multiple challenges, including differences in management between regions. In the USA, vector control is overseen by state-run Mosquito Abatement Districts, established as public enterprises to protect public health13. In Europe, vector control is largely conducted by private companies, often with limited ecological knowledge and poor integration with surveillance data, leading to inefficiencies despite expenditures exceeding €100 million annually13. Public, non-profit enterprises in the USA and select European countries maintain quality control to ensure effective vector suppression13.

Conclusion

Climate change is an ongoing, largely uncontrollable process with widespread consequences for wildlife and human health. This review highlights the risks associated with vector-borne diseases under changing climatic conditions. Lessons from the COVID-19 pandemic, including rapid diagnostics using nanoparticles and mRNA vaccine development, demonstrate the potential of innovative approaches to controlling emerging pathogens. Similarly, drones may enhance vector control by targeting previously inaccessible breeding sites, addressing limitations of conventional methods. Evidence from ecological studies underscores the urgency of implementing measures to mitigate climate change and its impact on vector-borne disease dynamics.

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