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The Impact of Climate Change on the Epidemiology of Plasmodium vivax Malaria in Temperate Regions: A Scoping Review

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ABSTRACT

Climate change is increasingly influencing the epidemiology of Plasmodium vivax malaria, particularly in temperate regions where shifting environmental conditions are altering transmission dynamics. This scoping review examined the impact of climate change on P. vivax malaria by evaluating the roles of temperature, precipitation, and vector habitat expansion in driving transmission patterns. Systematic research and synthesis of peer-reviewed literature, climate models, and epidemiological data were conducted to assess the interplay between climatic factors and malaria risk. Findings revealed that rising temperatures extend mosquito breeding seasons and reduce winter mortality, while changes in precipitation and humidity create favorable conditions for vector proliferation. Additionally, the expansion of Anopheles mosquito habitats into higher latitudes and elevations, coupled with prolonged transmission periods, increases the risk of malaria resurgence in previously non-endemic temperate regions. Human factors such as migration, socioeconomic disparities, and land-use changes further exacerbate transmission risks. The review underscored the need for integrated public health strategies, including enhanced surveillance, vector control, and climate-informed risk assessments, to mitigate the impact of climate change on P. vivax malaria. Proactive measures and interdisciplinary collaboration are essential to address the evolving threat of malaria in temperate climates and to prevent its re-emergence in vulnerable populations.

Keywords: Plasmodium vivax malaria, Climate change, Temperate regions, Vector dynamics, Malaria transmission.

INTRODUCTION

Malaria remains a significant global health burden, with Plasmodium vivax recognized as the most geographically widespread species of the malaria-causing parasite [1–3]. Historically, P. vivax malaria has been predominantly associated with temperate regions, exhibiting a distinct epidemiological pattern compared to P. falciparum [4, 5]. Unlike P. falciparum, which thrives in tropical and subtropical climates, P. vivax has demonstrated remarkable adaptability to cooler climates due to its ability to form dormant liver-stage hypnozoites, leading to relapses months or even years after the initial infection. The epidemiology of P. vivax malaria has been shaped by climatic variables such as temperature, humidity, and precipitation, all of which influence vector distribution, parasite development, and transmission dynamics.Climate change is increasingly altering the ecological landscape of vector-borne diseases, including malaria [6, 7]. Rising global temperatures, shifting precipitation patterns, and extreme weather events are modifying the geographical distribution and seasonality of malaria transmission in previously non-endemic or low-transmission areas. These environmental shifts have profound implications for the re-emergence of P. vivax malaria in temperate regions, where changing climate conditions may expand the habitat suitability for Anopheles mosquitoes, the primary vectors of malaria. This scoping review aims to examine the impact of climate change on the epidemiology of P. vivax malaria in temperate regions by evaluating key climatic determinants, vector dynamics, and human-related factors that may contribute to altered transmission patterns.

Impact of Climate Change on the Epidemiology of Plasmodium vivax Malaria in Temperate Regions

i. **Temperature and Its Role in Transmission:** Temperature plays a critical role in the lifecycle of both the P. vivax parasite and its mosquito vectors [8]. Warmer temperatures accelerate the extrinsic incubation period of the parasite within the vector, shortening the time required for mosquitoes to become infectious. Traditionally, the transmission of P. vivax in temperate regions has been constrained by cold winters, which limit mosquito survival [9]. However, climate-induced temperature increases are extending mosquito breeding seasons, reducing winter mortality rates, and allowing for multiple transmission cycles in regions previously unsuitable for sustained malaria transmission.

Temperature increases also have implications for parasite biology. P. vivax can develop at lower temperatures than P. falciparum, with a minimum threshold of approximately 15°C, compared to P. falciparum, which requires at least 18°C. This lower threshold increases the likelihood of malaria transmission in cooler climates as global temperatures rise. Additionally, warming trends in temperate regions are expanding the altitudinal and latitudinal range of malaria transmission, with areas previously considered malaria-free now exhibiting seasonal transmission risks.

ii. **Changes in Precipitation and Humidity:** Rainfall and humidity significantly influence mosquito breeding and survival [10]. Climate change is projected to cause shifts in precipitation patterns, leading to increased rainfall in some regions and drought in others. Enhanced rainfall can create ideal breeding sites for Anopheles mosquitoes, increasing vector density and the likelihood of malaria transmission. Conversely, excessive rainfall leading to flooding may destroy breeding sites, temporarily disrupting transmission cycles.

Humidity also affects mosquito survival and biting behavior. Increased humidity promotes longer mosquito lifespan, enhancing their ability to transmit the parasite. In contrast, aridification of temperate regions due to reduced precipitation may limit mosquito breeding. However, human adaptation strategies such as water storage may inadvertently create artificial breeding sites, sustaining mosquito populations despite drier conditions.

iii. **Expansion of Vector Habitats:** Climate change is facilitating the expansion of Anopheles mosquito habitats into new geographic areas [11, 12, 13, 14, 15, 16]. As temperatures rise and precipitation patterns shift, vectors are establishing themselves in regions previously deemed unsuitable for malaria transmission. In Europe, North America, and parts of Asia, increasing reports of Anopheles mosquitoes in higher latitudes and elevations indicate a growing risk of P. vivax transmission.

Changes in land use, urbanization, and deforestation interact with climate change to modify mosquito habitats. Warmer temperatures in urban environments due to the heat island effect may support mosquito breeding in peri-urban settings. Furthermore, deforestation-driven changes in microclimates may expose human populations to higher malaria risks by bringing human settlements closer to vector habitats.

iv. **Seasonal Shifts and Prolonged Transmission Periods:** Climate change is influencing the seasonality of P. vivax malaria transmission in temperate regions. Warmer temperatures and increased precipitation are extending the active transmission period, allowing malaria cases to persist beyond their historical seasonal windows [17, 18, 19]. Previously, temperate regions experienced malaria transmission limited to summer months. However, climate projections suggest that transmission periods may extend into spring and fall, increasing the overall burden of malaria.

The hypnozoite reservoir of P. vivax also contributes to extended transmission cycles. Unlike P. falciparum, P. vivax infections can reactivate months or even years after the initial infection, complicating malaria elimination efforts. Warmer temperatures may influence relapse dynamics, increasing the frequency and severity of secondary infections.

Human and Societal Factors Influencing Transmission

Human migration, travel, and socioeconomic factors play a crucial role in the epidemiology of P. vivax malaria in the context of climate change [20, 21, 22]. Increased global mobility and displacement due to climate-induced environmental changes may introduce P. vivax cases into previously malaria-free regions. Migrant populations from endemic regions may serve as reservoirs of infection, reintroducing malaria into temperate areas with competent mosquito vectors. Additionally, socioeconomic disparities influence malaria risk in changing climates. Vulnerable populations, particularly those with limited access to healthcare and vector control measures, face increased susceptibility to malaria resurgence. Agricultural practices, irrigation systems, and water management strategies in response to climate change can also create micro-environments conducive to mosquito breeding, further exacerbating transmission risk.

CONCLUSION

Climate change is reshaping the epidemiology of P. vivax malaria in temperate regions, driven by rising temperatures, altered precipitation patterns, and shifting vector habitats. These environmental changes are expanding the geographical range of malaria transmission, prolonging seasonal transmission periods, and increasing the risk of malaria resurgence in areas previously considered malaria-free. Understanding the interplay between climatic factors and P. vivax transmission is essential for developing effective mitigation strategies. Strengthening surveillance systems, enhancing vector control programs, and incorporating climate data into malaria risk assessments will be crucial for minimizing the impact of climate change on malaria epidemiology. Additionally, addressing human-related factors such as migration patterns, socioeconomic vulnerabilities, and healthcare accessibility will be key to preventing malaria re-emergence in temperate regions. As climate change continues to alter disease landscapes, proactive public health measures and interdisciplinary collaboration will be necessary to anticipate and manage the evolving threat of P. vivax malaria in temperate climates. Future research should focus on refining climate-malaria models, assessing adaptive strategies, and identifying policy interventions to mitigate the health consequences of climate-driven malaria expansion.

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