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A Review of Spatio-Temporal Distribution of *Aedes aegypti* in Uttar Pradesh

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ABSTRACT

The mosquito *Aedes aegypti* is a principal vector responsible for the transmission of major arboviral diseases such as dengue, chikungunya, and Zika, posing a serious public health challenge in India. The present review aims to synthesize existing knowledge on the spatio-temporal distribution of *Aedes aegypti* in Uttar Pradesh, one of the most densely populated states with recurring outbreaks of mosquito-borne diseases. The analysis of available literature indicates that the distribution of *Aedes aegypti* is highly heterogeneous across the state and is strongly influenced by environmental, climatic, and anthropogenic factors. Urban and peri-urban regions, including cities such as Lucknow, Kanpur, and Varanasi, have been identified as major hotspots due to high population density, inadequate waste management, and the presence of numerous artificial breeding habitats. Spatial distribution patterns reveal that districts with rapid urbanization and poor sanitation infrastructure exhibit higher entomological indices, including House Index (HI), Container Index (CI), and Breteau Index (BI), indicating an elevated risk of dengue transmission. Temporal analysis demonstrates a strong seasonal trend, with peak mosquito densities occurring during the monsoon and post-monsoon periods, primarily due to increased rainfall and optimal temperature conditions that favor breeding and survival. In contrast, population density declines during extreme summer and winter conditions. Furthermore, climate change is expected to influence the expansion of mosquito distribution and prolong the transmission season, thereby increasing disease risk. The review highlights the importance of integrated vector management strategies, including environmental control, community participation, and the application of modern tools such as Geographic Information Systems (GIS) for surveillance and risk mapping. Strengthening vector monitoring systems and promoting public awareness are essential for effective control of mosquito populations. This study provides valuable insights for policymakers and researchers to develop targeted interventions aimed at reducing the burden of vector-borne diseases in Uttar Pradesh.

Introduction

The mosquito *Aedes aegypti* is one of the most important vectors responsible for the transmission of several arboviral diseases, including dengue, chikungunya, Zika, and yellow fever (World Health Organization [WHO], 2017; Gubler, 2011). It is a highly adaptive, container-breeding mosquito species that thrives in urban and semi-urban environments and shows a strong preference for human hosts (Christophers, 1960; Kraemer *et al.*, 2015). India has witnessed a rapid increase in dengue incidence over the past few decades, largely due to the expansion of *Aedes aegypti* populations across different geographical regions (NVBDCP, 2020; Shepard *et al.*, 2016). Uttar Pradesh, being one of the most populous states in India, presents a unique epidemiological landscape where rapid urbanization, climatic variability, and socio-economic factors contribute to the proliferation of mosquito vectors (Kumar *et al.*, 2018). The distribution of *Aedes aegypti* is not uniform; rather, it exhibits strong spatial and temporal variability influenced by environmental and climatic factors (Kraemer *et al.*, 2015; Brady *et al.*, 2013). Studies indicate that the vector is widely prevalent in Indo-Gangetic plains, including Uttar Pradesh, where favorable temperature and humidity conditions support its survival and reproduction (Dhimal *et al.*, 2015). Moreover, urbanized regions of Uttar Pradesh have shown particularly high vector prevalence due to increased human population density and availability of artificial

breeding habitats (Tiwari *et al.*, 2017). Spatial distribution refers to the geographical spread of mosquito populations across different regions, while temporal distribution relates to seasonal fluctuations in their abundance. Both aspects are critical for understanding disease transmission dynamics (Eisen & Moore, 2013). Research has demonstrated that *Aedes aegypti* populations are strongly influenced by climatic variables such as temperature, rainfall, and humidity, which directly affect breeding, larval development, and adult survival (Morin *et al.*, 2013; Brady *et al.*, 2013). For instance, increased rainfall during monsoon seasons leads to the accumulation of water in containers, providing ideal breeding sites and resulting in population surges (Gubler, 2011). Temporal variations in mosquito populations are closely linked with seasonal patterns. Peak densities of *Aedes aegypti* are generally observed during the post-monsoon period when environmental conditions are most favorable for breeding and survival (Kumar *et al.*, 2018; Tiwari *et al.*, 2017). Conversely, during extreme winter or dry summer conditions, population densities tend to decline due to unfavorable environmental conditions (Dhimal *et al.*, 2015). The role of urbanization in shaping the distribution of *Aedes aegypti* cannot be overlooked. Rapid expansion of urban areas, inadequate waste management, and poor water storage practices create numerous artificial breeding habitats such as discarded containers, tires, and water storage tanks (WHO, 2017; Gubler, 2011). These anthropogenic factors significantly enhance vector density and

facilitate disease transmission (Kraemer *et al.*, 2015). In Uttar Pradesh, cities such as Lucknow, Kanpur, and Varanasi have reported frequent dengue outbreaks, indicating a strong association between urban environments and vector proliferation (NVBDCP, 2020). A study conducted in Lucknow revealed a high prevalence of *Aedes aegypti* populations, with a significant proportion of mosquito samples belonging to this species (Kumar *et al.*, 2018). This highlights the importance of localized studies in understanding vector distribution patterns and implementing targeted control strategies. Another critical factor influencing the distribution of *Aedes aegypti* is climate change. Increasing global temperatures and changing precipitation patterns are expected to expand the geographical range of the vector, potentially increasing the risk of disease transmission in new areas (IPCC, 2014; Ryan *et al.*, 2019). Climate-driven changes in vector ecology may lead to longer breeding seasons and higher population densities, thereby exacerbating public health challenges (Morin *et al.*, 2013). Advancements in spatial modeling techniques, such as Geographic Information Systems (GIS) and remote sensing, have significantly improved the understanding of vector distribution patterns. These tools allow researchers to map mosquito habitats, identify high-risk areas, and predict future distribution scenarios based on climatic and environmental variables (Eisen & Moore, 2013; Kraemer *et al.*, 2015). Such approaches are essential for developing effective vector surveillance and control programs. Despite extensive research, several gaps remain in the understanding of the spatio-temporal dynamics of *Aedes aegypti* in Uttar Pradesh. Many studies are limited to specific regions or short time periods, making it difficult to generalize findings across the state. Additionally, there is a lack of integrated studies that combine ecological, climatic, and socio-economic factors to provide a comprehensive understanding of vector distribution (Tiwari *et al.*, 2017). Therefore, the present review aims to synthesize existing knowledge on the spatial and temporal distribution of *Aedes aegypti* in Uttar Pradesh. It seeks to identify key factors influencing vector dynamics, highlight regional variations, and provide insights into effective vector control strategies. Understanding these patterns is crucial for predicting disease outbreaks and implementing timely interventions to reduce the burden of mosquito-borne diseases (WHO, 2017).

The mosquito *Aedes aegypti* has been extensively studied due to its role as a primary vector of dengue, chikungunya, Zika, and yellow fever viruses. Early foundational work by Christophers (1960) provided detailed insights into the biology, behavior, and breeding ecology of *Aedes aegypti*, establishing its strong association with human habitats. Subsequent studies have emphasized its anthropophilic nature and its ability to adapt to urban and peri-urban environments (Gubler, 2011; Kraemer *et al.*, 2015). Globally, the distribution of *Aedes aegypti* has expanded significantly over the past few decades. Kraemer *et al.* (2015) developed global distribution maps demonstrating that the species is now present in tropical and subtropical regions worldwide. This expansion has been attributed to factors such as globalization, increased travel, urbanization, and climate change (Brady *et al.*, 2013; Messina *et al.*, 2019). In India, the spread of *Aedes aegypti* has been particularly rapid, with increasing reports of dengue outbreaks across multiple states, including Uttar Pradesh (NVBDCP, 2020). Several studies have examined the spatial distribution of *Aedes aegypti* in India, highlighting the importance of environmental and climatic variables. Dhimal *et al.* (2015) reported that temperature and humidity are critical determinants of mosquito survival and reproduction, with optimal conditions ranging between 25°C and 30°C. Similarly, Morin *et al.* (2013) demonstrated that rainfall patterns significantly influence breeding site availability, particularly in urban settings where water accumulates in artificial containers. In the Indo-Gangetic plains, including Uttar Pradesh, these climatic conditions are highly favorable for mosquito proliferation (Kumar *et al.*, 2018).

In Uttar Pradesh, spatial distribution studies have revealed that urban centers such as Lucknow, Kanpur, and Varanasi serve as major hotspots for *Aedes aegypti* populations (Tiwari *et al.*, 2017; Kumar *et al.*, 2018). These cities provide abundant breeding habitats

due to high population density, poor waste management, and water storage practices. Studies conducted in Lucknow have reported high larval indices, indicating intense vector breeding and a high risk of disease transmission (Kumar *et al.*, 2018).

Temporal distribution patterns of *Aedes aegypti* are closely linked with seasonal variations. Research indicates that mosquito populations peak during the monsoon and post-monsoon seasons due to increased availability of breeding sites (Gubler, 2011; Morin *et al.*, 2013). In Uttar Pradesh, Tiwari *et al.* (2017) observed that the highest vector densities occur between July and October, coinciding with the rainy season. During winter months, lower temperatures reduce mosquito activity and survival rates, leading to a decline in population density (Dhimal *et al.*, 2015). The influence of urbanization on mosquito distribution has been widely documented. Rapid urban growth, particularly in developing countries like India, has created favorable conditions for *Aedes aegypti* proliferation (Kraemer *et al.*, 2015). Unplanned urbanization leads to the accumulation of waste materials, stagnant water, and inadequate sanitation, all of which provide ideal breeding habitats for mosquitoes (WHO, 2017). Studies by Eisen and Moore (2013) have shown that urban landscapes with high human density are strongly correlated with increased mosquito abundance and disease transmission risk. Socio-economic factors also play a significant role in determining mosquito distribution. Areas with limited access to clean water often rely on water storage practices, which inadvertently create breeding sites for *Aedes aegypti* (Gubler, 2011). In Uttar Pradesh, variations in socio-economic conditions across districts contribute to differences in vector density and disease incidence (Kumar *et al.*, 2018). This highlights the need for targeted public health interventions that consider local socio-economic contexts.

Climate change has emerged as a critical factor influencing the spatio-temporal dynamics of *Aedes aegypti*. Studies have shown that rising temperatures can accelerate mosquito development, increase biting rates, and shorten the incubation period of viruses within the mosquito (Bale *et al.*, 2002; Ryan *et al.*, 2019). Additionally, changes in precipitation patterns can alter the availability of breeding sites, leading to fluctuations in mosquito populations (IPCC, 2014). Predictive models developed by Messina *et al.* (2019) suggest that climate change may expand the geographical range of *Aedes aegypti* into previously unsuitable areas.

The use of Geographic Information Systems (GIS) and remote sensing has significantly advanced the study of mosquito distribution. These tools allow researchers to map vector habitats, identify high-risk areas, and analyze the relationship between environmental variables and mosquito abundance (Eisen & Moore, 2013; Kraemer *et al.*, 2015). In India, GIS-based studies have been used to predict dengue risk zones and guide vector control programs (Dhimal *et al.*, 2015). Such approaches are particularly useful in densely populated states like Uttar Pradesh, where targeted interventions are essential for effective disease control. Entomological indices, such as the House Index (HI), Container Index (CI), and Breteau Index (BI), are commonly used to assess mosquito breeding and disease risk. Studies have shown that high values of these indices are associated with increased dengue transmission (WHO, 2017). In Uttar Pradesh, several studies have reported elevated indices during the monsoon season, indicating a high risk of outbreaks (Tiwari *et al.*, 2017). Monitoring these indices is crucial for early detection and prevention of epidemics. Vector control strategies have been extensively studied in relation to *Aedes aegypti*. Traditional methods include chemical control using insecticides, environmental management, and community participation (WHO, 2017). However, the development of insecticide resistance in mosquito populations has raised concerns about the effectiveness of chemical control methods (Ranson *et al.*, 2010). As a result, alternative approaches such as biological control, genetic modification, and integrated vector management (IVM) are being explored (Achee *et al.*, 2015).

Biological control methods, including the use of larvivorous fish and microbial agents such as *Bacillus thuringiensis israelensis* (Bti),

have shown promise in reducing mosquito populations (Lacey, 2007). Additionally, novel approaches such as the release of Wolbachia-infected mosquitoes have been developed to reduce virus transmission (Hoffmann *et al.*, 2011). These innovative strategies offer sustainable alternatives to conventional control methods and have the potential to significantly reduce disease burden. Public awareness and community participation are critical components of effective vector control. Studies have shown that community-based interventions, such as eliminating breeding sites and promoting hygiene practices, can significantly reduce mosquito populations (Gubler, 2011). In Uttar Pradesh, awareness campaigns and government initiatives have been implemented to control dengue outbreaks, although challenges remain in achieving widespread participation (NVBDCP, 2020). Despite extensive research, several gaps remain in the understanding of the spatio-temporal distribution of *Aedes aegypti* in Uttar Pradesh. Many studies are limited to urban areas, with rural regions receiving less attention. Additionally, there is a lack of long-term data on mosquito population dynamics, which is essential for understanding trends and predicting future outbreaks. Furthermore, integrated studies that combine climatic, ecological, and socio-economic factors are limited, highlighting the need for multidisciplinary research approaches. Recent advances in modeling and data analysis offer new opportunities for studying mosquito distribution. Machine learning and artificial intelligence techniques are being increasingly used to predict disease outbreaks and identify high-risk areas (Ryan *et al.*, 2019). These approaches can improve the accuracy of predictions and support decision-making in public health planning. In summary, the literature indicates that the spatio-temporal distribution of *Aedes aegypti* in Uttar Pradesh is influenced by a combination of climatic, environmental, socio-economic, and anthropogenic factors. While significant progress has been made in understanding these dynamics, there is a need for more comprehensive and integrated studies to address existing gaps and improve vector control strategies.

Discussion

The present review synthesizes available evidence on the spatio-temporal distribution of *Aedes aegypti* in Uttar Pradesh and reveals that the dynamics of this vector are governed by a complex interaction of environmental, climatic, and anthropogenic factors. The findings clearly indicate that the distribution of *Aedes aegypti* is highly heterogeneous across the state, with urban and peri-urban areas emerging as major hotspots for vector proliferation (Kraemer *et al.*, 2015; Tiwari *et al.*, 2017). This spatial heterogeneity is primarily driven by variations in population density, infrastructure, and availability of artificial breeding habitats.

One of the most significant determinants of *Aedes aegypti* distribution is the urban environment. Rapid urbanization in cities such as Lucknow, Kanpur, and Varanasi has created favorable conditions for mosquito breeding through the accumulation of water-holding containers, inadequate drainage systems, and poor waste management practices (WHO, 2017; Gubler, 2011). The anthropophilic nature of *Aedes aegypti*, combined with its preference for indoor and peridomestic habitats, further enhances its success in densely populated urban settings (Christophers, 1960). As a result, these urban centers consistently report higher larval indices and increased risk of dengue transmission (Kumar *et al.*, 2018).

Temporal variation in mosquito populations is another critical aspect highlighted in the literature. The abundance of *Aedes aegypti* shows a strong seasonal pattern, with peak densities observed during the monsoon and post-monsoon periods (Morin *et al.*, 2013; Dhimal *et al.*, 2015). Increased rainfall during these seasons leads to the formation of numerous temporary breeding sites, including stagnant water in containers, construction sites, and discarded materials. This seasonal surge in mosquito populations directly correlates with an increase in dengue cases reported in Uttar Pradesh, indicating a clear link between vector abundance and disease transmission dynamics (NVBDCP, 2020).

Climatic factors such as temperature, humidity, and rainfall play a fundamental role in regulating the life cycle and survival of *Aedes*

aegypti. Optimal temperatures ranging between 25°C and 30°C promote faster larval development, increased biting rates, and higher reproductive success (Bale *et al.*, 2002; Brady *et al.*, 2013). In Uttar Pradesh, such conditions are prevalent for a significant part of the year, particularly during the monsoon season, thereby supporting sustained mosquito populations. However, extreme climatic conditions, such as low winter temperatures or prolonged dry periods, can limit mosquito survival and reduce population density (Dhimal *et al.*, 2015). The influence of climate change on the distribution of *Aedes aegypti* is an area of growing concern. Rising global temperatures and changes in precipitation patterns are expected to extend the geographical range and breeding season of the mosquito (IPCC, 2014; Ryan *et al.*, 2019). This could lead to the emergence of new transmission zones and increased frequency of outbreaks in previously unaffected areas. Predictive modeling studies suggest that climate-driven expansion of *Aedes aegypti* could significantly increase the burden of vector-borne diseases in the coming decades (Messina *et al.*, 2019). Therefore, understanding the relationship between climate variables and vector dynamics is essential for effective disease forecasting and control. Anthropogenic factors, particularly water storage practices and waste management, have a profound impact on the spatial distribution of *Aedes aegypti*. In many parts of Uttar Pradesh, irregular water supply compels households to store water in containers, which serve as ideal breeding sites for mosquitoes (Gubler, 2011). Similarly, improper disposal of solid waste, including plastic containers and tires, creates additional habitats for larval development (WHO, 2017). These human-induced factors significantly enhance vector density and contribute to the persistence of mosquito populations even during unfavorable climatic conditions. Socio-economic conditions also influence mosquito distribution and disease risk. Areas with lower socio-economic status often lack adequate sanitation and infrastructure, leading to increased exposure to mosquito breeding sites (Kumar *et al.*, 2018). Moreover, limited awareness and poor community participation in vector control programs further exacerbate the problem. This highlights the need for targeted public health interventions that address socio-economic disparities and promote community engagement in vector control activities.

The role of entomological indices, such as the House Index (HI), Container Index (CI), and Breteau Index (BI), is critical in assessing the risk of dengue transmission. High values of these indices indicate increased mosquito breeding and a higher likelihood of disease outbreaks (WHO, 2017). Studies conducted in Uttar Pradesh have reported elevated indices during the monsoon season, emphasizing the need for continuous surveillance and timely intervention (Tiwari *et al.*, 2017). These indices serve as valuable tools for monitoring vector populations and guiding control strategies. Vector control remains a major challenge in managing *Aedes aegypti* populations. Traditional methods, including chemical insecticides, have been widely used but are increasingly facing limitations due to the development of insecticide resistance (Ranson *et al.*, 2010). This has necessitated the adoption of integrated vector management (IVM) approaches that combine chemical, biological, and environmental control methods (Achee *et al.*, 2015). Biological control strategies, such as the use of larvivorous fish and microbial agents like *Bacillus thuringiensis israelensis* (Bti), offer environmentally friendly alternatives to chemical control (Lacey, 2007). Recent advances in vector control include the use of genetically modified mosquitoes and Wolbachia-based interventions, which aim to reduce the ability of mosquitoes to transmit viruses (Hoffmann *et al.*, 2011). These innovative approaches have shown promising results in reducing disease transmission and represent a significant step forward in vector control technology. However, their implementation requires careful evaluation of ecological and ethical considerations.

The application of modern technologies, such as Geographic Information Systems (GIS) and remote sensing, has greatly enhanced the understanding of mosquito distribution patterns. These tools enable the identification of high-risk areas, mapping of breeding sites, and prediction of future outbreaks based on

environmental data (Eisen & Moore, 2013; Kraemer *et al.*, 2015). In Uttar Pradesh, GIS-based studies can be particularly useful in developing district-level risk maps and optimizing resource allocation for vector control programs.

Despite significant progress, several research gaps remain in the study of *Aedes aegypti* distribution in Uttar Pradesh. Many studies are limited in spatial and temporal scope, focusing on specific cities or short time periods. There is a need for long-term, large-scale studies that integrate climatic, ecological, and socio-economic factors to provide a comprehensive understanding of vector dynamics. Additionally, rural areas remain underrepresented in the literature, despite their potential role in disease transmission.

Another important gap is the lack of interdisciplinary research that combines entomology, epidemiology, and data science. The integration of machine learning and artificial intelligence techniques can improve the prediction of disease outbreaks and support decision-making in public health management (Ryan *et al.*, 2019). Such approaches can enhance the effectiveness of vector control strategies and reduce the burden of mosquito-borne diseases.

In conclusion, the spatio-temporal distribution of *Aedes aegypti* in Uttar Pradesh is influenced by a multifactorial interplay of environmental, climatic, and anthropogenic factors. Urbanization, climate variability, and human behavior emerge as key drivers of vector dynamics. Addressing these challenges requires a holistic approach that combines scientific research, technological innovation, and community participation. By improving surveillance systems, adopting integrated vector management strategies, and enhancing public awareness, it is possible to effectively control mosquito populations and reduce the incidence of vector-borne diseases in the region.

Conclusion

The present review provides a comprehensive understanding of the spatio-temporal distribution of *Aedes aegypti* in Uttar Pradesh, highlighting its critical role as a vector of major arboviral diseases such as dengue, chikungunya, and Zika. The synthesis of available literature clearly indicates that the distribution of *Aedes aegypti* across the state is highly heterogeneous and strongly influenced by environmental, climatic, and anthropogenic factors (Kraemer *et al.*, 2015; Gubler, 2011). Urban and peri-urban regions, particularly rapidly growing cities, have emerged as major hotspots due to the abundance of artificial breeding habitats and high human population density (WHO, 2017). Seasonal fluctuations play a crucial role in shaping mosquito population dynamics, with peak abundance consistently observed during the monsoon and post-monsoon periods when temperature, humidity, and rainfall conditions are optimal for breeding and survival (Morin *et al.*, 2013; Dhimal *et al.*, 2015). This temporal pattern closely aligns with the incidence of vector-borne diseases, underscoring the importance of timely surveillance and intervention strategies (NVBDCP, 2020). Anthropogenic factors, including unplanned urbanization, poor waste management, and water storage practices, significantly contribute to the persistence and proliferation of *Aedes aegypti* populations even under suboptimal climatic conditions (Gubler, 2011; Kraemer *et al.*, 2015). Furthermore, climate change is expected to exacerbate the situation by extending the breeding season and expanding the geographical range of the vector, thereby increasing the risk of disease transmission in new areas (IPCC, 2014; Ryan *et al.*, 2019). Despite advances in vector surveillance and control, challenges such as insecticide resistance, limited community participation, and inadequate infrastructure continue to hinder effective management (Ranson *et al.*, 2010). Therefore, the adoption of integrated vector management (IVM) strategies, combining environmental management, biological control, and community-based interventions, is essential for sustainable control of mosquito populations (Achee *et al.*, 2015). In conclusion, controlling the spread of *Aedes aegypti* in Uttar Pradesh requires a multidisciplinary and proactive approach that integrates scientific research, technological tools such as GIS-based mapping, and strong public health policies. Strengthening surveillance systems, improving urban infrastructure, and enhancing community awareness are crucial steps toward reducing the burden of vector-

borne diseases. Future research should focus on long-term monitoring and predictive modeling to better understand vector dynamics and support evidence-based decision-making.

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