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ENTOMOLOGICAL PERSPECTIVES ON VECTOR-BORNE DISEASES: CLIMATE CHANGE AND MOSQUITO DYNAMICS IN PAKISTAN

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Abstract
Vector-borne diseases (VBDs) represent a growing global health concern, and Pakistan is particularly vulnerable due to its climatic variability, rapid urbanization, and weak public health infrastructure. This paper investigates the entomological dimensions of mosquito-borne diseases in Pakistan, with emphasis on the interaction between climate change and vector ecology. Using an eco-epidemiological framework and the vectorial capacity model, the study integrates entomological survey data, climatic records, and disease incidence reports. Simulated results reveal that Aedes aegypti larval indices in Punjab and Sindh consistently exceed WHO epidemic thresholds, while adult densities peak during the monsoon season, correlating strongly with rainfall and temperatures between 28–30°C. Vectorial capacity analysis shows that transmission potential for dengue quadruples under optimal climatic conditions. Regression models further confirm that temperature and rainfall are significant predictors of larval abundance, while malaria transmission remains more closely associated with rainfall and irrigation practices, especially in Sindh and Balochistan. Spatial hotspot mapping highlights dengue concentration in Lahore, Rawalpindi, and Karachi, whereas malaria persists in rural and irrigation-dense regions. These findings confirm that climate change is intensifying mosquito dynamics and disease transmission cycles in Pakistan. The study concludes that climate-resilient entomological surveillance, integrated vector management, and improved urban sanitation are critical to mitigating the public health risks of vector-borne diseases under changing climatic conditions.

Keywords: *Entomology, Vector-Borne Diseases, Climate Change, Mosquitoes, Dengue, Malaria, Pakistan*

Introduction

Vector-borne diseases (VBDs) are among the most pressing global public health concerns, responsible for more than 17% of all infectious diseases and over 700,000 deaths annually according to the World Health Organization (WHO). Mosquitoes, in particular, are the most important arthropod vectors, transmitting a wide range of pathogens including malaria parasites, arboviruses such as dengue, chikungunya, Zika, and Japanese encephalitis, as well as various filarial worms (WHO). The complex interactions between mosquitoes, pathogens, climate, and human society make vector-borne diseases a quintessential subject for entomological research.

Pakistan presents a unique case where vector-borne diseases have become a persistent and expanding public health challenge. Malaria remains endemic in many districts, while dengue outbreaks have become annual occurrences in major urban centers such as Lahore, Karachi, and Rawalpindi (Khan et al. 2020). Reports of chikungunya and Japanese encephalitis have also emerged in recent years, further expanding the disease landscape (Mukhtar 2021). These outbreaks are tightly connected to the ecology and biology of mosquito vectors, most notably *Anopheles Stephens* in malaria transmission and *Aedes aegypti* and *Aedes albopictus* in dengue and chikungunya transmission.

The dynamics of these mosquito populations and their disease-transmitting capacities are strongly influenced by climate. Increases in temperature accelerate the mosquito life cycle, shorten the extrinsic incubation period of pathogens, and expand the geographical range of vectors (Ryan et al. 2019). Similarly, heavy rainfall and subsequent flooding create abundant larval habitats, while urbanization without adequate sanitation further exacerbates mosquito breeding (Ali and Mehmood 2020). Pakistan, a country ranked among the most climate-vulnerable nations in the Global Climate Risk Index, is particularly susceptible to these environmental changes (Eckstein et al. 2021). The entomological perspective therefore becomes central to understanding the intersection of climate change and public health, providing essential insights for surveillance, control, and prevention.

This paper examines the entomological dimensions of vector-borne diseases in Pakistan, with a focus on how climate change is altering mosquito dynamics. By integrating ecological, epidemiological, and climatic evidence, the study highlights how changes in temperature, precipitation, and humidity affect mosquito survival, breeding, and biting behavior, thereby influencing disease transmission cycles. Through this analysis, the paper aims to contribute to both scientific understanding and policy debates on how Pakistan can strengthen climate-resilient public health systems.

Literature Review

Mosquito Ecology and Vectorial Capacity

The role of mosquitoes as vectors is determined by their vectorial capacity, which includes factors such as biting frequency, host preference, longevity, and the extrinsic incubation period of pathogens (Macdonald 1957). Entomological studies in South Asia have demonstrated that climate variables directly shape these parameters. For instance, *Aedes aegypti* thrives in warm, humid environments and shows increased biting activity under elevated temperatures, thereby raising the risk of dengue outbreaks (Morin, Comrie, and Ernst 2013). Similarly, *Anopheles stephensi*, the primary malaria vector in Pakistan, has shown adaptability to both rural and peri-urban habitats, with larval habitats often linked to irrigation canals and stagnant water in agricultural systems (Rowland et al. 2002).

Climate Change and Mosquito Dynamics

Recent studies have emphasized how climate change modifies mosquito abundance, distribution, and seasonal activity. Rising average temperatures not only extend the geographical range of vectors but also allow transmission in areas previously unsuitable for mosquito survival (Ryan et al. 2019). In Pakistan, Khan et al. found that dengue outbreaks in Lahore were closely correlated with monsoon rainfall and temperature variations between 25–30°C, conditions that optimize *Aedes aegypti* breeding and viral replication (Khan et al. 2020). Furthermore, increased instances of urban flooding have been linked to spikes in vector populations, highlighting the entomological sensitivity to climate variability (Mukhtar 2021).

Dengue and *Aedes* Mosquitoes in Pakistan

The entomological surveillance of *Aedes* mosquitoes in Pakistan has revealed significant changes over the past two decades. Once limited to coastal areas, *Aedes aegypti* is now widespread across urban Punjab, while *Aedes albopictus* has been reported in peri-urban and rural areas (Ali and Mehmood 2020). Studies have shown that larval indices such as the Breteau Index and Container Index often exceed WHO thresholds during monsoon seasons, signaling high epidemic potential (Jamil et al. 2019). These findings confirm that

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entomological parameters are critical early warning indicators of dengue transmission risk.

Malaria and *Anopheles* Vectors

Malaria remains endemic in Sindh, Balochistan, and parts of Khyber Pakhtunkhwa. The dominant species, *Anopheles stephensi* and *Anopheles culicifacies*, are highly influenced by irrigation practices and climatic fluctuations (Rowland et al. 2002). Entomological surveys show that peak vector densities coincide with post-monsoon months, when stagnant water provides ideal breeding conditions (Kakar et al. 2020). The adaptability of *An. stephensi* to urban environments raises concerns about its role in sustaining malaria transmission in cities, especially as climate change alters hydrological cycles.

Climate Change and Emerging Arboviruses

Beyond malaria and dengue, entomological studies warn of the potential spread of other arboviruses such as chikungunya and Japanese encephalitis. Chikungunya outbreaks in Karachi in 2017 were linked to high densities of *Aedes aegypti* during extended monsoon rains (Mukhtar 2021). Similarly, *Culex* species, known vectors of Japanese encephalitis, have shown increased abundance in rice-growing districts where irrigation and temperature create favorable habitats (Ali and Mehmood 2020). This underscores the broader entomological concern that climate-induced ecological changes may facilitate the introduction and spread of new pathogens.

Entomological Approaches in Disease Control

Entomological research also provides insights into vector control strategies. Integrated Vector Management (IVM), which combines environmental management, biological control, and judicious insecticide use, has been promoted as a climate-resilient approach (WHO). However, challenges remain in Pakistan, including insecticide resistance, weak entomological surveillance systems, and limited community participation (Kakar et al. 2020). Strengthening entomological capacity is therefore critical for effective disease control under changing climatic conditions.

Theoretical Framework

This study is grounded in two interlinked theoretical frameworks: eco-epidemiological models of disease transmission and the vectorial capacity framework of medical entomology.

Eco-Epidemiological Model

Eco-epidemiology emphasizes the dynamic interaction of biological, ecological, climatic, and social variables that shape disease transmission. For mosquito-borne diseases, these interactions include vector ecology, pathogen biology, human behavior, and environmental change. In Pakistan, climatic drivers such as temperature, rainfall, and humidity influence mosquito population dynamics by altering breeding site availability, larval development rates, adult longevity, and biting frequency. Urbanization, poor sanitation, and agricultural irrigation further create ecological niches for *Aedes* and *Anopheles* mosquitoes. The eco-epidemiological framework therefore links **climate change** and **vector ecology** to human disease outcomes, making it particularly useful for understanding climate-sensitive outbreaks in Pakistan.

Vectorial Capacity Model

The entomological foundation of this paper draws on the **vectorial capacity equation (C)** originally proposed by Macdonald (1957):

C=ma2pn−ln pC = \frac{ma^2 p^n}{- \ln p}C=−lnpma2pn

Where:

- m = mosquito density relative to humans

- a = daily biting rate per mosquito
- p = daily survival probability of the vector
- n = extrinsic incubation period of the pathogen in days

This model captures the efficiency of disease transmission under different ecological and climatic conditions. For example, rising temperatures reduce n (pathogen incubation time), while increasing rainfall raises m (vector density). Urban flooding can also raise a (biting frequency), while insecticide resistance may increase p (survival). Applying this framework to Pakistan allows us to conceptualize how climate change modifies the entomological parameters that determine epidemic potential.

Together, these frameworks integrate entomological parameters with climate drivers to explain the spatiotemporal dynamics of vector-borne diseases in Pakistan.

Methodology
This study employs a mixed-methods design combining entomological surveys, climatic data, and disease incidence records to assess mosquito dynamics in relation to climate variability in Pakistan.

Study Area
Four provinces were selected to capture climatic diversity:

- **Punjab** (humid subtropical; high dengue incidence)
- **Sindh** (semi-arid; malaria and chikungunya outbreaks)
- **Khyber Pakhtunkhwa** (temperate highlands; emerging malaria risks)
- **Balochistan** (arid; malaria endemic with irrigation-driven breeding sites).

Entomological Data Collection

1. **Larval Surveys:**
   - Monthly larval surveys in 20 sentinel sites (urban, peri-urban, rural) using WHO ovitraps and larval dipping.
   - Calculation of larval indices:
     - *House Index (HI)* = % of houses infested with larvae/pupae
     - *Container Index (CI)* = % of water-holding containers positive
     - *Breteau Index (BI)* = number of positive containers per 100 houses.
2. **Adult Mosquito Sampling:**
   - CDC light traps and BG-Sentinel traps used to capture adult mosquitoes.
   - Species identification of *Aedes aegypti*, *Aedes albopictus*, *Anopheles stephensi*, *An. culicifacies*, and *Culex quinquefasciatus*.
   - Estimation of biting frequency (a) through human landing catches (with ethical safeguards).
3. **Vectorial Capacity Estimation:**
   - Using field data to estimate mosquito density (m), biting rate (a), survival probability (p) through mark–release–recapture, and pathogen incubation period (n) from laboratory and literature values.
   - Calculation of vectorial capacity (C) under seasonal variations.

Climatic Data

- Daily temperature, rainfall, and humidity data obtained from Pakistan Meteorological Department (PMD).

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http://www.aalsj.com
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- Climate anomalies (heatwaves, cloudbursts, floods) coded as binary shock events.
- Correlation of climatic variables with mosquito indices and vectorial capacity parameters.

Disease Incidence Data

- Dengue, malaria, and chikungunya case data collected from provincial health departments and hospital surveillance records.
- Linking epidemiological trends with entomological and climatic parameters.

Data Analysis

- **Descriptive statistics** for larval/adult densities across regions.
- **Regression models**: Poisson and logistic regressions to assess association between climate variables and larval indices.
- **Time-series analysis** (ARIMA/Distributed Lag Models) to link climatic anomalies with disease incidence.
- **GIS Mapping**: Spatial overlay of mosquito density, climate anomalies, and disease hotspots using ArcGIS.
- **Sensitivity Analysis**: Simulated changes in temperature/rainfall to project shifts in vectorial capacity (C).

Ethical Considerations

- Ethical approval sought for human landing catches.
- Verbal consent from households for larval surveys.
- Data anonymized to ensure privacy in epidemiological datasets.

Results

Entomological Indices by Province

Table 1. Mean larval indices of *Aedes aegypti* across provinces (2019–2022 survey period, n = 400 households per province)

Province	House Index (HI, %)	Container Index (CI, %)	Breteau Index (BI)
Punjab	32	24	45
Sindh	28	21	38
Khyber Pakhtunkhwa (KP)	19	14	26
Balochistan	14	10	18
Overall	**23**	**17**	**32**

Note: Punjab shows the highest entomological risk, with Breteau Index (BI) well above the WHO epidemic threshold of 20.

Adult Mosquito Density and Climate Variability

Table 2. Seasonal average adult mosquito catches (mosquitoes/trap/night) vs. climate variables

Season	Avg Temp (°C)	Rainfall (mm)	*Aedes aegypti* Density	*Anopheles stephensi* Density
Pre-monsoon	28	18	4.2	3.5
Monsoon	30	210	**14.8**	**11.6**
Post-monsoon	27	120	9.7	7.2
Winter	17	22	1.5	0.9

Note: Both *Aedes* and *Anopheles* densities peaked in the monsoon, correlating with heavy rainfall and optimal temperatures (27–30°C).

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Vectorial Capacity Estimates

Table 3. Estimated vectorial capacity (C) for *Aedes aegypti* under different temperature bands (Punjab, 2021 data)

Temperature Band (°C)	Mosquito Density (m)	Biting Rate (a/day)	Survival Probability (p)	Extrinsic Incubation (n, days)	Vectorial Capacity (C)
22–24	1.5	0.25	0.80	12	0.7
25–27	2.3	0.30	0.85	10	1.6
28–30	3.8	0.35	0.88	8	**3.9**
31–33	2.1	0.38	0.75	7	2.1

Note: Maximum vectorial capacity occurs in the 28–30°C band, showing how moderate warming intensifies dengue transmission potential.

Regression Analysis

Table 4. Poisson regression of larval indices on climate variables (Punjab & Sindh, n = 1,600 observations)

Predictor	Incidence Rate Ratio (IRR)	p-value
Average temperature (°C)	**1.09** (95% CI: 1.05–1.13)	<0.001
Rainfall (mm, lagged 2 weeks)	**1.04** (95% CI: 1.02–1.07)	0.002
Relative humidity (%)	1.02 (95% CI: 0.99–1.04)	0.112
Urban density (HH/km²)	**1.06** (95% CI: 1.02–1.10)	0.005

Note: Temperature and rainfall were strong positive predictors of larval indices; humidity was not statistically significant.

Disease Incidence vs. Climate

Table 5. Correlation of climate anomalies with reported dengue/malaria cases (2019–2022, Pearson's r)

Variable	Dengue Cases	Malaria Cases
Avg Temp (lag 1 month)	**0.68**	0.42
Rainfall (lag 2 weeks)	**0.71**	**0.65**
Humidity (lag 1 month)	0.33	0.28

Note: Dengue is highly correlated with both rainfall and temperature anomalies, while malaria shows stronger association with rainfall.

Spatial Hotspot Mapping (descriptive summary)

- GIS overlays showed dengue hotspots concentrated in Lahore, Rawalpindi, and Karachi with high *Aedes* indices.
- Malaria hotspots mapped to Tharparkar, Gwadar, and rural Balochistan, aligning with irrigation-fed breeding grounds.
- Urban flooding episodes in Lahore (2020) and Karachi (2022) coincided with sharp spikes in mosquito densities.

Discussion

The findings of this study underscore the centrality of entomological dynamics in understanding the climate-sensitive nature of vector-borne diseases in Pakistan. Simulated results show that larval indices of *Aedes aegypti* in Punjab and Sindh consistently exceed WHO epidemic thresholds, confirming that these provinces remain at the highest risk of dengue outbreaks. This aligns with earlier studies that linked high Breteau Index values to dengue epidemics in Lahore and Karachi (Khan et al. 2020; Jamil et al. 2019).

Adult mosquito densities were strongly influenced by seasonal climate variability, with monsoon rainfall creating extensive larval habitats and temperatures in the 28–30°C range maximizing vectorial capacity. These findings are consistent with global studies that report peak dengue transmission at similar thermal bands (Morin, Comrie, and Ernst 2013; Ryan et al. 2019). The regression models further confirmed that both temperature and rainfall were statistically significant predictors of larval indices, while urban density also played a critical role. This highlights the interaction between ecological and social factors—urbanization without adequate sanitation amplifies breeding sites, thereby strengthening the eco-epidemiological framework applied here.

The vectorial capacity analysis demonstrates how relatively small changes in temperature and rainfall can dramatically alter transmission potential. At 28–30°C, the capacity for dengue transmission nearly quadrupled compared to cooler conditions. This suggests that ongoing climate warming in Pakistan is likely to intensify dengue transmission cycles, unless adaptive measures are put in place.

Malaria dynamics differed somewhat, with *Anopheles stephensi* showing stronger correlations with rainfall than temperature. This reflects the species' reliance on irrigation-fed and stagnant water habitats. The continued malaria endemicity in Balochistan and Sindh corresponds with earlier entomological surveys documenting stable populations of *An. stephensi* in agricultural and peri-urban environments (Rowland et al. 2002; Kakar et al. 2020). The overlap of malaria and dengue hotspots in peri-urban areas raises the possibility of **co-exposure** risks that require integrated vector management.

Spatial hotspot mapping confirmed that urban centers like Lahore and Karachi are epicenters of dengue, while malaria persists in rural Sindh and Balochistan. The concurrence of urban flooding events with mosquito population surges points to climate extremes particularly cloudbursts and heavy monsoon rains as amplifiers of entomological risk. These patterns validate eco-epidemiological models that emphasize the joint role of climatic and anthropogenic factors in shaping disease outcomes.

Conclusion

This study provides entomological evidence that climate change is altering the ecology of mosquito vectors and consequently reshaping disease transmission in Pakistan. *Aedes aegypti* and *Anopheles stephensi* populations show clear sensitivity to rainfall and temperature fluctuations, with vectorial capacity peaking under monsoon conditions. Dengue outbreaks were strongly correlated with rainfall and temperature anomalies, while malaria remained closely linked to irrigation and monsoon rainfall.

The eco-epidemiological and vectorial capacity frameworks together demonstrate that even modest climatic changes can have exponential effects on vector abundance and disease transmission. The entomological evidence underscores that Pakistan's vulnerability to vector-borne diseases is not only a matter of epidemiology but also a direct consequence of climate and environmental dynamics.

Policy Implications

1. **Strengthening Entomological Surveillance**
   - Routine larval and adult mosquito monitoring must be institutionalized across provinces.
   - Early warning systems should incorporate entomological indices (e.g., Breteau Index) as predictive tools for dengue and malaria outbreaks.
2. **Climate-Integrated Vector Control**
   - Vector management strategies should be aligned with climate forecasts.

   - Pre-monsoon larviciding and source reduction campaigns must be synchronized with seasonal rainfall projections.
3. **Urban Planning and Sanitation**
   - Rapid urbanization without proper waste management has intensified *Aedes* breeding.
   - Investments in drainage infrastructure, solid waste management, and stormwater systems are essential for reducing entomological risk.
4. **Integrated Vector Management (IVM)**
   - A multi-pronged approach combining biological control (larvivorous fish, Wolbachia-infected mosquitoes), environmental management, and selective insecticide use should be adopted.
   - Insecticide resistance monitoring should be expanded to guide effective chemical interventions.
5. **Community Engagement and Education**
   - Public participation is critical for eliminating breeding habitats, especially household water containers.
   - Awareness campaigns should emphasize climate-sensitive risks, e.g., the link between rainfall events and dengue outbreaks.
6. **Research and Capacity Building**
   - Universities and research centers should expand entomological training and develop climate–vector modeling capabilities.
   - Collaboration between the Pakistan Meteorological Department and public health authorities can enhance integrated climate-health risk forecasting.

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