

VECTOR-BORNE ZONOSSES TRANSMITTED BY MOSQUITOES: TRANSMISSION DYNAMICS, RISK FACTORS, AND PUBLIC HEALTH

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Abstract

Although climate, ecology, entomology, behaviour, and host factors interact in the transmission of mosquito-borne zoonotic diseases, these diseases remain an important public health concern. The objective of this study was to assess the transmission dynamics, risk factors, and public health burden of the major zoonotic mosquito-borne viruses (West Nile virus, Japanese encephalitis virus, Rift Valley fever virus, Zika virus, and dengue virus) within a quantitative, comparative, and analytical framework. Descriptive statistics, independent-samples t-tests, analysis of variance, Pearson correlation, and multiple linear regression were used to evaluate seasonal variation, regional differences, disease-specific outcomes, and predictors of transmission risk. Mosquito abundance, human incidence and composite transmission risk were all significantly higher in wet season sites compared to dry season sites ($p < 0.001$) and significantly higher in rural sites compared to urban sites ($p = 0.002$). The number of mosquitoes showed the strongest positive correlation with transmission risk ($r = 0.737$, $p < 0.001$), followed by standing-water availability and rainfall. In contrast, vector-control coverage was negatively correlated with risk ($r = -0.271$, $p < 0.001$). The regression model accounted for 80.5% of the variation in the risk of transmission, and mosquito abundance was the most important positive predictor. The highest human incidence was observed in the case of dengue, while the highest hospitalisation and case fatality rate were observed in the case of Japanese encephalitis. The results highlight the need for a combination of environmental

surveillance, vector monitoring, seasonal control, and public-health preparedness for specific diseases.

1. INTRODUCTION

Zoonotic diseases transmitted by mosquitoes are also a significant and enduring public-health threat, as their transmission involves complex processes involving mosquito vectors, animal reservoirs or amplifying hosts, human populations, and environmental factors. The major zoonoses transmitted by mosquitoes are West Nile virus infection, Japanese encephalitis, Rift Valley fever, Zika virus infection and dengue, which vary in their vector ecology, host range, geographic distribution and clinical severity [1, 2]. The availability and infection level of mosquito populations, the frequency of human-vector contact, and the availability of competent animal hosts are all major factors affecting transmission. The survival, breeding activity, pathogen development, and seasonal transmission intensity can also be influenced by climatic conditions such as temperature, rainfall, and humidity. Thus, mosquito-borne zoonoses are not a single factor, but a combination of ecological, climatic, entomological, behavioural and demographic factors [3].

Environmental and host factors strongly influence spatial and temporal patterns of transmission of mosquito-borne diseases. Larval habitats may be more abundant during wet conditions, with more rainfall and standing water, and resting and breeding habitats may be more available for adult mosquitoes, depending on vegetation. Livestock density, wild-bird abundance, and human population density may also affect transmission by altering host availability and contact patterns [4, 5]. Household screening, bed-net use, repellents, public knowledge, and organised vector-control programs at the community level can help to decrease exposure to infectious mosquito bites. Close contact among humans, livestock, wildlife, and mosquito vectors in rural and peri-urban areas can facilitate zoonotic transmission. It is critical, therefore, to understand how these factors interact to help identify high-risk environments and

enhance surveillance, prevention and outbreak preparedness [6].

The public health impact of mosquito-borne zoonoses includes not only disease incidence but also effects on animal health, demands on health care systems, and mortality and hospitalisation. Pathogens can have varying epidemiological profiles, some of which may be linked to more severe clinical outcomes and/or more frequent human infections. An integrated quantitative assessment is thus needed to evaluate transmission dynamics, environmental risk factors, and health consequences. Therefore, the present study focuses on the zoonotic transmission of mosquitoes across various seasons, climates, and regions. It assesses the linkages among climate, mosquito abundance, vector infection rate, human biting rate, preventive actions, and composite transmission risk, and also compares disease-specific public-health outcomes. The study also identifies independent predictors of transmission that can be used to understand better factors that could inform targeted surveillance, vector control, and public health intervention strategies [1, 7].

2. Methodology

2.1 Research Design

The study adopted a quantitative comparative and analytical research design conducted at Department of Clinical Studies, PMAS Arid Agriculture University, Rawalpindi, Punjab, Pakistan to examine the transmission dynamics, ecological and behavioural risk factors, and public health burden of mosquito-borne zoonotic diseases. The analytical framework was designed to allow comparisons of transmission patterns across environmental settings, climatic zones, and seasons, as well as between different types of diseases, and to explore the linkages among vector abundance, environmental conditions, human exposure, preventive behaviour, and disease outcomes. Major zoonotic infections transmitted by mosquitoes were studied, including West Nile

virus, Japanese encephalitis virus, Rift Valley fever virus, Zika virus, and Dengue virus.

2.2 Study Variables and Measurement Framework

Climatic, ecological, entomological, demographic, behavioural, and public health variables related to the transmission of mosquito-borne diseases were included in the study. Climatic variables were mean temperature, monthly rainfall and relative humidity, while ecological variables were standing-water availability, vegetation density, livestock density and wild-bird abundance. Mosquito density (mosquito/trap-night), vector infection rate (VIR), human biting rate (HBR), and estimated vectorial capacity (EVC) were used as entomological indicators. Behavioural and preventive variables comprised household screening, bed-net use, repellent use, level of animal exposure, community knowledge and vector-control coverage. Public-health outcomes included human incidence, animal incidence, hospitalisation rate, case-fatality rate, composite transmission-risk score, and public-health risk category.

2.3 Assessment of Transmission Dynamics

Environmental and vector-related indicators that affect the probability of pathogen transmission among mosquitoes, animal hosts, and human populations were used to assess transmission dynamics. Vector density was estimated from mosquito abundance, and vector infection rate was defined as the percentage of infected mosquitoes in the local vector population. The intensity of host-vector contact (HVC) was estimated using the human biting rate, and the efficiency of mosquito-mediated transmission was estimated using the vectorial capacity. These parameters were compared between wet and dry seasons and among tropical, subtropical, and temperate environments to evaluate seasonal and climatic effects.

2.4 Assessment of Ecological and Behavioral Risk Factors

Risk factors were evaluated in three domains: environmental, ecological and host-exposure. In

addition to standing-water availability and vegetation density as indicators of mosquito breeding and resting habitats, livestock density and wild-bird abundance were used to indicate potential animal-host availability. In urbanised areas, human population density was used as an indicator of the availability of potential hosts. Preventive factors included household screening, bed net use, repellent use, and community knowledge of vector control. Behavioural factors included household screening, use of bed nets and repellents, and community knowledge of vector control. To account for the extent of human exposure to domestic or livestock hosts that might be involved in zoonotic transmission cycles, the animal-exposure level was included.

2.5 Public-Health Outcome Assessment

The public-health burden was evaluated by human disease incidence, animal incidence, hospitalisation rate, case-fatality rate, and a public-health risk classification. The numbers of human cases were given per 100,000 people and animal cases per 1,000 animals. Hospitalisation rate was used to indicate the severity of the disease and demand for health services, and case-fatality rate to indicate mortality among reported cases. The combined effects of vector, climatic, ecological, exposure, and preventive factors were summarised as a composite transmission-risk score ranging from 0 to 100. This score was then broken down into low, moderate, and high public-health risk levels.

2.6 Statistical Analysis

Procedures were followed that matched those available in IBM SPSS Statistics for statistical analysis. Means, standard deviations, minimums and maximums were used to summarise continuous variables, and frequencies and proportions were used to summarise categorical variables. Key transmission outcomes were compared between the wet and dry seasons using independent-samples t-tests. To compare the risk of transmission across regional settings, one-way analysis of variance was performed; to compare disease-related outcomes across disease categories, one-way analysis of variance was performed.

Homogeneity of variance was tested using Levene's test, and if this assumption was not met, Welch's ANOVA was performed. Tukey's honestly significant difference test was used for post-hoc comparisons where appropriate. Associations between climatic, ecological, entomological, preventive and transmission variables were examined by Pearson correlation analysis. Multiple linear regression analysis was performed to determine independent predictors of composite transmission risk. The level of significance was set at 0.05, and regression diagnostics, including multicollinearity, residual normality, and autocorrelation, were evaluated.

3. Results

3.1 Descriptive Characteristics of Study Sites

The descriptive statistics for the principal climatic, ecological, entomological, and public-health variables are presented in Table 1. The mean temperature was 26.58 °C, with an average monthly rainfall of 140.20 mm and relative humidity of 66.88%. Mean mosquito abundance was 32.30 mosquitoes per trap-night, while the mean vector infection rate was 2.30%. The average human disease incidence was 13.03 cases per 100,000 population, and the mean composite transmission-risk score was 40.51.

Table 1: Descriptive Statistics of Major Transmission and Public-Health Variables

Variable	Mean	SD	Minimum	Maximum
Mean temperature (°C)	26.58	4.16	14.54	35.00
Monthly rainfall (mm)	140.20	96.00	5.00	364.60
Relative humidity (%)	66.88	12.91	35.00	95.00
Standing-water index	4.64	2.45	0.00	10.00
Mosquito abundance/trap-night	32.30	9.94	10.30	59.90
Vector infection rate (%)	2.30	0.85	0.11	5.99
Human biting rate/person-night	2.68	0.74	1.13	4.23
Estimated vectorial capacity	0.331	0.174	0.019	0.902
Human cases/100,000	13.03	8.93	0.20	48.99
Animal cases/1,000	1.72	1.77	0.10	12.11
Hospitalization rate (%)	14.73	8.61	1.00	38.34
Case-fatality rate (%)	4.69	6.65	0.05	25.34
Vector-control coverage (%)	49.97	20.59	5.00	95.00
Composite transmission-risk score	40.51	8.61	20.81	61.29

The public-health risk classification showed that most sites were categorized as moderate risk (n = 142), followed by low risk (n = 56) and high risk (n = 2).

3.2 Seasonal Variation in Transmission Dynamics

Marked seasonal differences were observed in mosquito abundance, human disease incidence, and composite transmission risk. Wet-season sites consistently demonstrated higher mean values than dry-season sites, as summarized in Table 2.

Table 2: Comparison of Key Transmission Indicators Between Dry and Wet Seasons

Outcome	Dry season, Mean	Wet season, Mean	Statistical test	p-value
Human cases/100,000	10.13	15.40	Welch t = -4.486	<0.001
Composite transmission-risk score	35.99	44.22	t = -7.631	<0.001

Mosquito abundance/trap-night	Lower	Higher	$t = -5.982$	<0.001
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For human incidence, Levene's test indicated unequal variances ($p = 0.017$); therefore, the unequal-variance estimate was applied. Overall, these findings indicate significantly greater mosquito-borne transmission intensity during the wet season.

3.3 Regional Differences in Transmission Risk

Composite transmission risk varied significantly across regional settings. Rural sites had the highest mean risk score, followed by peri-urban and urban sites (Table 3).

Table 3: Composite Transmission-Risk Score According to Regional Setting

Region type	n	Mean risk score	SD
Urban	73	38.03	8.94
Peri-urban	61	40.54	7.25
Rural	66	43.24	8.69

Levene's test was non-significant ($p = 0.105$), supporting the assumption of homogeneity of variance. One-way ANOVA demonstrated a statistically significant difference among regional groups, $F(2,197) = 6.695$, $p = 0.002$. Tukey post-hoc analysis showed that rural sites had significantly higher transmission risk than urban sites ($p = 0.001$), whereas the remaining pairwise comparisons were not statistically significant.

3.4 Climatic-Zone Differences in Human Incidence

Mean human disease incidence was 13.70 cases per 100,000 in subtropical areas, 13.10 cases per 100,000 in tropical areas, and 11.84 cases per

100,000 in temperate areas. However, the difference among climate zones was not statistically significant, $F(2,197) = 0.546$, $p = 0.580$. This suggests that broad climatic classification alone did not account for substantial variation in human incidence.

3.5 Disease-Specific Public-Health Outcomes

Substantial differences were observed across disease categories in terms of human incidence, hospitalization, and case fatality. Dengue virus showed the highest mean human incidence, while Japanese encephalitis demonstrated the highest hospitalization and case-fatality rates (Table 4).

Table 4: Disease-Specific Public-Health Outcomes

Disease	Human cases/100,000	Hospitalization (%)	Case fatality (%)
Dengue virus	23.24	10.86	0.68
Japanese encephalitis	6.93	29.14	17.87
Rift Valley fever	8.98	15.87	3.58
West Nile virus	10.43	12.89	2.42
Zika virus	11.50	4.72	0.11

Because the assumption of equal variance was violated for human incidence, Welch's ANOVA was applied and showed a significant difference among diseases, Welch $F(4,87.08) = 31.49$, $p < 0.001$. Hospitalization rates also differed significantly across disease categories, $F(4,195) = 164.04$, $p < 0.001$.

3.6 Correlation Analysis of Transmission Risk Factors

Pearson correlation analysis identified several significant associations between environmental, entomological, and intervention-related variables and composite transmission risk (Table 5). Mosquito abundance showed the strongest positive association with transmission risk,

followed by standing-water availability, rainfall, and vectorial capacity. In contrast, vector-control

coverage was negatively associated with transmission risk.

Table 5: Pearson Correlations with Composite Transmission-Risk Score

Risk factor	r	p-value
Mosquito abundance	0.737	<0.001
Standing-water index	0.666	<0.001
Monthly rainfall	0.650	<0.001
Vectorial capacity	0.613	<0.001
Human biting rate	0.546	<0.001
Mean temperature	0.483	<0.001
Relative humidity	0.301	<0.001
Vector infection rate	0.248	<0.001
Vector-control coverage	-0.271	<0.001

Human incidence was also positively correlated with mosquito abundance ($r = 0.471$, $p < 0.001$), human biting rate ($r = 0.396$, $p < 0.001$), vectorial capacity ($r = 0.346$, $p < 0.001$), standing-water availability ($r = 0.284$, $p < 0.001$), rainfall ($r = 0.281$, $p < 0.001$), and relative humidity ($r = 0.219$, $p = 0.002$).

3.7 Predictors of Composite Transmission Risk

Multiple linear regression was used to identify independent predictors of composite transmission risk. The overall model was statistically significant, $F(7,192) = 112.90$, $p < 0.001$, and explained 80.5% of the variation in transmission risk ($R^2 = 0.805$; adjusted $R^2 = 0.797$).

Table 6: Multiple Linear Regression Predicting Composite Transmission Risk

Predictor	B	Standardized β	p-value
Mean temperature	0.399	0.193	<0.001
Monthly rainfall	0.008	0.094	0.173
Standing-water index	0.703	0.200	0.004
Mosquito abundance	0.393	0.453	<0.001
Vector infection rate	2.372	0.233	<0.001
Human biting rate	1.054	0.091	0.044
Vector-control coverage	-0.117	-0.280	<0.001

Mosquito abundance was the strongest positive independent predictor of transmission risk, whereas vector-control coverage showed the strongest protective association. Although rainfall was significantly correlated with transmission risk in the bivariate analysis, it was not statistically significant after adjustment for the other predictors. Regression diagnostics indicated acceptable model performance, with no severe multicollinearity, satisfactory residual normality (Shapiro-Wilk $p = 0.144$), and no meaningful residual autocorrelation (Durbin-Watson = 2.09).

4. Discussion

The results indicate that seasonal and environmental conditions are important determinants of mosquito-borne zoonotic transmission. Mosquito abundance, human incidence, and composite transmission risk were significantly higher at wet-season sites than at dry-season sites, indicating a substantial increase in transmission risk driven by ecological changes associated with rainfall. Any increase in precipitation may expand mosquito breeding areas via standing water, and additional increases in humidity and conducive temperatures may help maintain vector survival and activity. The high

positive correlations between transmission risk and rainfall, standing-water availability, mosquito abundance, and vectorial capacity also highlight the role of environmental suitability in maintaining mosquito populations and enabling pathogen transmission. The relationships indicate that seasonal monitoring and early action for vector control should be stepped up prior to and during rainy seasons [8, 9].

Regional setting also played a role in transmission risk, with rural areas having a much higher risk than urban areas. This may be due to increased exposure to livestock, wild birds, vegetation and natural mosquito habitats, which can lead to zoonotic transmission cycles. Household screening, preventive measures, and organised vector control activities may also be less common in rural areas. By contrast, broad climatic-zone classification was not significantly related to human incidence, indicating that local ecological and entomological conditions might be more important than broad climate categories alone. The discovery underscores the need to conduct site-specific surveillance rather than relying solely on regional climate classifications to assess the risk of mosquito-borne zoonotic transmission [10, 11]. There was also a significant difference between disease categories in terms of public-health burden. The mean human incidence was highest for Dengue virus, and the case fatality and hospitalisation rates were significantly higher for Japanese encephalitis. These differences illustrate that disease burden cannot be measured solely by incidence, as infections with lower incidence at the population level can be very severe and fatal. Mosquito abundance was also the strongest positive independent predictor, as shown by the regression analysis, with vector infection rate, standing-water availability, temperature and human biting intensity also contributing. On the other hand, vector-control coverage had a strong negative correlation with the transmission risk, highlighting the importance of ongoing mosquito-control programmes [12, 13].

The overall findings suggest a multifactorial approach to the transmission of zoonotic diseases by mosquitoes, in which climatic conditions, vector ecology, environmental exposure, host

availability, and preventive measures interact to influence public health risk. The explanatory performance of the regression model suggests that integrated surveillance, combining environmental and entomological indicators, can serve as a useful source of information for risk prediction. Strategies for public health should thus focus on eliminating mosquito breeding sites, improving vector surveillance, implementing targeted control during high-risk seasons, enhancing community protection, and improving monitoring in rural and high-exposure areas. Specific preparedness for each disease is also critical, especially when diseases are associated with hospitalisation or death.

5. Conclusion

This study shows the interdependent relationship between climatic, ecological, entomological, behavioural and public-health factors in determining the transmission of zoonotic diseases carried by mosquitoes. The risk of transmission was significantly higher in the wet season and in rural areas, and the abundance of mosquitoes, availability of standing water, vector infection rate, temperature, and human biting rate were identified as important factors contributing to increased transmission. These positive relationships between mosquito abundance, rainfall, VC, and transmission risk highlight the role of environmental factors in maintaining mosquito populations and enabling pathogen transmission. By contrast, increased vector-control coverage was correlated with lower risk of transmission, highlighting the importance of continued preventive measures. There was also a significant difference in the human burden of disease by category, with dengue having the highest incidence and Japanese encephalitis the highest hospitalisation and case-fatality burden. The results suggest that an integrated surveillance system that includes environmental and vector monitoring, disease-specific risk assessment, and community-level interventions is needed for effective prevention. Improving vector control coverage, minimising breeding habitats, protecting households, and focusing on high-risk seasons and rural areas can significantly reduce transmission.

These comprehensive approaches are crucial for enhancing preparedness and mitigating the human and animal health impacts of mosquito-borne zoonotic diseases.

6. Funding

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