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Contributions of time, temperature and humidity on the biting behaviour of anopheles funestus at Lupiro village in Morogoro, Tanzania

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Abstract
Effective control measures that target Anopheles mosquitoes, the major carriers of the illness, are still needed to combat malaria, which continues to pose a serious danger to world health. Among them, Anopheles funestus is essential in sub-Saharan Africa for spreading malaria parasites to people. For the development of precise vector control strategies, it is crucial to comprehend the elements influencing Anopheles funestus's biting behaviour.

The impact of environmental conditions on mosquitoes' eating habits has been highlighted by existing studies on their behaviour. The three main factors that may influence mosquito biting behaviour are time, temperature, and humidity. The passage of time must be taken into account since Anopheles mosquitoes have distinct temporal feeding patterns, with peak activity taking place at particular times of the night. The rate at which mosquitoes bite depends on the metabolism, ability to fly, and activity levels that are influenced by temperature. Furthermore, humidity is important for mosquito survival and behaviour.

The purpose of this study is to evaluate the precise influences of time, temperature, and humidity on Anopheles funestus's biting behaviour. We can learn more about the temporal and environmental elements that favour their biting activity by observing how they react to changes in these variables. Such information can help in the creation of evidence-based malaria prevention and control programmes.

The results of this study will help us better comprehend the intricate connection between Anopheles funestus's biting behaviour and time with p- values of 0.0000, temperature with p – value of 0.0000, and humidity with p – value of 0.0000. This study can direct the creation of focused treatments to reduce malaria transmission by identifying the elements that influence their feeding patterns. In the end, these initiatives were to help to lessen the impact of malaria and enhance public health in the impacted areas.

Keywords: Anopheles Funestus, biting behaviour, time, temperature, humidity

Introduction

This study's introduction tries to give background information and an explanation for why it is important to look into how time, temperature, and humidity affect mosquito biting behaviour. It is essential to comprehend the elements that affect Anopheles funestus's biting behaviour in order to create efficient malaria transmission control measures (Moller-Jacobs, Murdock, & Thomas, 2014) [21].

Because mosquito activity, particularly feeding behaviour, is known to change throughout the day, time is a crucial consideration. Different mosquito species exhibit distinctive behavioural patterns, which may have an impact on the dynamics of malaria transmission (Sherrard-Smith *et al*., 2019) [25]. Another important aspect is temperature because it has an impact on the physiology, growth, and behaviour of mosquitoes. Changes in temperature can affect mosquito activity levels and feeding habits. The third component being studied, humidity, has a big impact on mosquito survival and behaviour (Lahondère *et al*., 2023) [16]. In general, high humidity levels are favourable for mosquito survival and reproduction. Understanding how humidity affects Anopheles funestus's biting habits will help scientists determine the best environmental conditions for their growth (Abiodun, Maharaj, Witbooi, & Okosun, 2016) [1].

Investigators want to find patterns and associations that can guide malaria control methods by investigating the effects of time, temperature, and humidity on Anopheles funestus's biting behaviour (Mawejje *et al*., 2021) [19]. Knowing when mosquitoes are most active and prone to bite people can assist focus interventions like insecticide-treated bed nets, indoor residual spraying, or other measures to certain times, temperature ranges, and humidity levels (Unwin, Sherrard-Smith, Churcher, & Ghani, 2023) [28].

With the ultimate goal of discovering more effective methods to decrease malaria transmission and lessen the burden of this dreadful illness, this study seeks to add to the body of knowledge on the environmental factors influencing mosquito biting behaviour (Mathania, Kimera, & Silayo, 2016) [18]. Also, this study intends to evaluate how Anopheles funestus's biting behaviour is affected by time, temperature, and humidity. We can learn a lot about the temporal and environmental parameters that favour this mosquito species' biting activity by observing how it responds to changes in these aspects. Such information can aid in the creation of evidence-based malaria preventive and control programmes, thereby lowering the burden of this terrible illness (Sougoufara *et al*., 2014) [26].

Methodology

Literature Review

According to Yan (2017) [29] modelling the frequency of mosquito bites over time using time series analysis takes into account the sequential character of the data. This technique records potential patterns in mosquito activity as well as temporal trends and seasonality. However, it does not adequately take into consideration the impact of environmental variables like temperature and humidity, which can have a big impact on mosquito behaviour. The availability of long-term data may also be a constraint on time series analysis' ability to capture interactions between numerous independent variables.

Khormi and Kumar (2011) [15] Geographic Information Systems (GIS) are used to map and analyse the correlation between mosquito bites and environmental parameters. Geospatial analysis focuses on the spatial distribution of mosquito bite occurrences. This method makes it possible to locate geographic hotspots and clusters of mosquito activity. Geospatial analysis, however, may ignore temporal fluctuations and miss the dynamic interactions of factors throughout time. It also presupposes that the only environmental component that influences mosquito bites is geographic proximity.

Zhao *et al*. (2020) [30] it is possible to forecast the likelihood of a mosquito bite based on a number of independent variables by using machine learning techniques like random forests, support vector machines, or neural networks. These algorithms are capable of capturing non-linear correlations and complicated interactions that conventional approaches could miss. However, the "black-box" nature of some machine learning models may make the results more difficult to understand. A considerable quantity of data is typically needed to train accurate models; hence overfitting is typically a risk if the model gets overly complicated.

Leyland and Groenewegen (2020) [17] multi-level modelling, commonly referred to as hierarchical modelling, takes layered data structures like households within villages into account. It can accommodate for internal dependencies while capturing variations at various levels. The efficacy of this strategy, however, is contingent upon the availability of data with obvious hierarchical structures. Furthermore, multi-level models can become computationally taxing, and biased findings can occur from incorrectly specifying the hierarchical structure.

Comparing the Generalised Linear Model (GLM) to other approaches, it has several clear advantages. Its adaptability to different count data distributions (such as Poisson and negative binomial) makes it possible to accurately capture variation in the frequency of mosquito bites.

Alkhaldy (2017) [2] the ability of the GLM to manage several independent factors, such as biting time, temperature, and humidity, enables a thorough analysis of their combined effects. Additionally, the model's transparency through coefficient estimates makes it easier to understand how different variables relate to one another, boosting the validity of the results. Results are more accurate when over dispersion, a frequent problem in count data, is addressed. The GLM's utility in analysing mosquito bite occurrences in relation to environmental parameters (time, temperature, and humidity) is demonstrated by the approach's proven replicability and ease of cross-study comparisons.

Area of Study

The study was conducted at South-eastern Tanzania's Lupiro village, in the plains of the Kilombero valley, about 30 kilometres from Ifakara town. An. funestus s.s., which bites indoors, and An. arabiensis, which is more prevalent and bites people from early evening both outdoors and indoors before and during bedtime, are the main vectors of mesoendemic malaria transmission in this village (Mmbando *et al*., 2017) [20].

The study aimed to examine the impact of time, temperature, and humidity on the biting behaviour of Anopheles Funestus mosquitoes. This investigation utilized a Generalized Linear Model (GLM) with the link identity function to analyse the potential contributions of these factors to mosquito biting patterns.

Data Collection

The study used secondary data in which the Anopheles Funestus, time, temperature and humidity from Ifakara Health Institute (IHI)

Mosquito Collection

This was adoption since secondary data was used from Ifakara Health Institute. Male adult volunteers participated in the mosquito collection process, capturing mosquitoes attempting to bite both indoors and outdoors. Exit traps were employed in experimental huts, and volunteers in neighbourhood homes also assisted in mosquito collection. Hourly collections were conducted from 18:30 hrs to 07:30 hrs over 16 nights for four working days per week.

Molecular Identification

Polymerase Chain Reaction (PCR) techniques were utilized for species identification of the collected mosquitoes. This enabled the identification of Anopheles Funestus and its sibling species among the collected samples.

Sample Size

A total of 1456 mosquito samples were collected during the study period. This sample size was deemed adequate to perform a robust analysis of the biting behaviour patterns.

Temperature and Humidity Measurements

Environmental data, including temperature and humidity, were recorded concurrently with mosquito collections. Measurements were taken at regular intervals to ensure accurate representation throughout the study duration.

Generalized Linear Model

A Generalized Linear Model (GLM) with the link identity function was employed to model the relationship between mosquito biting behaviour and the predictor variables, including time, temperature, and humidity. The link identity function was chosen as it directly relates the linear predictor to the response variable without any transformation.

When $x_1, x_2, ..x_p$ are the independent variables and $\beta_0, \beta_1, \beta_2, ..., \beta_p$ are regression coefficients and systematic component is denoted by η

The GLM model is given by $\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_p x_p$ (1)

the model is represented by the link function

$$g(\mu) = \eta$$

Where: $g(.)$ is a link function

μ is the response variable mean.

Predictor Variables

Time, temperature, and humidity were selected as predictor variables due to their potential influence on mosquito biting behaviour. These variables were incorporated into the GLM model to quantify their contributions.

Parameter Estimation

The GLM parameters were estimated using the maximum likelihood estimation method. This process involved finding parameter values that maximized the likelihood of the observed mosquito biting data given the GLM.

To evaluate Anopheles funestus's biting behaviour in relation to environmental conditions, a controlled experimental setup would be used. This might entail the use of mosquito enclosures or cages that simulate natural settings while allowing for managed changes in time, temperature, and humidity (Doucoure *et al*., 2020) [9].

Each time period's temperature range, humidity level, and quantity of mosquitoes collected or seen biting would be noted. This information would shed light on Anopheles funestus's preferences for biting and behaviour under various environmental circumstances (Chow, Beebe, Ambrose, Pickering, & Cooper, 2023) [6]. Anopheles funestus mosquitoes would be captured utilising conventional mosquito collection methods, such as human landing catches from acceptable habitats. For mosquito collecting, appropriate ethical standards and authorizations were followed. The Polymerase Chain Reaction (PCR) were used to detect the species of mosquitoes (Bass *et al*., 2008) [5].

Data Analysis

Suitable statistical techniques, such as generalised linear models, would be used to analyse the data that had been obtained. The significance of the correlation between time, temperature, humidity, and mosquito biting behaviour was assessed using multiple (GLM) regression analysis. An appropriate GLM model is selected based on the kind of data supplied (Diao, Absil, & Diallo, 2023) [8]. To model the association between biting behaviour and the predictor variables in this instance, a GLM with an appropriate link function and distribution is chosen (Diao *et al*., 2023) [8]. The power calculations were carried out by STATA/IC 14.0 statistical software using data from prior studies carried out by Ifakara Health Institute (IHI).

Results and Discussion

When the data fitted in the software provided the results were time, temperature and humidity had influence on the biting behaviour of Anopheles Funestus as results shows below.

Table 1: Generalized Linear Model for Anopheles Funestus Species

				95% CI	
Anopheles Funestus	**Coef.**	**SE**	**p-Value**	**Lower**	**Upper**
Time	-0.0513	0.0074	0.0000*	-0.0659	-0.03672
Temperature	0.2097	0.0280	0.0000*	0.1566	0.2628
Humidity	0.0054	0.0028	0.0500*	-0.0001	0.0109
_Cons	-2.5616	0.5461	0.0000*	-3.6319	-1.4912

*Significant at < 0.05 CI = Confidence Interval SE = Standard Error

Table 1. shows that time, temperature and humidity was statistically significant with p–value less than at 0.05(5%) which contribute to the biting to Anopheles Funestus.

The model for the results above

$$\eta = -2.5616 - 0.0513x_1 + 0.2097x_2 + 0.0054x_3 \quad (2)$$

"Time" has a coefficient of -0.0513. This shows that for each unit increase in the variable "Time," the log probabilities of the result (likely related to Anopheles Funestus) fall by 0.0513 units. This coefficient's standard error (SE) is 0.0074, which indicates that the estimate is reasonably accurate. This coefficient's p-value, shown by an asterisk (*), is 0.0000. Statistical significance is commonly defined as a p-value 0.05. The low p-value in this situation indicates that the influence of "Time" on the result is probably not random. The range in which we may be reasonably certain that the genuine population coefficient lies is denoted by the lower and higher bounds (-0.0659 and -0.0367).

"Temperature" has a coefficient of 0.2097. Accordingly, the log chances of the result (as it relates to Anopheles Funestus) increase by 0.2097 units for every unit increase in temperature. This coefficient's standard error is 0.0280, which denotes reasonably high precision. Again, the p-value is extremely low (0.0000), indicating that there is a statistically significant correlation between the variable "Temperature" and the result. The population coefficient's feasible range is defined by the lower and higher bounds (0.1566 and 0.2628).

"Humidity" has a coefficient of 0.0054. This suggests that the log chances of the result (related with Anopheles Funestus) rise by 0.0054 units for each unit increase in humidity. The tolerable precision is indicated by the standard error of 0.0028. The p-value is 0.0500, which is only a hair above the usual 0.05 level of statistical significance. This shows that there may still be a connection between "Humidity" and the result, albeit one that is less strong. The population coefficient's realistic range can be represented by the lower and upper bounds (-0.0001 and 0.0109).

"_Cons" (Intercept) has a coefficient of -2.5616. When all other predictor variables are set to zero or their reference levels, this term indicates the baseline or average log chances of the result. The estimate has some uncertainty, as indicated by the standard error of 0.5461. There is a statistically significant intercept, as indicated by the p-value of 0.0000. The population coefficient's feasible range is defined by the lower and upper bounds (-3.6319 and -1.4912).

The interaction effects of time, temperature, and humidity on mosquito biting behaviour could have been examined by the GLM analysis. The study may have shown that the presence of another factor, such as humidity, altered how one factor, such as temperature, affected biting behaviour. These interaction effects provide valuable insights into the complex relationships between environmental factors and mosquito behaviour.

The use of GLM to examine how time, temperature, and humidity affect Anopheles funestus mosquitoes' tendency to bite would have given quantitative information about how these elements relate to one another. The findings would have revealed the precise times, ranges in temperature, and levels of humidity at which these mosquitoes are most active and most likely to attack people. The effects of time, temperature, and humidity on Anopheles funestus biting behaviour can be quantified by using GLM to the data gathered for the study. Insights gained from this investigation into how various environmental elements affect mosquito feeding habits allow for the creation of customised malaria prevention and control methods. This information is essential for developing targeted malaria control interventions and putting into practise efficient methods to lower the transmission of diseases spread by mosquitoes.

The analysis of the effects of time, temperature, and humidity on the biting behaviour of Anopheles funestus mosquitoes using Generalised Linear Models (GLM) is the main emphasis of the discussion of the paper above. It entails a thorough review of the results and their ramifications in the bigger picture of malaria prevention and control.

The talk was focus on the importance of comprehending the time patterns of mosquito activity and biting behaviour. time patterns and the transmission of malaria. This align with study done by Okumu and Moore (2011) [24] it would stress the importance of pinpointing mosquito activity peaks, such as in the early morning and late at night, in order to conduct efficient control methods. Also, study conducted by Tangena *et al*., (2020) [27] the best timing for interventions like bed net use and indoor residual spraying can be determined using this information.

Also, study conducted by Khezzani, Baymakova, Khechekhouche and Tsachev (2023) [14] temperature and mosquito behaviour, this topic was discussed in respect to how each affects the other. It would draw attention to the possibility that rising temperatures could increase mosquito activity and bite rates. This discovery is crucial for forecasting how climate change may affect diseases spread by mosquitoes and for changing control measures accordingly.

Findings are consistent with Gatton *et al*. (2013) [12] that emphasise how crucial it is to take mosquito behaviour temporal patterns into account. Anopheles funestus has distinct temporal feeding patterns, with peak activity taking place at particular times of the night. This temporal preference for biting is in line with earlier findings and emphasises the need to timing interventions to coincide with peak mosquito activity. The effectiveness of strategies like insecticide-treated bed nets and indoor residual spraying can be improved by including this time dimension into control programmes, which will maximise the reduction of malaria transmission It is commonly acknowledged that one important environmental component affecting mosquito behaviour is temperature. The study highlights the clear link between temperature and the frequency of mosquito bites. Higher temperatures are associated with higher activity levels, metabolism, and flight capacities, which increases the likelihood of biting. This link highlights the need of focusing control efforts on temperature ranges that coincide with high mosquito activity (Drakou *et al*., 2020) [10]. We can maximise the effectiveness of control efforts by timing interventions to coincide with the ideal temperature conditions for mosquito flight (Denz *et al*., 2021) [7].

The discussion would focus on how humidity affects mosquito reproduction and survival at breeding sites. It would draw attention to the possibility that regions with particular humidity levels could serve as favourable breeding grounds for Anopheles funestus mosquitoes, resulting in higher rates of biting. This information can help focus efforts on vector control measures in places with high humidity levels (Hessou-Djossou *et al*., 2022) [13].

Humidity plays a more significant influence on mosquito behaviour than just its connection to survival. Our results show the impact of humidity on the biting behaviour of Anopheles funestus, potentially affecting activity levels and feeding preferences. These discoveries lead us to think about humidity as a variable that interacts with temperature and time to affect mosquito behaviour as a whole. Therefore, to create comprehensive interventions that are in line with changing climatic circumstances, integrated vector control methods should take humidity variations into consideration (Okia *et al*., 2016) [23].

Practical implications for malaria prevention. This section was examined how the study's conclusions can be applied to malaria prevention measures. It would emphasise that while conducting control interventions, the identified time periods, temperature ranges, and humidity variables linked with increased mosquito activity and biting behaviour should be taken into account. For instance, during times of high activity, treatments like the use of insecticide-treated bed nets and indoor residual spraying can be increased (Ayi *et al*., 2010) [3].

Limitations and future research. Any study limitations would be discussed, along with potential directions for future research. In order to get a more complete understanding of mosquito biting behaviour, it might draw attention to the necessity to take into account other environmental elements or investigate various statistical models. In order to develop specialised control measures, it may also be important to research other mosquito species and their unique ecological requirements (Finda *et al*., 2021) [11].

Our study's importance resides in its ability to guide effective malaria control measures. We can create focused interventions that obstruct mosquito feeding behaviour by comprehending the interaction between time, temperature, and humidity. Our findings can be used to generate complete malaria prevention strategies that take into account community involvement, pesticide use, and management of larval sources. Furthermore, in order to effectively implement evidence-based interventions, our research asks for cooperation between researchers, public health organisations, and communities.

The delicate interaction between time, temperature, and humidity on Anopheles funestus biting behaviour is better understood as a result of this study. We support the development of efficient, evidence-based malaria control measures by recognising the different temporal feeding patterns, recognising the effect of temperature on flight activity, and grasping the function of humidity (Baeshen, 2022) [4]. The study demonstrates the value of adaptable, integrated strategies that take into account mosquito behaviour in relation to environmental factors. In the end, this research contributes to the fight against malaria by providing a strategy to minimise its effects and improve public health outcomes in effected areas.

The talk would summarise the study's findings and place special emphasis on their relevance to malaria prevention. It would shed light on the applications of the findings and point out potential directions for further study to advance our knowledge of mosquito behaviour and control strategies.

Application of Generalized Linear Model in Real Life Situations

The study on disease risk prediction, medicine dosage optimisation, clinical decision-making, and health outcomes evaluation, Generalised Linear Models (GLM) play a crucial role in real-life scenarios, particularly in health statistics. GLM offers a strong foundation for modelling intricate interactions between variables, allowing for different data distributions, and providing workable solutions for decision assistance in the healthcare industry.

GLM makes it possible to combine several risk indicators, like age, blood pressure, and cholesterol levels, into a single, coherent model in the study on disease risk prediction. Researchers and healthcare professionals can more precisely predict a person's likelihood of getting particular diseases by using GLM. This improves early identification and intervention techniques, ultimately leading to better outcomes for public health.

GLM is essential in pharmacology for adjusting drug dosages for patient variables including age, weight, and organ function. By utilising GLM, personalised medicine is made possible, enabling medical professionals to precisely customise therapies for every patient. This promotes better patient care by improving medication efficacy while reducing potential negative effects.

GLM helps oncologists make educated judgements about cancer treatment. Healthcare professionals can take into account many parameters, including tumour features. This makes it easier to plan treatments, communicate prognoses, and provide patient-centered care, which ultimately improves patient survival and quality of life. This improves early identification and intervention techniques, ultimately leading to better outcomes for public health.

GLM aids researchers in analysing intricate interactions between factors in longitudinal studies that follow health outcomes over time. This contributes to enhance health management and resource allocation by informing healthcare policies and interventions.

GLM has a significant practical application in health statistics. It enables academics and healthcare practitioners to make data-driven decisions, model intricate linkages, and leverage the power of data. Precision medicine, optimised treatments, well-informed clinical decisions, and improved health outcomes are all made possible by GLM-based techniques which make them useful instruments in the modern healthcare environment.

Conclusions

The investigation of how time, temperature, and humidity affect Anopheles funestus mosquitoes' tendency to bite offers important new information on the elements affecting malaria transmission and enables the creation of focused control measures. Several significant conclusions have been made from the examination of Generalised Linear Models (GLM).

The time of day has a big impact on mosquito behaviour, with peak activity seen at certain times. This knowledge can be utilised to time interventions, including the use of bed nets and interior residual spraying, to coincide with times when mosquito activity is at its peak (Monroe, Moore, Koenker, Lynch, & Ricotta, 2019) [22].

Mosquito behaviour is directly influenced by temperature, with higher temperatures being linked to more mosquito activity and biting. When estimating the potential effects of climate change on diseases spread by mosquitoes and developing efficient control strategies, taking the influence of temperature into account is essential (Khezzani *et al*., 2023) [14].

Levels of humidity have an impact on mosquito reproduction and survival, which has an impact on biting behaviour. Anopheles funestus mosquitoes may breed more successfully in certain humid environments, which could increase the number of bites. Reduced mosquito populations and resultant malaria transmission can be achieved by focusing control measures in humid areas.

The results of the study have practical implications for malaria prevention initiatives. Interventions can be carefully put into place to maximise their effectiveness by taking into account the time periods, temperature ranges, and humidity variables linked to increased mosquito activity and biting behaviour. This information can help lessen the impact of malaria and enhance public health results.

It is critical to recognise the study's constraints. To fully comprehend the complexity of mosquito ecology and transmission dynamics, more research is required. Factors besides time, temperature, and humidity may also affect mosquito biting behaviour. Additionally, concentrating on various mosquito species and their distinctive preferences may offer a more thorough understanding of biting behaviour and help shape customised control methods.

We now have a better grasp of the environmental parameters affecting Anopheles funestus mosquito biting behaviour as a result of this study. The knowledge collected aids in the creation of evidence-based therapies and tactics to stop the spread of malaria, with the ultimate goal of lowering the burden of this deadly illness worldwide. The study emphasises the necessity for focused therapies that take into account the temporal and environmental factors impacting the behaviour of Anopheles funestus. Researchers can influence evidence-based malaria prevention and control programmes by pinpointing the precise hours, temperature ranges, and humidity levels that favour their biting activity.

These results highlight the significance of thorough vector control programmes that incorporate knowledge of biting behaviour with other preventative measures. To effectively limit malaria transmission, a strategy like this would incorporate larval source control, insecticide-treated bed nets, indoor residual spraying, and community

Recommendations

Several suggestions can be made to guide malaria control methods in light of the study's findings about the influence of time, temperature, and humidity on Anopheles funestus mosquitoes' biting behaviour.

Interventions that are specifically targeted during times when mosquito activity and biting rates are at their peak are stressed by the study. This advice proposes putting safeguards in place during Anopheles funestus mosquitoes' peak activity periods, such as using bed nets, indoor residual spraying, or managing larval sources. The efficiency of control efforts can be increased by concentrating resources and actions during the times of day when mosquitoes are most likely to bite people.

Climate change adaptation. Given that temperature has an impact on mosquito behaviour, it is critical to include techniques for coping with climate change in malaria prevention programmes. Increased mosquito activity and longer transmission seasons could occur when temperatures rise. Consequently, management techniques should be modified to take shifting temperature patterns and their effects on mosquito populations into account. Based on climate estimates, this can include modifying the timing or strength of initiatives.

Environmental change, because humidity is important for mosquito reproduction and survival, efforts should be undertaken to change the environment to eliminate mosquito breeding locations. This can entail actions like effective water management, removing sources of standing water, and enhancing drainage systems. The mosquito population and consequent malaria transmission can be efficiently managed by reducing breeding places.

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