Correlation Analysis of Malaria Cases and Meteorological Factors in Lagos State, Nigeria.

Authors

Oluwatosin Onasanya¹, ², ⁴, Muhammad Sani Ibrahim², Ayo Stephen Adebowale³, Adefisoye Oluwaseun Adewole¹, Muhammad Shakir Balogun¹, ², Patrick Mboya Nguku¹, Olufemi Ajumobi¹, Ikeoluwapo Oyeneye Ajayi¹, ³.

Affiliations

1. Nigeria Field Epidemiology and Laboratory Training Programme, Abuja, Nigeria.
2. Department of Community Medicine, College of Health Sciences, Ahmadu Bello University, Zaria, Nigeria.
3. Department of Epidemiology and Medical Statistics, College of Medicine, University of Ibadan, Nigeria.
4. Department of Health Planning Research and Statistics, Lagos State Primary Health Care Board, Yaba, Nigeria.
Abstract

Background

Malaria transmission affects malaria infection rates. There are several potential drivers of malaria transmission. A suitable meteorological factor such as rainfall, temperature, and relative humidity encourages the breeding of the vector. This improves the survival of the parasite in the host. The female *Plasmodium falciparum* plays a crucial role in the variability of malaria prevalence. Lagos State is a coastal malaria-endemic area in Nigeria. This study presents a correlation analysis of malaria cases and meteorological factors between the periods of January 2015 to April 2018 in Lagos state.

Methods

The study was a secondary data analysis of meteorological variables and records of malaria cases reported by health facilities in Lagos state. We accessed weather variables through free access “weather underground.com” a meteorological data sharing service system (MDSSS). The MDSSS provides real-time online weather information from four meteorological monitoring stations in Lagos state. We accessed the malaria cases through the district health information system 2 databases. It is used to report cases of malaria by all the private and public health facilities in the state. We performed the correlation analyses to show the relationship between temperature, humidity, rainfall, and malaria cases at a 5% level of significance. We analysed data using the statistical package for social sciences version 25.
Results

Malaria cases peaked between the period of July to November 2016 and the period of April to May 2017 and declined between March to May 2017. The temperature, relative humidity, and rainfall showed a positive correlation with malaria cases. The temperature is most correlated with the occurrence of malaria cases ($r = 0.65$, $p < 0.02$).

Conclusion

This correlation analysis provides an approach for studying the impact of meteorological variability on the prevalence of malaria cases. This can help to forecast the malaria epidemic while preparing for the elimination of malaria in Lagos state.

Keywords: Malaria, Meteorological factors, Correlation, Malaria elimination.
Background

Malaria has remained a notable public health challenge. According to the 2019 malaria report, it affects about 228 million people worldwide (95% confidence interval [CI]: 206–258 million). It is the leading cause of morbidity and mortality among over 90% of the populace in Africa. Nigeria has the largest burden of malaria in West Africa because of poor prevention, and control measures. Occurring in Nigeria is over half of these malaria cases in West Africa. Endemic in Nigeria, malaria poses severity in vulnerable groups like pregnant women and under-five. Most Nigerians live in areas of mesoendemic transmission conversely, some live in areas of hyper-holoendemic transmission. The climatic factors relate to the seasonality and transmission of malaria. Invariable Nigeria accounts for several varying climatic conditions across states. In the last decade, there have been changes in malaria endemicity with variations in patterns of parasite risk across the various states. Studies show variation in the prevalence of malaria across the country. The prevalence of malaria in Lagos state is 5.4%, and Ogun State is 56.6%.

There is little information on the direct potential effects of weather factors on malaria incidence in Lagos state. The predisposing climatic factors of malaria are high temperature, high humidity, and persistent rainfall. An accurate weather prediction is an essential tool for planning malaria prevention and control, and for estimation of disease burden. There has been a huge financial commitment to eliminate the disease. Poor control practices, ineffective disease surveillance, and fluctuating environmental factors have made malaria to remain a major public health challenge. The entire population is at the risk of infection with malaria, but the vulnerability levels vary by age, place of residence, and atmospheric conditions.
have shown the seasonal variation of other tropical diseases like dengue fever and a host of others(9). There has been an association between annual variation in malaria incidences and climatic factors like rainfall and temperature(10). In this study, we conducted a correlation between temperature, humidity, rainfall, and the confirmed cases of malaria. The findings from this study will aid malaria programmers and Lagos state Government to implement effective control measures.

Methods

Study Area

Lagos state is in the Southwestern part of Nigeria, at the bay of Benin. The map of Nigeria showing Lagos state (Figure 1). It lies on longitude 3.406448 and latitude 6.465422. Ogun state borders it on the Northeast(10,11). Lagos state shares a border to the west with the Benin Republic(11). Lagos state has two major climatic seasons: dry season within the periods of November to March and wet season within the periods of April to October. The mean temperature range is between 17 and 36 °C. The mean annual rainfall is about 1300-1800 mm, even up to 25, mm in the coastal area. Malaria transmission is endemic in the state. *Plasmodium falciparum* is the main malaria species(2,12). Lagos state is one of the most populated states in the country(3,11,13) It has a population of 9,013,534, according to the 2006 National census(11). Lagos state has 20 LGA and 37 Local Council Development Areas as administrative units in the state(11). There are 256 functional public primary health centers, 26 public secondary facilities, 3 public tertiary facilities, and 2886 private facilities(14).
Study Design

The study was a secondary data analysis of meteorological variables and malaria cases. The data include the period between January 2015 and April 2018. We accessed data on the malaria cases from the District Health Information system-2 (DHIS-2). The database is open-source software used for reporting routinely collected facility data(15). The DHIS-2 platform displays data elements into the state, local government areas (LGA), and wards(15). The rollback malaria managers in the 20 LGA of the states report all malaria cases through the malaria surveillance system. They combine malaria reports into indicators and display them through tables on the Dhis-2 platform. We collected meteorological data online from the free access, “weather underground.com”. The database is a meteorological data sharing service system (MDSSS). The MDSSS forecasts and provides free, real-time online weather information from four meteorological monitoring stations in the state(16). These are Murtala Muhammed International Airport, Ikeja, Lagos yacht club, Lagos Island, Lekki, and Apapa(16). The distributions of the location represent Lagos state.

Data Abstraction

We extracted meteorological variables, monthly rainfall (mm), relative humidity (%), and temperature (°C). Malaria data included records of confirmed malaria cases attended to at the primary, secondary and tertiary centers compiled at the LGA level, and imputed to the Dhis-2 database monthly. Rollback malaria managers validate the malaria reports by routine data quality assurance across all the facilities in the state. Health workers confirm malaria cases either by rapid diagnostic tests or microscopically. We analyzed data using the Statistical Package for Social Sciences (SPSS version 25, Inc., Chicago, IL, USA).
Data Analysis

The monthly malaria cases were the dependent variable and meteorological variables (monthly temperature, relative humidity, and the mean rainfall) the independent variables. We estimated a monthly mean value. We represented the frequency distribution of the mean values of temperature, humidity, rainfall, and malaria cases on the line graph. We performed four rounds of analyses to show the relationship between mean temperature (mt), mean humidity (mh), mean rainfall (mr), and malaria cases at a 5% level of significance as shown in the equations below.

\[
\text{Malaria cases} = \beta_{01} + \beta_1 \text{mt} + \varepsilon_1 \quad (1)
\]

\[
\text{Malaria cases} = \beta_{02} + \beta_2 \text{mr} + \varepsilon_2 \quad (2)
\]

\[
\text{Malaria cases} = \beta_{03} + \beta_3 \text{mh} + \varepsilon_3 \quad (3)
\]

\[
\text{Malaria cases} = \beta_{04} + \beta_1 \text{mt} + \beta_2 \text{mr} + \beta_3 \text{mh} + \varepsilon_4 \quad (4)
\]

We analyzed the seasonal variation of the malaria cases within the additive time series model (Trend line = seasonal variation + observed malaria cases). We analyzed the seasonal variation to find the variation per quarter.
Results

The malaria cases in Lagos state vary across the months of the year studied. The trend in the malaria cases in the study period, from January 2015 to April 2018 (Figure 2). Malaria cases peaked between the period of July and November 2016 and the period of April and May 2017. In contrast, there was a steady decline in malaria cases between March and May 2017. The peak period of cases of malaria does not correspond to the wet season in Lagos state; conversely, the decline in malaria cases corresponds to the wet season. The trends of mean temperature mean humidity and mean rainfall January 2015–April 2018 (Figure 3). The variation in temperature, humidity, and rainfall against malaria cases over the months (Figure 4, 5, 6). The temperature has a stronger variation than other factors with a correlation constant of 0.4 (Figure 4).

Spearman Correlation

The mean temperature mean humidity and mean rainfall positively correlate with malaria cases over the study period. The mean humidity most correlated positively to the malaria incidence (r1 = 0.65, p<0.02) over the study period (Table 1).

Table 1: Correlation of meteorological factors and malaria cases in Lagos state Nigeria

|                | Mean temperature | Mean humidity | Mean rainfall | Malaria cases |
|----------------|------------------|---------------|--------------|---------------|
| Mean temperature | 1.00             |               |              |               |
| Mean humidity    | 0.39             | 1.00          |              |               |
| Mean rainfall    | 0.21             | 0.35          | 1.00         |               |
r=correlation coefficient, p<0.02

Linear Analysis

The mean temperature exhibited a strong positive correlation $R = 0.65$ and correlation coefficient $R^2=0.42$ with $p < 0.02$ (95% CI 64.69, 145.14). The mean humidity, exhibiting a medium positive correlation $R=0.50$ and correlation coefficient $R^2=0.25$ with $p < 0.02$ (95% CI 3.41, 12.32). The mean rainfall having the least positive correlation $R=0.41$ and correlation coefficient $R^2=0.17$ with $p< 0.02$ (4.17-25.36) (Table 2).

### Table 2: Correlation and regression analysis of the meteorological variables with malaria cases in Lagos state Nigeria January 2015 to April 2018

| Meteorological Variables | R  | R$^2$ | $\beta$ | Constant | Lower  | Upper  |
|--------------------------|----|------|--------|----------|--------|--------|
| (Non-adjusted Model)     |    |      |        |          |        |        |
| Mean temperature         | 0.65 | 0.42 | 104.91*| -1361.41 | 64.69 | 145.14 |
| Mean humidity            | 0.50 | 0.25 | 7.87*  | 964.32 | 3.41  | 12.32  |
| Mean rainfall            | 0.41 | 0.17 | 14.77* | 1429.42 | 4.17  | 25.36  |
| (Adjusted Model)         |    |      |        |          |        |        |
| Mean temperature         |    |      |        |          | 83.22*| 43.33  | 123.10 |
| Mean humidity            |    |      |        |          | 3.52  | -.506.0| 7.54   |
| Mean rainfall            |    |      |        |          | 8.48  | -.087.0| 17.05  |
| Constant                 |    |      |        | -1162.91| -2223.87| -101.93|


*Significant at 5%, R and $R^2$ for the adjusted $\beta$ is 0.74 and 0.55.

\[
\text{Malaria cases} = -1361.41 + 104.913 \times AT
\]

\[
\text{Malaria cases} = 964.32 + 7.87 \times AH
\]

\[
\text{Malaria cases} = 1429.42 + 14.77 \times AR
\]

\[
\text{Malaria cases} = -1162.91 + 83.22 \times AT + 3.52 \times AH + 8.48 \times AR
\]

**Trend Series**

The trend series by deseasonalization of data illustrates a positive trend with an increase in the cases of malaria and vice versa. The higher the size of the quarterly variable values, the more the expected cases of malaria. The data show that the highest reported cases of malaria occurred in the first quarter (January to March) and the lowest cases in the second quarter (April to June). Similar trends occurred in the first and third quarters (Table 3).

**Table 3: Deseasonalization of the cases of malaria in Lagos state Nigeria January 2015 to April 2018**

| Year | Quarter 1 | Quarter 2 | Quarter 3 | Quarter 4 |
|------|-----------|-----------|-----------|-----------|
| 2015 | 193.33    | -176.67   | 102.67    |           |
| 2016 | 360       | -935.33   | 558       | 240.67    |
| 2017 | -287      | 623.67    | -393.67   | -372.67   |
| 2018 |           |           |           |           |
| Total| 73        | -118.33   | -12.33    | -29.33    |
| Mean | 24.33     | -39.44    | -4.11     | -9.78     | -7.25 |
Quarter variation

|          | +7.25 | +7.25 | +7.25 | +7.25 |
|----------|-------|-------|-------|-------|
|          | 31.58 | -32.19| 3.14  | -2.53 |

**Discussion**

The meteorological factor affects the seasonal and temporal patterns of infectious agents borne by a vector (17–19). Malaria thrives in tropics where the weather is hot and wet and makes inhabitants of that area prone to the disease. Meteorological factors affect the number and distribution of malaria according to the Intergovernmental Panel on Climate Change Fourth Assessment Report (19). Several other factors (such as changes in land use, population density, and human behavior) influence the distribution of disease vectors and the extent of infection (20).

The malaria incidence fluctuates over the months depending on the most favorable climatic conditions. This creates a pattern of infection transmission (12). The female Anopheles mosquito, the malaria parasite carrier, depends on a favorable climatic condition to transmit the malaria parasite to humans (21). Climate influences the three major aspects of the female Anopheles mosquito life cycle. It determines the seasonality and pattern of malaria infection. Thus, for Anopheles mosquitoes to thrive, for about 9-12 days there must be adequate rainfall for the breeding of the vector (20,21). This study showed that increased humidity and rainfall poses a risk to malaria infection. Other studies have shown also that increased precipitation predisposes to malaria infection (22,23). It has been demonstrated that rainfall and flooding resulted in about 30% more risk of an individual having a positive result of a malaria diagnostic test in areas affected by flooding (20,24). Research has shown that common water bodies, in the wet months and early dry months; aid the development of the parasite consequently affects its transmission in urban areas.
Rainfall creates mosquito-breeding sites (20). Climatic variables like rainfall have also affected temperature, and humidity as rainfall increases accordingly humidity increases (23,25).

The existence of a malaria parasite within the adult mosquito requires temperatures of $\geq 20\,^\circ C$ for *Plasmodium falciparum* $\geq 15\,^\circ C$ for *Plasmodium vivax* (26). Warmer temperature shortens the extrinsic cycle of the parasite that occurs in the female Anopheles mosquito. This increases the chances of the parasite surviving in the mosquito. This study observed that malaria cases increase with temperature increase.

In contrast, another study describes a lower temperature may favor the survival of the parasite in the mosquito which can translate to an increase in incidence (27). Temperature regulates the rate of development of the mosquito larvae and influences mosquito survival rates. Higher temperatures aid the rapid multiplication of the Plasmodium inside the vector (26). These two climatic variables create conditions that aid malaria transmission in endemic countries. Excessive rainfall or rainfall accompanied by thunderstorms can destroy the breeding sites of the malaria vector. Other studies have shown precipitation intensity and month of the year affect the existence of the malaria infection, whether in the wet or dry season (28).

Human behavior varies in various climates that may determine the exposure to the vector. Studies have shown warm climatic condition discourages the use of Long-lasting insecticide-treated nets (LLIN), increasing the likelihood of exposure to a mosquito bite (12).

Studies have shown a transmission model for predicting the impact of temperature and rainfall on the distribution of malaria vectors. Similar factors that have been recognized in studies have shown malaria vector and predictability of malaria infection to be socioeconomic development, drug resistance, and immunity of the human host (29). Other studies have shown that higher malaria
infection distribution does not only result from weather change but there are other key drivers of malaria infection such as economic situations, climate change, land conversion deforestation host movement, and demography(30).

As the World Health Organization (WHO) framework for malaria elimination stresses, most countries have diverse transmission intensity(31). Factors such as ecology, immunity, vector behavior, social factors, and health system characteristics influence both the diversity of transmission and the effectiveness of tools, intervention packages, and strategies in each locality(32,33). The WHO Framework goes further to encourage strategic planning and interventions appropriate for the diverse settings or strata within a country(2). This implies that the nature of malaria transmission in these strata will change as temperature, rainfall, humidity, and human response change(2). Countries not only need to adapt malaria activities to existing strata, but also be alert to changes in transmission and thus changes needed in strategies. Climate, vector habitat, and transmission changes affect vector control activities. The receptivity of an area (to vector control interventions) is not static but is affected by determinants such as environmental and climate factors. Case detection will become even more crucial as transmission drops and the success of elimination programs depends on identifying, tracking, and responding to remaining cases.

The data used is secondary data. The data is facility-based and there is the possibility of under-reporting of malaria cases and self-treatment of malaria in the community. The accessibility of the facility in the community can affect facility data. Some confounding factors might have influenced the results of the study. These include the impact of malaria control activities and other related interventions. Preventive practices such as distribution and use of LLIN and larviciding may be
responsible for the malaria pattern seen in this study. The accuracy of the Malaria surveillance system is a problem common to other low-income malaria-endemic regions.

**Conclusion**

This study describes a correlation of meteorological factors: temperature, humidity and rainfall, and malaria dynamics over a period. The measurement of the fluctuation of the climatic variables can predict Malaria incidence. Public health interventions can target months of likely high incidence. The State should direct resource allocations to the months with the highest malaria risk. In planning for eliminating malaria in Lagos State, prevention measures, indoor house spraying, larviciding seasonal chemoprophylaxis, community distribution of LLIN should target the first and third quarter months.

**List of Abbreviations**

DHIS 2 District health information system-2.

LLIN Long-lasting insecticide-treated nets.

MDSS Meteorological data sharing service system.

mh mean relative humidity.

mr mean rainfall

mt mean temperature.

WHO World Health Organization.
Declarations

Ethics approval and consent to participate

As the study was based on secondary data, no human subjects were involved and hence were exempted from human subject ethical requirements.

Consent for publication

Available

Availability of data and materials

All data supporting the conclusions of this study are available upon reasonable request.

Competing interests

The authors of this paper do not have any commercial interest or other associations which pose a conflict of interest in this paper.

Funding

There is no funding source.

Authors’ contributions

OO, SA conceived, analyzed, and drafted the manuscript, AA analyzed the data. MIS, OA, IO MS, and PS reviewed and critically edited the manuscript. All authors read and approved the final manuscript.

Acknowledgements

The authors appreciate the Lagos State meteorological data sharing service system for access to the study data.
Author’s Information

Corresponding Author

Dr Oluwatosin Onasanya,

winnchi@yahoo.com.

References

1. UNICEF. Malaria in Africa - UNICEF DATA [Internet]. UNICEF DATA UNICEF Data: Monitoring the situation of children and women. 2019 [cited 2020 Oct 20]. Available from: https://data.unicef.org/topic/child-health/malaria/

2. WHO | World malaria report 2018. WHO. 2019;

3. Indicator M, Indicators K. Nigeria Malaria Indicator Survey 2015 - Key Indicators Report [PR70] - PR70.pdf. 2015; Available from: http://dhsprogram.com/pubs/pdf/PR70/PR70.pdf

4. WHO. Fact sheet about malaria. Geneva: World Health Organization; 2016.

http://www.who.int/mediacentre/factsheets/fs094/en/. Accessed 5 Mar 2017. [Internet]. Available from: http://www.who.int/mediacentre/factsheets/fs094/en/

5. Malaria Indicator Survey. Geneva, Switzerland: World Health Organization; 2005.

6. Tompkins AM, Giuseppe F DI. Potential Predictability of Malaria in Africa Using ECMWF Monthly and Seasonal Climate Forecasts. [cited 2019 Jan 27]; Available from: http://www.ametsoc.org/PubsAcronymList

7. Onwujekwe O, Uguru N, Etiaba E, Chikezie I, Uzochukwu B, Adjagba A. The Economic Burden of Malaria on Households and the Health System in Enugu State Southeast
Nigeria. Fernandez-Reyes D, editor. PLoS One [Internet]. 2013 Nov 4 [cited 2019 Jan 27];8(11):e78362. Available from: https://dx.plos.org/10.1371/journal.pone.0078362

8. WHO | Fact sheet: WHO/UNICEF report “Achieving the malaria MDG target.” WHO [Internet]. 2015 [cited 2019 Jan 27]; Available from: https://www.who.int/malaria/media/malaria-mdg-target/en/

9. Wongkoon S, Jaroensutasinee M, Jaroensutasinee K. Distribution, seasonal variation & dengue transmission prediction in Sisaket, Thailand. Indian J Med Res [Internet]. 2013 Sep [cited 2019 Jan 27];138(3):347–53. Available from: http://www.ncbi.nlm.nih.gov/pubmed/24135179

10. Ngarakana-Gwasira ET, Bhunu CP, Masocha M, Mashonjowa E. Assessing the Role of Climate Change in Malaria Transmission in Africa. Malar Res Treat [Internet]. 2016 Mar 15 [cited 2019 Jan 27];2016:1–7. Available from: http://www.hindawi.com/journals/mrt/2016/7104291/

11. About Lagos – Lagos State Government [Internet]. [cited 2020 Sep 24]. Available from: https://lagosstate.gov.ng/about-lagos/

12. Prevention C-C for DC and. CDC - Malaria - About Malaria - Biology. 2020;

13. NATIONAL BUREAU OF STATISTICS [Internet]. [cited 2019 Jan 27]. Available from: http://www.nigerianstat.gov.ng/

14. LAGOS AND EQUITABLE HEALTHCARE SERVICES – Lagos State Government [Internet]. [cited 2020 Sep 24]. Available from: https://lagosstate.gov.ng/blog/2017/07/05/lagos-and-equitable-healthcare-services/

15. Collect, Manage, Visualize and Explore your Data | DHIS2 [Internet]. [cited 2020 Sep 24]. Available from: https://www.dhis2.org/
16. Local Weather Forecast, News and Conditions | Weather Underground [Internet]. [cited 2020 Sep 25]. Available from: https://www.wunderground.com/

17. Dhewantara PW, Marina R, Puspita T, Ariati Y, Purwanto E, Hananto M, et al. Spatial and temporal variation of dengue incidence in the island of Bali, Indonesia: An ecological study. Travel Med Infect Dis. 2019 Nov 1;32:101437.

18. Adeleye SA. International Journal of Advanced Research in Biological Sciences Global Climate Change and Changes in Disease Distribution: A Review in Retrospect. [cited 2020 Sep 25]; Available from: http://dx.doi.org/10.22192/ijarbs.2020.07.02.004

19. Cella W, Baia-Da Silva DC, de Melo GC, Tadei WP, Sampaio VDS, Pimenta P, et al. Do climate changes alter the distribution and transmission of malaria? Evidence assessment and recommendations for future studies [Internet]. Vol. 52, Revista da Sociedade Brasileira de Medicina Tropical. Sociedade Brasileira de Medicina Tropical; 2019 [cited 2020 Sep 25]. Available from: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0037-86822019000100251&lng=en&nrm=iso&tlng=en

20. Mattah PAD, Futagbi G, Amekudzi LK, Mattah MM, De Souza DK, Kartey-Attipoe WD, et al. Diversity in breeding sites and distribution of Anopheles mosquitoes in selected urban areas of southern Ghana. Parasites and Vectors [Internet]. 2017 Jan 13 [cited 2020 Sep 25];10(1):25. Available from: http://parasitesandvectors.biomedcentral.com/articles/10.1186/s13071-016-1941-3

21. Ateba FF, Sagara I, Sogoba N, Touré M, Konaté D, Diawara SI, et al. Spatio-temporal dynamic of malaria incidence: A comparison of two ecological zones in Mali. Int J Environ Res Public Health [Internet]. 2020 Jul 1 [cited 2020 Sep 25];17(13):1–21.
22. Yé Y, Louis VR, Simboro S, Sauerborn R. Effect of meteorological factors on clinical malaria risk among children: an assessment using village-based meteorological stations and community-based parasitological survey. BMC Public Health [Internet]. 2007;7. Available from: https://doi.org/10.1186/1471-2458-7-101

23. Kifle MM, Teklemariam TT, Teweldeberhan AM, Tesfamariam EH, Andegiorgish AK, Azaria Kidane E. Malaria Risk Stratification and Modeling the Effect of Rainfall on Malaria Incidence in Eritrea. J Environ Public Health [Internet]. 2019 [cited 2020 Sep 25];2019. Available from: /pmc/articles/PMC6466923/?report=abstract

24. Boyce R, Reyes R, Matte M, Ntaro M, Mulogo E, Metlay JP, et al. Severe Flooding and Malaria Transmission in the Western Ugandan Highlands: Implications for Disease Control in an Era of Global Climate Change. J Infect Dis [Internet]. 2016 Nov 1 [cited 2020 Sep 25];214(9):1403–10. Available from: /pmc/articles/PMC5079365/?report=abstract

25. Caminade C, Kovats S, Rocklov J, Tompkins AM, Morse AP, Colón-González FJ. Impact of climate change on global malaria distribution. Proc Natl Acad Sci USA [Internet]. 2014;111. Available from: https://doi.org/10.1073/pnas.1302089111

26. CDC - Malaria - About Malaria - Biology [Internet]. [cited 2020 Sep 24]. Available from: https://www.cdc.gov/malaria/about/biology/index.html

27. Beck-Johnson LM, Nelson WA, Paaijmans KP, Read AF, Thomas MB, Bjørnstad ON. The Effect of Temperature on Anopheles Mosquito Population Dynamics and the Potential for Malaria Transmission. Costa FTM, editor. PLoS One [Internet]. 2013 Nov 14 [cited 2019 Jan 28];8(11):e79276. Available from:
28. Paaijmans KP, Read AF, Thomas MB. Understanding the link between malaria risk and climate. Proc Natl Acad Sci USA [Internet]. 2009;106. Available from: https://doi.org/10.1073/pnas.0903423106

29. de Castro MC, Fisher MG. Is malaria illness among young children a cause or a consequence of low socioeconomic status? Evidence from the United Republic of Tanzania. Malar J [Internet]. 2012;11. Available from: https://doi.org/10.1186/1475-2875-11-161

30. Lowe R, Chirombo J, Tompkins AM. Relative importance of climatic, geographic and socio-economic determinants of malaria in Malawi. Malar J [Internet]. 2013 Dec 14 [cited 2019 Jan 28];12(1):416. Available from: https://malariajournal.biomedcentral.com/articles/10.1186/1475-2875-12-416

31. WHO | Global targets. WHO [Internet]. 2019 [cited 2019 Jan 27]; Available from: https://www.who.int/malaria/areas/global_targets/en/

32. Bui HM, Clements ACA, Nguyen QT, Nguyen MH, Le XH, Hay SI, et al. Social and environmental determinants of malaria in space and time in Viet Nam. Int J Parasitol [Internet]. 2011;41. Available from: https://doi.org/10.1016/j.ijpara.2010.08.005

33. Israel OK, Fawole OI, Adebowale AS, Ajayi IO, Yusuf OB, Oladimeji A, et al. Caregivers’ knowledge and utilization of long-lasting insecticidal nets among under-five children in Osun State, Southwest, Nigeria. Malar J [Internet]. 2018 Jun 18 [cited 2020 Sep 25];17(1):231. Available from: https://malariajournal.biomedcentral.com/articles/10.1186/s12936-018-2383-5
