Malaria patterns across altitudinal zones of Mount Elgon following intensified control and prevention programs in Uganda

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Research article

Keywords: Afromontane, ecohealth, malaria, ecotones, climate change, infectious diseases

Posted Date: February 19th, 2020

DOI: https://doi.org/10.21203/rs.2.23944/v1

Version of Record: A version of this preprint was published on June 17th, 2020. See the published version at https://doi.org/10.1186/s12879-020-05158-5.

Abstract

Background Malaria remains a major tropical vector-borne disease of immense public health concern owing to its debilitating effects in sub-Saharan Africa. In the recent past, the high altitude areas in Eastern Africa have been reported to experience dramatic cases of malaria. However, its patterns following intensified control and prevention interventions remains and the changing climate remains widely unexplored in these regions. This study thus analyzed malaria patterns across altitudinal zones of Mount Elgon, Uganda. Methods Times-series data on malaria cases (2011 - 2017) from five level III local health centers occurring across three altitudinal zones; low, mid and high altitude was utilized. Inverse Distance Weighted (IDW) interpolation regression and Mann Kendall trend test were used to analyze malaria patterns. Autoregressive Integrated Moving Average (ARIMA) model was used to project malaria patterns for a seven year period. Results On average, 66±69/1000 individuals suffered from malaria on a monthly basis. This was most pronounced in the months of May-August 89±88/1000 compared to the months of November-February (40±33/1000). Malaria patterns varied with season and altitude and declined over time across the three altitudinal zones. Observed cases, revealed an annual average of 587±750/1000; 345±321/1000 and 338±351/1000 cases in lower, mid and high altitudes respectively. Conclusions Despite observed decline in malaria cases across the three altitudinal zones, the high altitude zone became a malaria hotspot as cases variably occurred in the zone. The projections of malaria revealed declining patterns of malaria cases in all the altitudinal zones. Malaria control interventions thus ought to be strengthened and strategically designed to achieve no malaria cases across all the altitudinal zones. Integration of climate information within malaria interventions can also strengthen eradication strategies of malaria in such differentiated altitudinal zones.

Background

Malaria is an infectious disease that globally affects more than 200 million people and whose morbidity and mortality is most pronounced in Africa [1]. Through bites of infected mosquitoes, disease causing parasites are transmitted [2]. In 2013 alone, a total of 584, 000 deaths attributed to malaria occurred [2]. Interventions over the last decade have led to observed decline in the malaria burden in sub-Saharan Africa. However, it still remains a major public health threat of international and regional concern [4].

Malaria occurrence has traditionally been observed in the low-land areas, bogs and generally in the plains within the tropical regions [5]. Comparative analysis have shown the occurrence of such patterns in Africa, Latin America and Caribbean as well as in south east Asia [6] [7] [8] [9]. Meanwhile, the Afromontane areas characterized with unique biota [11], that had hitherto been known for being malaria free zones due to altitudinal effect, have seen increased malaria incidences with some areas experiencing a rise while others declining [12] [13]. Malaria cases have lately been observed to be on the rise in the afromontane ecotones within sub-Saharan Africa such as in the Rwenzori highlands of south western Uganda [14][15]. Similar patterns have been experienced in the neighboring highlands of Butare (Rwanda) as well as in the Mount Kilimanjaro area (Tanzania) [16, 17]. These patterns in malaria have led to increased cost of malaria interventions [18, 19]. Such trends have been attributed to climate change that is creating ambient conditions within the highland altitudinal belts [17].

Malaria in Uganda has been endemic in the savannah areas of northern and eastern Uganda especially in Apac district, followed by Tororo district [20]. All these areas are within 1,100 m altitude. However, highland areas especially Elgon region have experienced a surge in malaria cases despite intensified interventions by both government, private sector and development partners [15]. Climate has been pointed out as a key risk factor for spatial-temporal patterns of malaria, especially in the highland areas [18]. Studies [19, 20] on malaria patterns in different mountainous areas have been undertaken but only a few [21, 22] have focused on the patterns of malaria within different altitudinal zones (ecotones). Yet ecotones are characterized with varying environmental conditions that can influence mosquito biology and malaria patterns [23, 24]. These studies have not documented patterns of malaria following intensified control and prevention interventions in mountainous areas such as Elgon region. This study analysed malaria patterns across altitudinal zones of Mount Elgon following intensified control and prevention interventions in the area.

Methods

Study area

The study was undertaken in the Mount Elgon highland region within Kween District located between 0125N and 3431E (Figure 1). Kween district borders the districts of Nakapiripirit to the north, Amudat to the northeast, Bukwo to the east, Kapchorwa to the west and Bulambuli to the northwest [22]. In the South, it boarders the Republic of Kenya and it is located on the northern slopes of Mount Elgon, at an average altitude of about 1,900 meters (6,200 Feet) above sea level [22]. It has administrative units ranging from Sub county, Parish and village [23] The area is characterized by high and well-distributed rainfall (averaging 1,200 mm/year) and consists of two seasons, a rainy season (March–September) and a dry season (October–April) [25]. It has cool temperatures which are on average 17˚C [26]. The human population of the district has been rising in the last three census conducted; 1991, 2002 and 2012 from 37,300, 67,200 to 103,300 respectively [27]. Its population is majorly consisting of subsistence farmers cultivating a range of crops including: maize, beans, bananas, wheat, barley and cowpeas and also rear some livestock [22]. The district has health centers with levels: IV, III and II with numbers amounting to 1, 9 and 13 respectively [22]. These health centres are supported by a team of village health teams also known as heath service providers constituting Health Center I and are mainly responsible for mobilization of communities to access health services.

Study design

This study employed a retrospective cross-sectional study design utilizing past records from health center IIIs across the three altitude zones (High, Middle and Lower) of Mount Elgon [28]. Data on climate variables was obtained across seven years (2011 to 2017). Data on confirmed malaria cases (using both microscopic and rapid diagnostic kits) from 2011 to 2017 was considered for this study and were computed to average number of true malaria cases per 1000 for each of the altitudinal zones. The rates of malaria cases was computed per month for each year. Climate data was obtained in retrospect for the seven year period (2011 to 2017). Rainfall and temperature parameters were the key climate parameters considered in this study as they play key roles in influencing breeding and survival of mosquitoes [29]. Analysis for the spatial temporal patterns was computed at parish level across the three altitudinal zones in the study area. Confounding factors like human population were checked for their effect on the patterns of malaria incidences. There was however no effect of human population on the spatiotemporal patterns of malaria in the study area. Forecasts for malaria were made using ARIMA models for a period of 7 years (84 months) from the year 2017 [30]. Rates of malaria and time in terms of months were included in the model to understand the trends.

Data collection

In this study, health centers from where data was collected were purposively selected basing on their capacity to confirm and report malaria cases, as well as the volume of their malaria records. Accordingly, the most suitable health centres that were used to collect data were the health center IIIs owing to their capacity to conduct malaria tests (both microscopic and Rapid Diagnostic Test kits). The cases selected for this study at least underwent through one of these tests but not both. These health centres were also fairly well distributed across the different altitude zones divided into higher (above 7150ft), middle (between 4317-7150ft) and lower altitudes (below 4317ft) in the district. Data was then collected from four out of nine Health Center IIIs in the four sub-counties of Benet, Binyiny, Kwanyiy and Ngenge. Data on the number of malaria cases for the past seven years was obtained from the Health Center IIIs records. Data collected included; malaria occurrence, parish of residence, tests as well as a range of socio-demographic characteristics (gender, age and location) of each patients were obtained for a period of seven years.

Data for climate variables (temperature and rainfall) was obtained from the Uganda National Meteorological authority [27].

Data analysis

Malaria patterns were determined using descriptive statistics of means and standard deviations (SD). These were compared across different altitudinal zones; low, mid and high altitude. Mean malaria cases per month per 1000 cases were computed over the years (2011 to 2017) for each of the three altitude zones (Higher, Middle and Lower). Secondly, in order to depict the spatial-temporal variation of malaria cases, an Inverse Distance Weighted (IDW) interpolation regression [28] at a distance of 15km was undertaken. The IDW is a deterministic regression procedure that estimates values at prediction points (V) using the following equation [29]: (see Equation 1 in the Supplementary Files)

Where d is the distance between prediction and measurement points, V_1 is the measured parameter value, and p is a power parameter. The advantage of IDW is that it uses non-Euclidean “path distances” for d. These path distances are calculated using an algorithm that accounts for the malaria cases from one cell to the next [30]. Trend analysis were done similarly to the approach by [35]. The average monthly numbers of malaria cases per 1000 were calculated for the full time-series (January 2009–December 2015). These were plotted to show temporal patterns in malaria and climate variables. The time series of malaria incidence was decomposed using seasonal-trend decomposition based on locally weighted regression to show: the seasonal pattern, the temporal trend and the residual variability. The time series data, the seasonal component, the trend component and the remainder component are denoted by Y_t, S_t, T_t, R_t respectively, for month t = 1 to N, and:

$$Y_t = S_t + T_t + R_t$$

The parameter setting "periodic" was used for the seasonal extraction, and all other parameters were by default. In the study, logarithmic transformations were used for the time series data [35].

Mann Kendal trend test [36] was used to depict the actual trends of the climate parameters and malaria. Relational analysis for malaria, temperature and precipitation was done in XLSTAT [37].

Results

Time series decomposition of malaria patterns revealed existence of seasonality of malaria across the years (2011 – 2017) in all the altitude zones (Figure 3). The number of cases of malaria declined from 2011 to least number of cases towards 2017 (Figure 3). There was statistical significant difference ($p<0.05$) in the number malaria cases per 1000 individuals across the three altitude zones (lower, mid and higher altitude) in each of the years (2011-2017) except the years 2013 and 2017 (Table 1 and Figure 2).

The cases of malaria per 1000 in high, mid and lower altitude were 49 (SD = 40), 67 (SD = 55) and 84 (SD = 96) respectively. Malaria cases revealed a normal curve-shaped trend over each year in the three areas (lower, middle and higher altitude areas) (Figure 3). Also the months of June revealed highest numbers of malaria cases (94, SD = 73; 103, SD = 73 and 128, SD = 134 in high, mid and lower altitudes respectively) over the years (2011 to 2017). The months of January (41, SD = 29; 45, SD = 41 and 52, SD = 67 in high, mid and lower altitudes respectively) and December (28, SD = 23; 29, SD = 21 and 38, SD = 23 in high, mid and lower altitudes respectively) had the least number of malaria cases.

Spatial variation of malaria (Figure 4) revealed higher number of cases of malaria in the lower altitude areas of Kween district. Higher and mid-altitude areas of the district had relatively lower number of malaria cases (49, SD = 40 and 67, SD = 55 respectively), while lower altitude areas had the highest (84, SD = 96) number of malaria cases. The trends however declined from 2011 to 2017 in all the altitudinal zones (Figure 4).

Mann-Kendal trend test revealed a Sen's slope of -29.0 and -10.9 (CI = 0.95) for malaria cases in the periods of March to September and October to February respectively in the higher altitude areas of Kween district. It also revealed a drastic decline of malaria cases over the seven year period (from 2011 to 2017) with Sen's value of -21.5 (CI = 0.95). In the middle altitude areas, the Sen's slope were -44.8, -56.0 and -29 annually, March to September, and October to February respectively (CI = 0.95). In the lower altitude, the Sen's values were -87.8, -120.7 and -41.9 annually, March to September and October to February respectively (CI = 0.95).

Malaria cases, rainfall and temperature interaction in different altitude zones

The mean temperatures in higher, mid and lower altitude areas of Kween district between 2011 and 2017 were 15.7°C (SD = 2.8), 18.4°C (SD = 1.3) and 21.4°C (SD = 1.8), respectively. Higher altitude areas experienced a very low positive correlation (0.47) between precipitation and number of malaria cases (Table 2 and Figure 5). Similarly, there was a very low negative correlation (-0.46) between temperature and number of malaria cases. Annually, there was a high positive correlation (0.79) between number of malaria cases and precipitation. The relationship between temperature and malaria cases showed a negatively high correlation (-0.84).

For mid-altitude there was a very low positive correlation (0.47) between precipitation and malaria cases (Table 2 and Figure 5). Similarly, there was a low negative correlation (-0.64) between temperature and malaria cases. Also annually, there was a low positive correlation (0.59) between precipitation and malaria cases. Meanwhile, temperature and malaria cases showed a negatively low correlation (-0.45).

Lower altitude reflected a positively high correlation (0.72) between precipitation and malaria cases (Table 2 and Figure 5). Similarly, there was a negatively high correlation (-0.78) between temperature and malaria cases. Annually, there was a positive moderate correlation (0.70) between malaria cases and precipitation. Meanwhile, temperature and malaria trends showed a negatively high correlation (-0.83).

Forecasting of malaria patterns

Forecasts for all the three altitudinal zones revealed malaria cases to continue to decrease if the conditions were kept constant and/or intervention efforts are strengthened (Figure 6). However, relaxation of the malaria control interventions would greatly allow for more increased number of cases of malaria (Figure 6).

Discussions

There was a declining number of malaria cases across all the altitudinal zones during the study period. This can be attributed to the intensified malaria control and prevention interventions within the area. Such patterns are similar to results in other studies in western Kenya on the Elgon area [38]. Malaria patterns revealed a normal curve trend of malaria with the highest peak being in the middle (June-August) of each of the seven years (Figure 3). This corresponded to the trends in temperature and precipitation. However, the months of January and December had the least number of malaria cases. This can be linked to the low precipitation amounts during this period limiting availability of water for breeding of mosquitoes.

This trend is similar to the results by [31] for the whole country (Uganda). This can be linked to the conditions suitable for growth and development of mosquitoes. Increase in temperature and availability of water sources favors mosquito breeding and its transmission of malaria parasites [40]. Results of this study revealed an overall malaria decline in the seven years of analysis. Similarly, analysis performed by [31] had shown declining trend in malaria over Uganda. These patterns could be attributed to significant intervention efforts by the Ministry of Health in malaria prevention and control through increasing access to health services including basic diagnostics, provision of insecticide-treated mosquito nets [34].

Spatially, the hotspot of malaria varied over the seven year period dominating the lowland areas of the district (Figure 4). The highland areas had lower number of malaria cases compared to the lowland areas. There was a positive correlation between malaria patterns in the lower belt and temperature. Temperature plays a key role in malaria transmission by influencing vector and parasite life cycles. Studies have highlighted the biological amplification nature of temperature on mosquitoes [32]. This study showed that the mean temperatures within the three altitudes varied. The difference in the contribution of maximum temperature to malaria cases between different altitudes is attributed to the differences in prevailing temperatures in the three zones. The study area (Kween district) being colder, temperature was probably the limiting factor in malaria vector development in the highland and lowland areas; hence a rise in the maximum temperature increased vector and parasite development rates [33]. Since temperature influences the development and survival rates of both vectors and parasites, malaria transmission rates tend to increase with increasing temperature but up to a given threshold [34].

The highland areas of the district that experienced a decline can be attributed to the increased malaria control interventions like use of mosquito nets. The question on existence of malaria in the higher altitude areas in East Africa raised by [36] is thus partly answered by this study.

Relational analysis results revealed a positive association between precipitation and malaria patterns (Table 2 and Figure 5). Malaria cases were more pronounced in the lower altitude zones compared to the higher altitude zones. This can probably be linked to environmental conditions favorable for mosquito growth and development. This result is in agreement with previous studies in Kabale, a highland region in southwestern Uganda [31] where lowland areas expirience higher number of malaria cases compared to highland areas. The alternating trends can be alluded to temperature and precipitation as the latter can either favor or discourage optimal growth and development of mosquitoes. [37] notes that mosquito growth and development greatly depend on ambient air temperature and rainfall not forgetting any changes within the norm greatly affects mosquito growth and development which in turn affects the malaria incidence in malaria endemic areas [38].

Forecasts of malaria patterns revealed a continued decline of malaria cases given conditions are remain constant. However, the number of malaria cases may significantly explode if temperature and rainfall increase. This implies that interventions at this point ought to be intensified. There is also a window of opportunity for eradication of malaria in the event that the existing control and prevention interventions are intensified. This thus calls for more studies to inform modification of the interventions.

One of the limitations of this study was the use of data from ministry departments in Uganda. There is therefore no proof of validity of this data as some of it was not complete. However, it gives a general picture of what can be done so as to curtail malaria infections within high altitude areas.

Conclusion And Recommendations

Malaria patterns decreased in all the zones. Also, malaria belt was highly variable in in the altitudinal zones with the higher altitude areas becoming hotspots at some points. This calls for strengthening of malaria control interventions irrespective of altitudinal ranges. The government of Uganda ought to design strategic malaria interventions to cater for different altitude zones. More large-scale studies should be undertaken in an attempt to understand the factors associated with such variations of malaria in different altitudinal zones. These studies should ensure validity of data by undertaking prospective studies within the population.

Declarations

Ethics approval and consent to participate

The study was approved by the Research Ethics Committee of Makerere University College of Veterinary Medicine, Animal Resources and Biosecurity (Reference number SBLS.SA.2018). The study followed guidelines and regulations stated in the approval document. Written and informed consent was also obtained from participants to participate in this study. Written and informed consent was sought from the participants to publish and disseminate the research findings.

Consent for publication

Informed consent from participants was obtained after information about the study was availed to respondents.

Availability of data and materials

The datasets used and analyzed during this study are available from corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interest.

Funding

The study was privately funded by the corresponding author.

Authors' contributions

AS designed the study, supervised the data collection, analysis and interpretation. AS wrote the first draft. AE, BJK and ATL participated in the data analysis and interpretation of results and assisted in manuscript write-up., BS assisted in drawing the maps for spatial distribution analysis. All authors read and approved the final draft.

Acknowledgement

Special thanks go to Ministry of Health Uganda, Uganda National Meteorological Authority, Kween district local government, and health service providers for providing data for malaria and weather. Also thanks to Makerere University College of Veterinary Medicine, Animal Resources and Biosecurity for providing necessary documents for this study.

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Tables

Table 1: Patterns of malaria cases across three altitudes (lower, middle and higher altitude in Kween district

Year	Lower altitude	Mid altitude	Higher altitude	P-value
2011	192±111	107±51	60±30	0.0004
2012	188±108	104±48	58±27	0.0003
2013	113±53	106±41	91±53	0.5268
2014	40±19	98±42	79±23	0.0001
2015	6±3	19±11	7±4	0.000
2016	23±13	13±5	26±17	0.0571
2017	23±11	17±10	21±9	0.3558

Table 2: Correlation between climate variability and malaria cases in Kween district

Altitude and time	*Variable*	*T*	*Df*	*P-value*	*Corr.*
Higher altitude					
Monthly	Precipitation and malaria	1.69	10	0.1219	0.4713
	Temperature and malaria	-1.65	10	0.1305	-0.4620
Annually	Precipitation and malaria	2.89	5	0.0343	0.7906
	Temperature and malaria	-3.49	5	0.0175	-0.8418
Mid altitude					
Monthly	Precipitation and malaria	1.70	10	0.1208	0.4725
	Temperature and malaria	-2.70	10	0.0224	-0.6492
Annually	Precipitation and malaria	1.70	5	0.1605	0.5930
	Temperature and malaria	-1.13	5	0.3091	-0.4516
Lower altitude					
Monthly	Precipitation and malaria	3.30	10	0.0080	0.7219
	Temperature and malaria	-3.91	10	0.0029	-0.7773
Annually	Precipitation and malaria	2.16	5	0.08	0.6955
	Temperature and malaria	-3.28	5	0.02	-0.8264

Figures

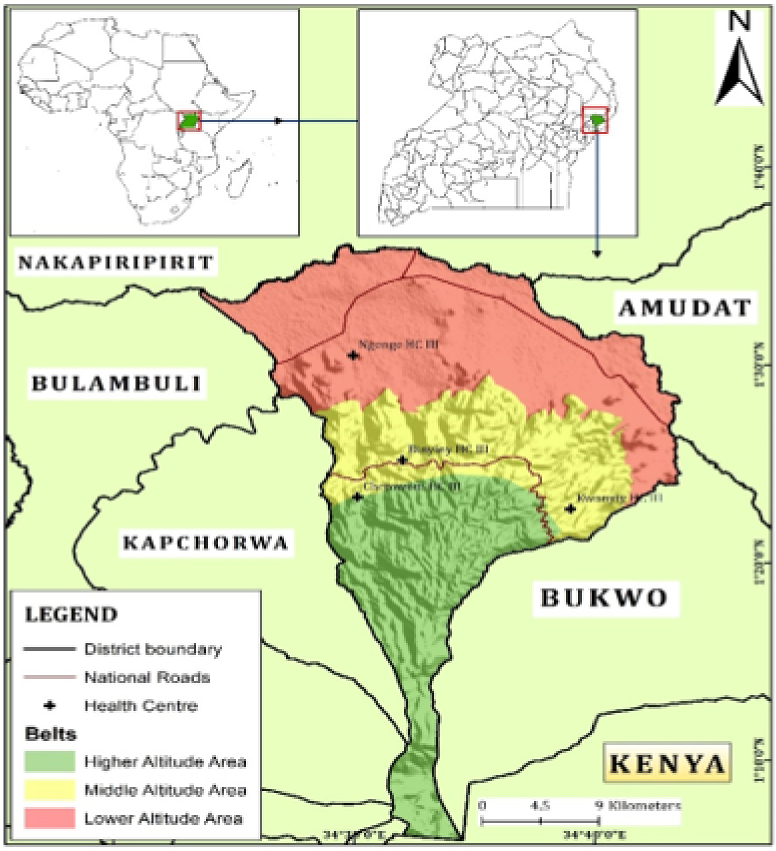

Figure 1

Location of Kween district

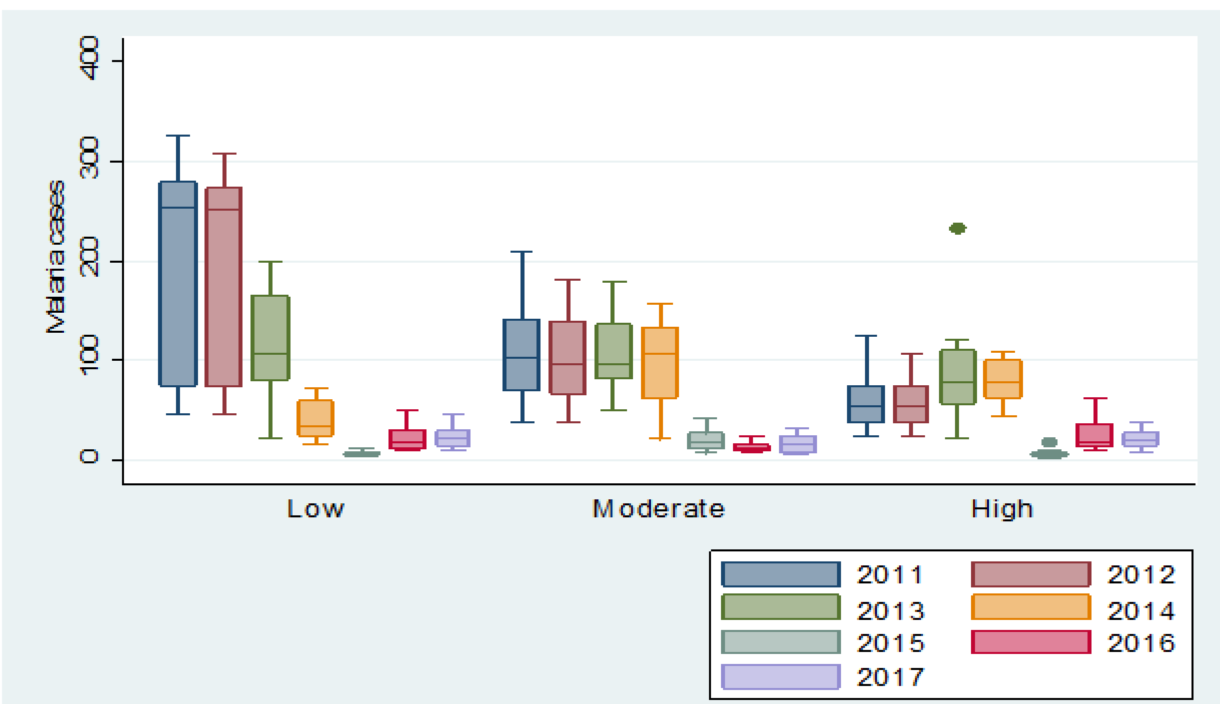

Figure 2

Malaria patterns across different altitudes (Low = Lower, Moderate =Middle altitude, High = Higher altitude) in Kween district (Low = Lower, Moderate =Middle altitude, High = Higher altitude)

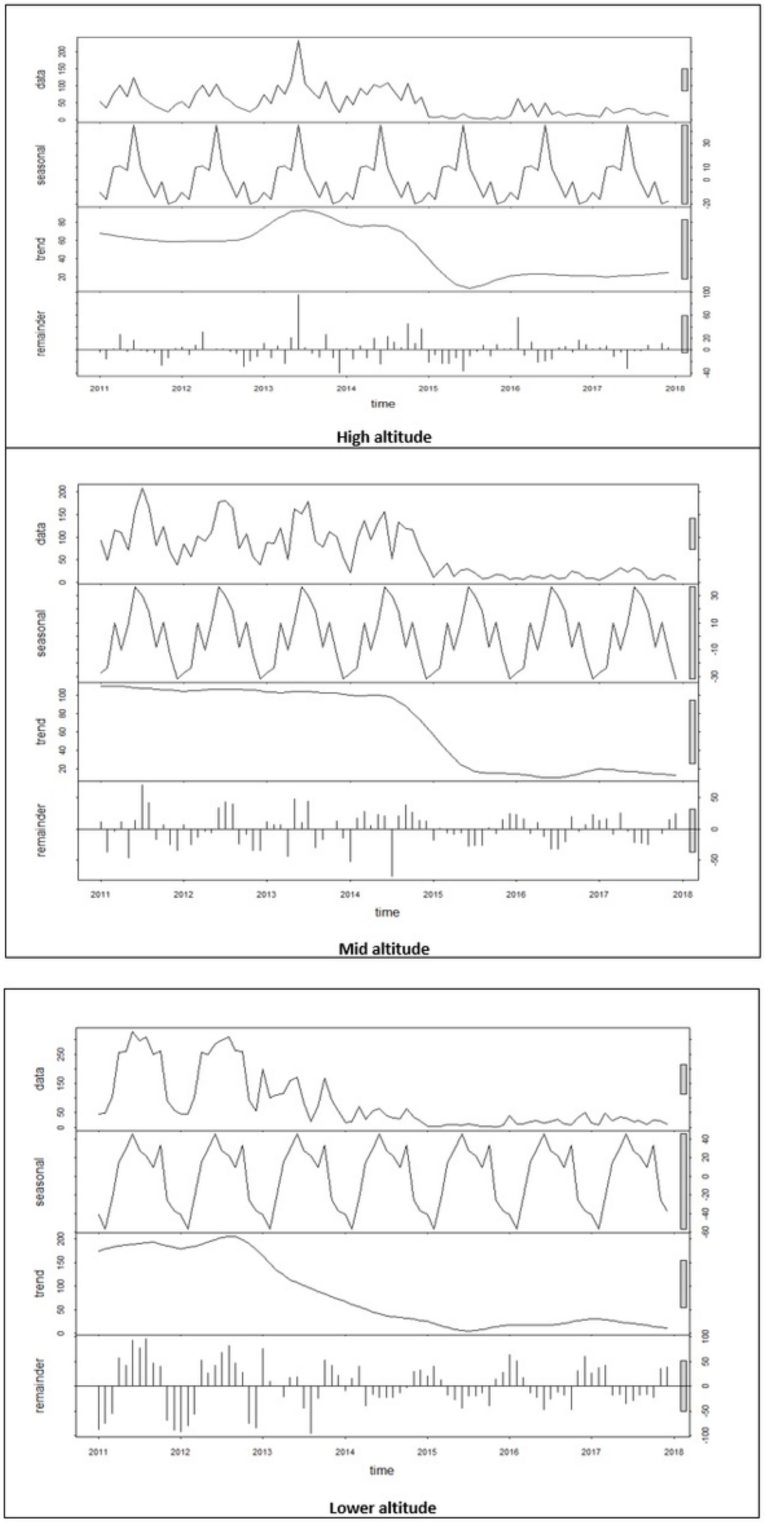

Figure 3

Annual trends in malaria cases in different altitudes in Mount Elgon from 2011 to 2017

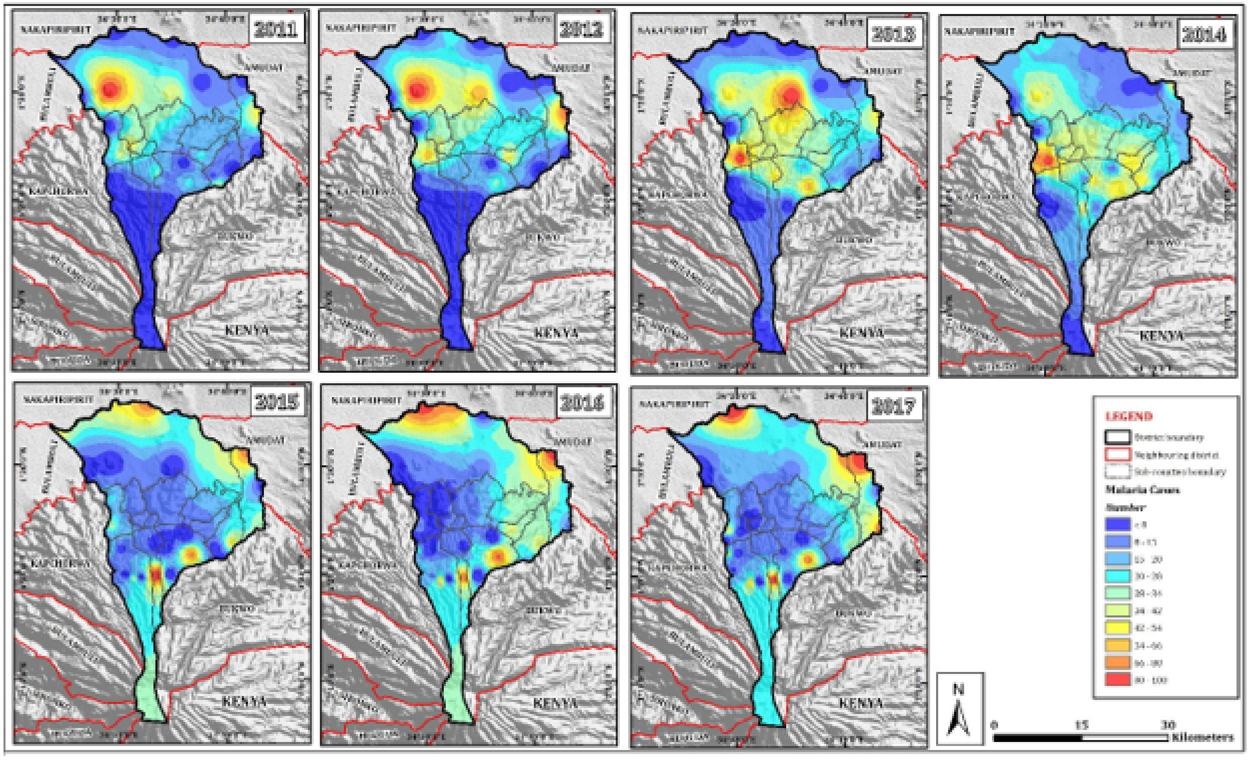

Figure 4

Spatial variation of malaria cases from 2011 to 2017 in Kween district

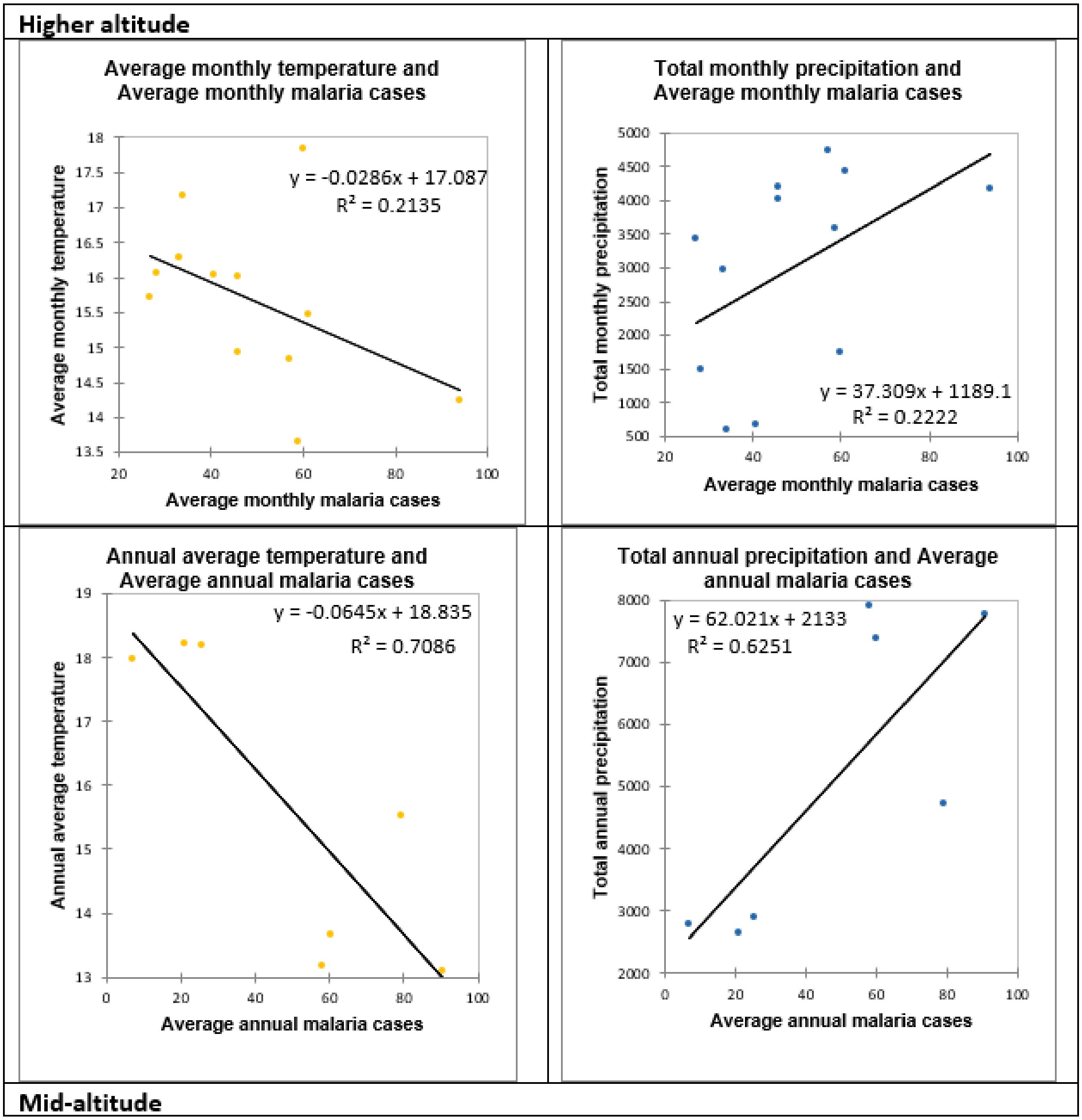

Figure 5

Correlation between climate variability and malaria patterns in Kween district

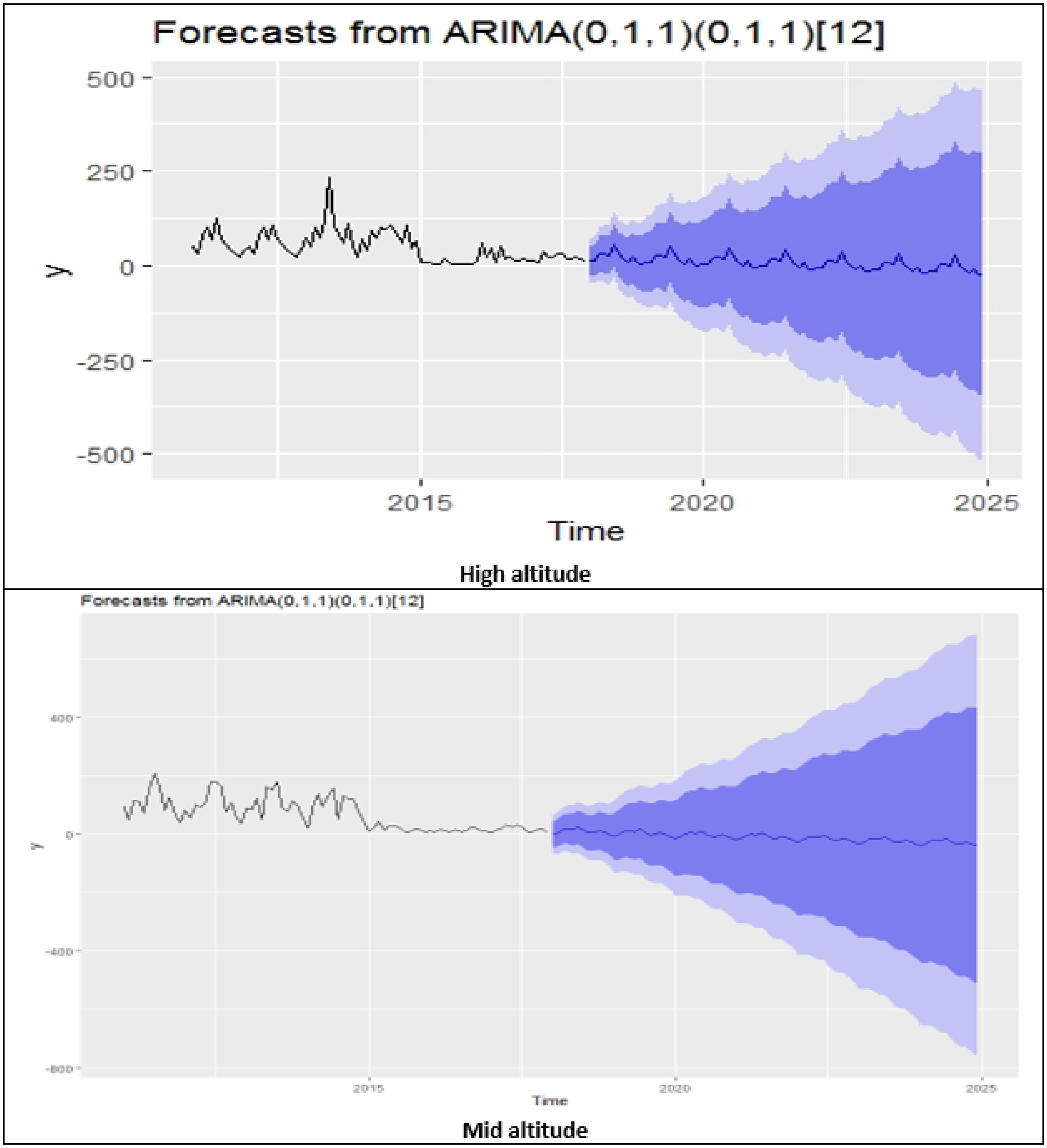

Figure 6

Forecasts for malaria patterns in different altitude zones (lower, mid and higher altitude)

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Equation1.jpg