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Malaria Vector Species Distribution and Seasonal Population Dynamics across Varied Ecological Zones in Baringo County, Kenya

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Abstract Vector populations fluctuate on a seasonal basis annually. Knowledge on seasonal abundance and distribution of vector species at the local level would improve vector control programmes and contribute to malaria prevention. Despite this, information on malaria vector species distribution and seasonal fluctuations in Baringo County is scarce. This study examined distribution and seasonal abundance of malaria vector species in Baringo. The study area was stratified into four ecological zones namely; lowland, riverine, midland and highland. Monthly collection of outdoor and indoor mosquitoes was conducted between June 2015 and May 2016 using CDC light traps and pyrethrum spray collection respectively. A total of 6,113 anopheline mosquitoes belonging to four species were collected across the four ecological zones. *Anopheles gambiae* was the most abundant malaria vector species accounting for (93.8%) while *An. pharoensis* and *An. funestus* accounted for 4.8% and 1.1% respectively. Mosquitoes were mainly collected from lowlands (79.8%) and riverine (19.0%) zones. Malaria vector abundance was higher in the dry season compared to the rainy season. *Anopheles gambiae* abundance showed high positive correlation with rainfall in the riverine zone only (r=0.7). Knowledge gained from this study, on malaria vector species distribution and seasonal abundance at local level, is important in implementation of control strategies against malaria by the Baringo County Health Department. The findings highlight the seasons when malaria cases are likely to be higher due to vector abundance and also inform specific areas to target for intervention.

Keywords Malaria; Vectors; Abundance; Distribution; Season; Baringo

Background

Mosquitoes are the most important group of biting diptera as they transmit a variety of diseases including malaria. About 60 mosquito species have been implicated in malaria transmission around the world (WHO, 1997). The dominant *Anopheles* vectors of human malaria in Africa are *An. gambiae* and *An. funestus* complexes (Gillies and Coetzee, 1987; Sinka et al., 2010). In Kenya, common mosquito species transmitting malaria are *An. gambiae* s.s. *An. arabiensis* and *An. funestus* s.s. (Mbogo et al., 1995; Okara et al., 2010). Two other species which have been reported in some parts of Kenya include *An. pharoensis* and *An. coustani* (Aniedu, 1992; Mwangangi et al., 2013).

The distribution and abundance of the mosquito vectors that transmit diseases are affected by various climatic factors (Minakawa et al., 2002). This may lead to seasonal variability in vector abundance and hence the epidemiology of vector borne diseases (VBDs) such as malaria (Githeko et al., 2000). Thus, effective VBD control measures require knowledge on mosquito vector species distribution and seasonal abundance at a localized scale (Coetzee et al., 2000; Kigadye et al., 2010). Several factors affect mosquito abundance either singly or synergistically. These factors include climatic variables such as rainfall, temperature (Minakawa et al., 2002; Lehmann et al., 2014) and altitudinal location (Protopopoff et al., 2007; Gone et al., 2014) which indirectly influences climatic factors. Information on the interaction of these factors and their influence on vector abundance and distribution in Baringo County of Kenya is crucial in mosquito vector control. Although several studies have been conducted on distribution, diversity, ecology and seasonal abundance of malaria vectors in parts of Baringo (Aniedu, 1992; Aniedu, 1993; Arum et al., 2010; Mala et al., 2011), none has covered the entire County

effectively. These studies have largely focused on entomological surveys around the lake regions in the lowland zone implying that vector distribution and population dynamics in the riverine, midland and highland zones within the County has not been established. The current study investigated the distribution and seasonal population dynamics of malaria vectors in four ecological zones, based on elevation, in Baringo County, Kenya.

1 Materials and Methods

1.1 Study area description

The study was conducted within Baringo County of Kenya (Figure 1), lying between 35.602 ℉-36.277 ℉ and 0.541 ℕ-0.723 ℕ at altitudes of between 870 and 2,499 m above sea level (asl). The study area was subdivided into four ecological zones on the basis of altitude. The four zones were: lowland zone lying at an elevation of 1,000 m asl and below, the mid altitude zone lying between 1,000 m and 1,500 m asl, the highland zone lying between 1,500 m and 2,300 m asl, and the riverine zone lying between 1,100 m and 1,200 m asl (Ochieng et al., 2016). There are four lakes within the study area, two of which are permanent (Lake Baringo and Lake Bogoria) while the other two are seasonal (Lake 94 and Lake Kamnarok). Most rivers in the area cease to flow during the dry season and are often characterized by pockets of small pools along the riverbed that provide suitable breeding micro-habitats for mosquito vectors. The mean annual rainfall is about 650 mm with temperature ranging between 30 ° to 37 ℃. Rainfall pattern is bi-modal with the long rain season occurring between March and May and one short rain season that is experienced between September and November. Rainfall varies from 1,000 mm to 1,500 mm in the highlands to 600 mm per annum in the lowlands (Baringo, 2014).

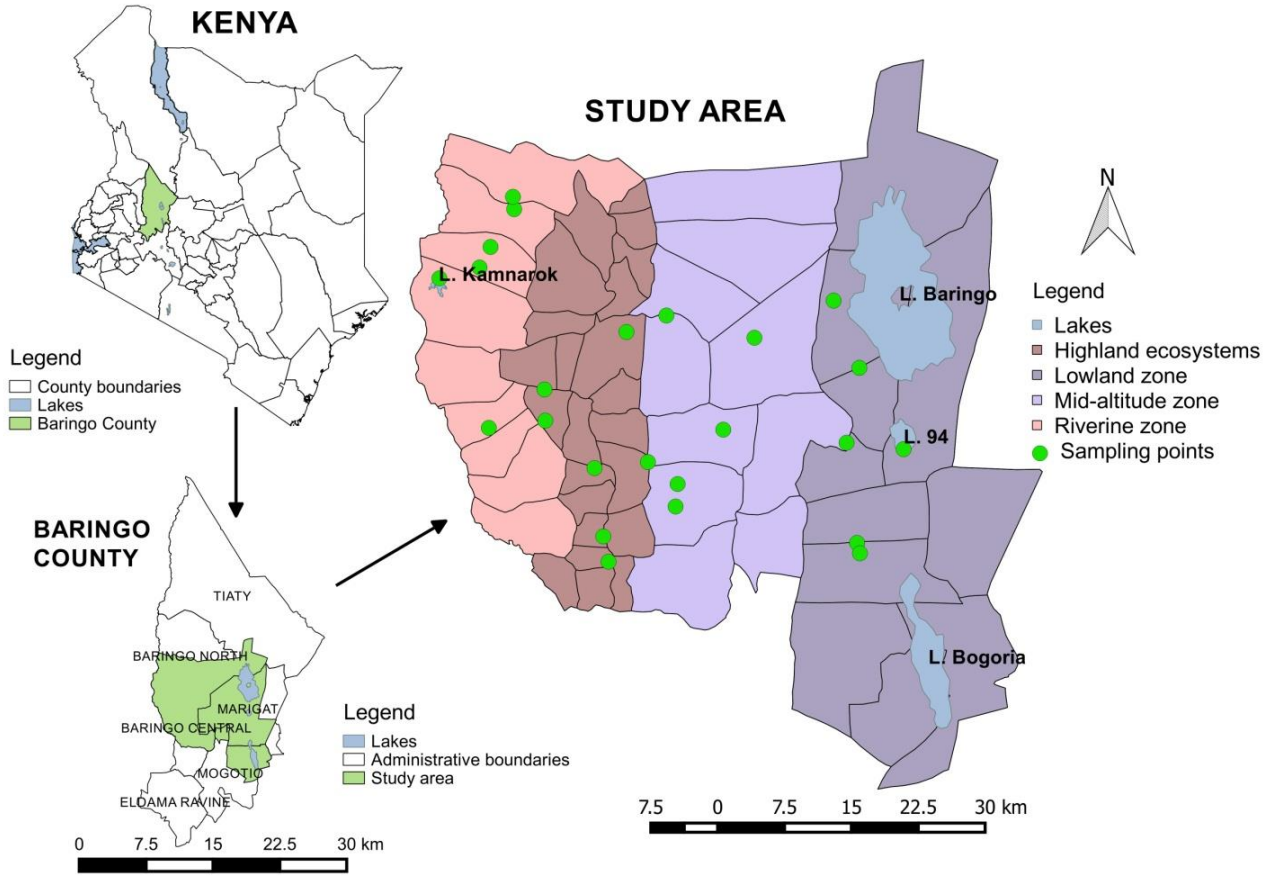

Figure 1 Map of study area showing sampling points within Baringo County

1.2 Sampling design, mosquito collection and identification

The study area was stratified into four ecological zones namely; lowland, riverine, midland and highland based on elevation. Six sampling points were randomly selected from each of the four zones to make a total of 24 sites. Outdoor and indoor resting mosquitoes were sampled monthly for a period of 12 months; between June 2015 and

May 2016. Different types of houses were randomly selected around potential breeding habitats and sampled by pyrethrum spray collection (PSC) method while outdoor resting mosquitoes were collected using the CDC light traps. Indoor sampling was conducted in the selected houses between 0600-0830 hours while outdoor sampling was done between 1800-0600 hours during the night preceding indoor sampling. All mosquitoes were identified morphologically to genus or species level under a dissecting microscope using taxonomic keys (Gillies and Coetzee, 1987).

1.3 Temperature and rainfall data acquisition

Monthly temperature was sourced from the International Research Institutes (IRI) of Climate and Society's database (Ceccato et al., 2010; Funk et al., 2014) to cover the study period (12 months). The monthly average rainfall data used was obtained from University of California Santa Barbara (UCSB) Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) v2p0 (Funk et al., 2014) for the study duration.

1.4 Statistical analysis

Relative abundance of the species was expressed as the percentage of the total number of mosquitoes collected. Generalized linear model with negative binomial distribution was fitted to assess the effect of season on malaria vector abundance while linear regression was used to assess the relationship between monthly rainfall and temperature with malaria vector population dynamics. Variation in vector abundance between indoor and outdoor mosquito collections was compared by Student *t*-test. Only *Anopheles gambiae* was used in analysis as it was the most abundant malaria vector species while *Anopheles funestus* and *Anopheles pharoensis* were excluded from statistical analysis due to their low numbers. Malaria vectors were mainly collected from lowland and riverine zones so midland and highland, which had negligible numbers of malaria vector mosquitoes, were not included in the analysis.

2 Results

2.1 Malaria vector species distribution in Baringo County

A total of 6,113 anopheline mosquitoes belonging to four species were collected from both indoor and outdoor resting places across the four ecological zones. Among the four species, three were malaria vectors namely; *Anopheles gambiae* s.l., *An. pharoensis* and *An. funestus*. *Anopheles gambiae* s.l. (93.8%) was the most abundant species of the three malaria vectors and was collected from all four ecological zones. *Anopheles gambiae* s.l. accounted for 88% and 90.8% of all anopheline mosquitoes collected in the lowland and riverine zones respectively. *Anopheles pharoensis* and *An. funestus* accounted for 4.8% and 1.1%, respectively, of the total anopheline species and were collected from lowland and riverine zones only. Another anopheline species, *Anopheles coustani,* was also collected in all ecological zones except the highland. Most mosquitoes were collected from lowland and riverine zones which contributed 79.8% and 19.0%, respectively, while midland and highland zones had 0.8% and 0.4%, respectively, of all malaria vectors collected (Table 1).

Table 1 Distribution of anopheline mosquitoes across the four ecological zones in Baringo County

Species	Lowland		Riverine		Midland		Highland		Totals	
	Total (N)	R.A. (%)	Total (N)	R.A. (%)	Total (N)	R.A. (%)	Total (N)	R.A. (%)	Total (N)	R.A. (%)
An. coustani	296	6.1	22	1.9	7	14.9	0	0.0	325	5.3
An. funestus[a]	12	0.2	57	4.9	0	0.0	0	0.0	69	1.1
An. gambiae s.l.[a]	4294	88.0	1053	90.8	40	85.1	25	96.2	5412	88.5
An. pharoensis[a]	277	5.7	14	1.2	0	0.0	0	0.0	291	4.8
Anopheles spp	1	0.02	14	1.2	0	0.0	1	3.8	16	0.3
Zone totals	4880 (79.8%)		1160 (19.0%)		47 (0.8%)		26 (0.4%)		6113 (100%)	

Note: [a]vectors of malaria in Baringo County; N-Total number collected; R.A-Relative Abundance

Indoor anophelines accounted for 80.8% of total collections compared to 19.2% collected outdoors (Table 2). *Anopheles gambiae* s.l. and *An. funestus* were mainly collected indoors; 89.5% and 89.9%, respectively, of total collections for individual species. On the other hand, *An. pharoensis* and *An. coustani* were mainly collected from

outdoors; 87.6% and 99.7%, respectively, of total collections for individual species. The sixteen unidentified anopheline specimens were all collected outdoors.

An independent-samples *t*-test was conducted to compare means for mosquitoes collected indoors and those collected outdoors. There was no significant difference in the mean number of indoor mosquitoes (M=206.50, SD= 637.7) and outdoor mosquitoes (M=33.96, SD=234.8), ($t_{(24)}$ =2.06, p=0.1999).

Table 2 Relative abundance of indoor and outdoor anopheline mosquitoes in Baringo County

		Indoors		**Outdoors**	
Species	Overall total	Total number (N)	Relative abundance (%)	Total number(N)	Relative abundance (%)
An. coustani	325	1	0.3	324	99.7
An. funestus[a]	69	62	89.9	7	10.1
An. gambiae s.l[a]	5412	4842	89.5	570	10.5
An. pharoensis[a]	291	36	12.4	255	87.6
Anopheles spp	16	0	0	16	100
Totals	6113	4941	100.0	1172	100.0
Relative abundance of indoor and outdoor		**80.8%**		**19.2%**	

Note: [a]vectors of malaria in Baringo County

2.2 Seasonality of malaria vector populations in Baringo County

The highest number of mosquitoes was collected in December 2015 accounting for 83.6% (N=1267) of the total anophelines collected in the lowland during the dry season. The lowland vector population reduced drastically to 181 in January and reduced further to 68 in February as the dry season progressed. The highest number of vectors (N=309) in the riverine zone was collected in the month of April 2016 which accounted for 60% of the total collections during the long rain season in the riverine zone (Table 3). In terms of season, the cold dry season had the highest mosquito population at 1,831 (31.7%) followed by dry season with 1,798 (31.2%) mosquitoes of the total collections during the 12-month sampling period (Table 3). Generally higher proportions of malaria vectors were collected during the drier seasons than rainy seasons.

Table 3 Seasonal malaria vector populations across the four ecological zones in Baringo County

Malaria vector numbers (N) across zones						
Season	**Month**	**Lowland**	**Riverine**	**Midland**	**Highland**	**Total**
Cold dry	June	446	186	9	6	647
	July	613	33	4	0	650
	August	487	46	1	0	534
Total		**1546**	**265**	**14**	**6**	**1831**
Short rains	September	588	24	15	12	639
	October	324	29	2	0	355
	November	368	18	1	0	387
Total		**1280**	**71**	**18**	**12**	**1381**
Dry season	December	1267	71	1	5	1344
	January	181	162	4	0	347
	February	68	39	0*	0	107
Total		**1516**	**272**	**5**	**5**	**1798**
Long rains	March	38	48	1	0	87
	April	41	309	0	0	350
	May	163	158	2	0	323
Total		**242**	**515**	**3**	**0**	**760**

Negative binomial modeling of mosquito abundance against seasons showed significant influence on *An. gambiae* s.l. population size in the lowland. The long rain season in the lowland was significantly different from the cold dry season which was used as a reference (p<0.000). However, seasons were not significantly different in the

riverine zone (Table 4). When rainfall and temperature were combined in the same model, only rainfall was significant in influencing *An. gambiae* s.l. populations in the lowland zone (p=0.044) and riverine zone (p=0.003). However, the significance level for rainfall was weaker in the lowland zone than in the riverine zone. Therefore, further analysis was done to determine the relationship of rainfall and temperature, as constituents of season, on *An. gambiae* s.l. populations in each of the two zones which had high numbers of mosquitoes.

Table 4 Influence of season on *An. gambiae* population in the lowland and riverine zones

Seasons in zone	Estimate	Std. Error	z value	P-value
Lowland zone				
Dry season	-0.1675	0.3809	-0.440	0.660
Long rains	-1.9246	0.3867	-4.977	0.000
Short rains	-0.2999	0.3823	-0.785	0.433
Cold dry season†				
Rainfall	-0.0078	0.0038	-2.013	0.044
Temperature	-0.0487	0.0910	-0.535	0.592
Riverine zone				
Dry season	-0.0229	0.6114	-0.038	0.970
Long rains	0.7215	0.6056	1.191	0.233
Short rains	-1.1747	0.6302	-1.864	0.062
Cold dry season†				
Rainfall	0.0100	0.0034	2.913	0.003
Temperature	0.2159	0.1244	1.735	0.082

Note: †Cold dry season was a reference season for comparison with other seasons

When mosquito abundance was regressed against rainfall in the lowland, there was no correlation (r=-0.08) and only 0.7% could be explained by rainfall (r^2 = 0.007) which was not statistically significant (p=0.796). Regression of *An. gambiae* s.l. population against temperature in the lowland zone showed a weak negative correlation (r=-0.19) but higher than that of rainfall and only 3.8% could be explained by temperature (r^2=0.038). The relationship between temperature and *An. gambiae* s.l. abundance was not statistically significant (p=0.544). When mosquito abundance was regressed against rainfall and temperature, correlation improved (r=0.29) and 8.6% of mosquito population in the lowland zone could be explained by rainfall and temperature (r^2=0.086). Overall, this was not significant (F=0.664) and both rainfall (p=0.505) and temperature (p=0.398) were not significant. Therefore, rainfall and temperature in the lowland may not be useful in predicting *An. gambiae* s.l. population dynamics in relation to the actual number of mosquitoes collected (Figure 2a; Figure 2b).

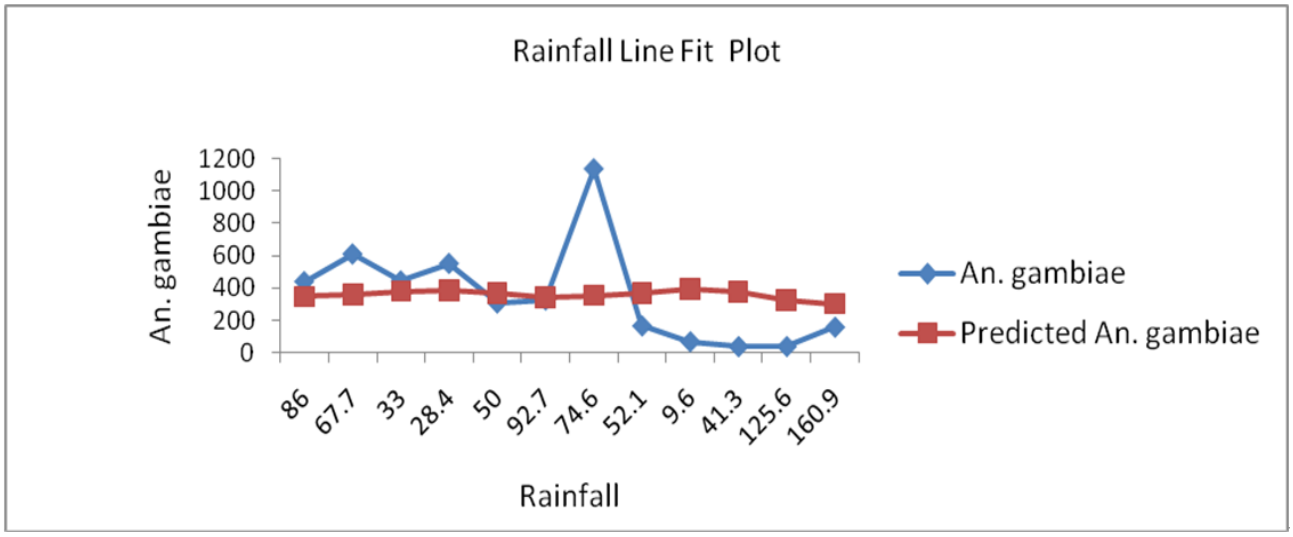

Figure 2a Prediction of *An. gambiae* s.l. population using rainfall in the lowland zone

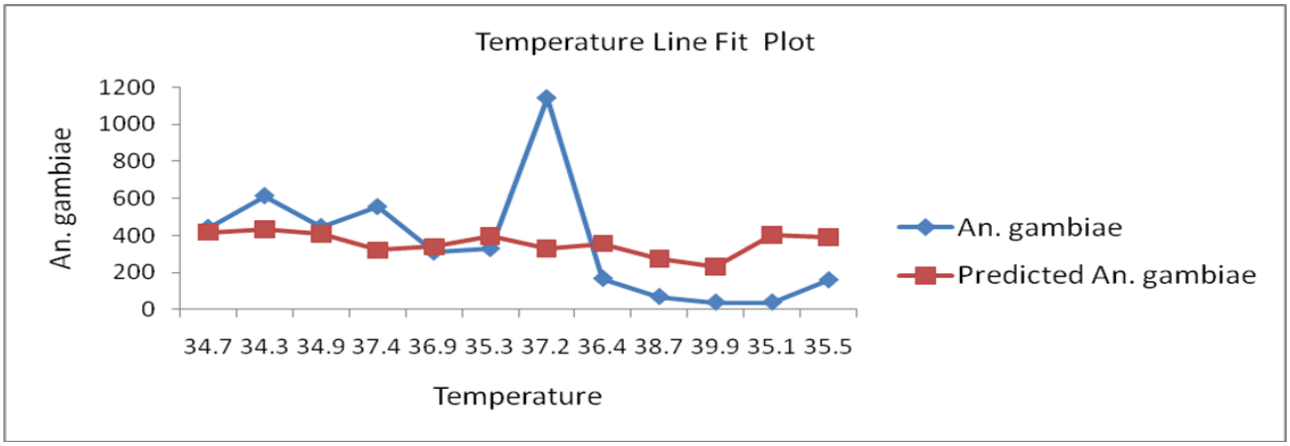

Figure 2b Prediction of *An. gambiae* s.l. population using temperature in the lowland zone

Regression of *An. gambiae* s.l. abundance against rainfall showed a strong positive correlation (r=0.7) and 49.5% of mosquito population in the riverine could be explained by rainfall (r^2=0.495) which was statistically significant (p=0.01). On the contrary, temperature in the riverine did not show any correlation with mosquito abundance (r=-0.01) and could not account for any change in vector population (r^2=0.00). Therefore, whereas rainfall pattern may be used to predict *An. gambiae* s.l. population in the riverine, temperature may not be useful (Figure 3a; Figure 3b). However, when mosquito population was regressed against rainfall and temperature, correlation improved to r=0.72 and 52.6% of mosquito population in the riverine could be explained by rainfall and temperature collectively (r^2=0.526).

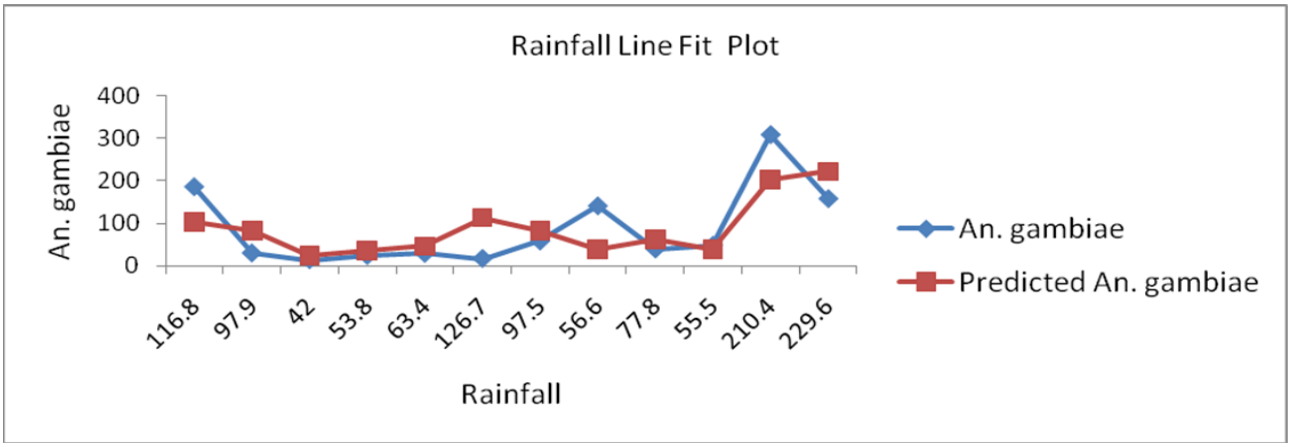

Figure 3a Prediction of *An. gambiae* s.l. population using rainfall in the riverine zone

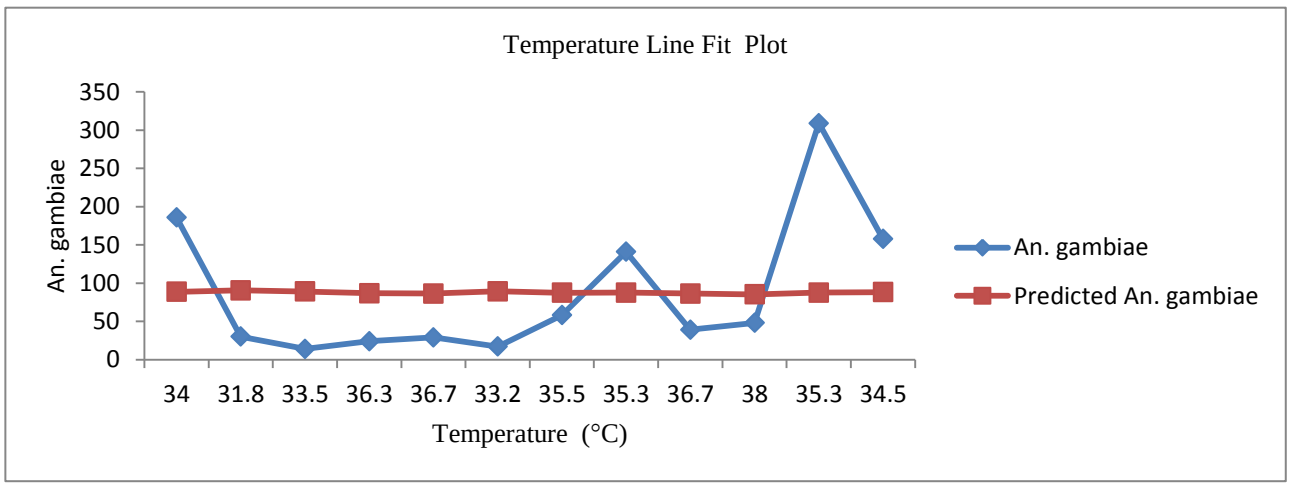

Figure 3b Prediction of *An. gambiae* s.l. population using temperature in the riverine zone

3 Discussions

Anopheles gambiae s.l. was the most abundant species of the three malaria vectors compared to *An. pharoensis* and *An. funestus*. This result corroborates findings of a previous study in the lowland zone of Baringo (Aniedu, 1992) and another one in western Kenya where *An. gambiae* was found to be the predominant vector of the total anophelines collected (Shililu et al., 1998). Most mosquitoes were collected from lowland and riverine zones while midland and highland zones had very few malaria vectors. This is in agreement with a study in western Kenya highlands which found high density of malaria vectors at valley bottom compared to mid hill and hill tops (Githeko et al., 2006). This information is important as it gives a guide on areas where vector control efforts should be scaled up. Therefore, bed net coverage and sensitization of the community to optimize net utilization should be focused in the riverine and lowland zones, which had high populations of vector mosquitoes and thus are high malaria risk areas. The proportion of *An. gambiae* s.l., the principal malaria vector in Baringo (Aniedu, 1997), in relation to other malaria vectors within the zones, was higher in the riverine zone compared to lowland zone. This may explain the higher number of malaria incidences found in riverine zone compared to lowland zone of Baringo County (Omondi et al., 2017) during the same period of this study.

Anopheles coustani and *An. pharoensis* were mostly collected outdoors while *An. gambiae* s.l. and *An. funestus* were mainly collected indoors. This, further points to the fact that *An. gambiae* and *An. funestus* are the main vectors of malaria in Baringo County (Aniedu, 1993). Although there is a general notion that malaria transmission occurs indoors, presence of *An. pharoensis* and *An. coustani*, which have been implicated in malaria transmission, possibly propagates outdoor transmission of malaria in Baringo County (Aniedu, 1993; Mwangangi et al., 2013). Despite the differences observed in vector abundance between indoor and outdoor populations, there was no significant statistical difference. This may imply that the risk of outdoor transmission could be real since pastoral community herders occasionally spend nights outside (Mboera et al., 2005; Chinwe et al., 2014).

Generally higher proportions of malaria vectors were collected during the drier seasons than rainy seasons. Similar results were obtained by studies in western Kenya (Ndenga et al., 2006) and south region of Cameroon (Bigoga et al., 2012) where *Anopheles* mosquito densities increased during periods of dry season. Contrary to findings of some studies in which *An. gambiae* s.l. mosquito abundance was high during rainy seasons (Minakawa et al., 2002; Shililu et al., 2004; Mwangangi et al., 2009), the proportion of malaria vectors collected during the long rain season was lowest in this study. This is not surprising because long and heavy rain affects breeding sites by flushing out larvae and killing them (WHO, 1975; Paaijmans et al., 2007). Hence, the breeding of a vector population is greatly reduced with repeated rains which cause flooding and wash away larvae. The high population of *An. gambiae* s.l. observed during the dry season in Baringo County may partly explain the many malaria incidences recorded among primary school children in a concurrent study in the same region during the same season (Omondi et al., 2017).

The present study found a high correlation between monthly average rainfall and *An. gambiae* s.l. population in the riverine zone (r=0.70) but not in the lowland zone (r=-0.08). The lack of correlation between malaria vector abundance and rainfall in the lowland zone of Baringo is consistent with the findings of Aniedu (1992). Most breeding habitats in the lowland zone are permanent water bodies whose productivity may not be significantly affected by rainfall trends hence low correlation between rainfall and vector abundance. Moreover, it has been shown through modeling simulations that rainfall alone does not control mosquito populations but accounts for only 60% (Bomblies, 2012) in water-limited semi-arid environments. Nonetheless, this is still greater than field observations where correlation between rainfall and reported vector abundance was much smaller (Koenraadt et al., 2004; Kelly-Hope et al., 2009). In this study, rainfall alone accounted for 49.5% mosquito population in the riverine zone and when temperature was included in the regression, this percentage increased to 52.6% which is still less than the simulated value. A study conducted in western Kenya highlands showed no correlation between mosquito abundance and monthly rainfall though population appeared to increase with rainfall or shortly after rainfall (Shililu et al., 1998). However, a later study in east African highlands showed a linear relationship between *An. gambiae* density and a 2-month lag in rainfall peak (Kristan et al., 2008). Similarly, a recent study in

Baringo County reported a 2-month lag between increased malaria cases and rainfall across the four ecological zones (Kipruto et al., 2017).

There was no correlation between vector abundance and temperature in the riverine zone compared to a very low correlation in the lowland zone which was not statistically significant. This implies that temperature may not be an important climatic factor regulating malaria vector abundance in semi-arid areas of Baringo County. This is supported by findings of a study in Bangladesh where temperature did not have an effect on abundance of anophelines (Bashar and Tuno, 2014). However, Minakawa et al. (2012) found a significant influence of temperature on malaria vector abundance in Kenya though their analysis included highlands and non-arid areas.

4 Conclusions

This study demonstrates distribution and seasonal population dynamics of malaria vector species across four ecological zones in Baringo County. Whereas previous studies concentrated on the lowland zone of Baringo County only, this study covered the entire county for the first time to give an account of malaria vector species distribution in the different ecological zones. Most malaria vectors were collected from the lowland and riverine zones. Overall, dry seasons had more mosquitoes than wet seasons. The knowledge gained from this study is important in implementation of control strategies against malaria by the Baringo County Health Department. The findings indicate season when malaria cases are likely to occur and areas to target for intervention. Based on the findings of this study, it would be necessary to occasionally monitor malaria vector populations as a useful prerequisite for implementation of malaria control strategies within Baringo County in the face of changing climate which may lead to unpredictable seasonal population fluctuations of malaria vectors.

Authors' contributions

IMO designed the study, collected data in the field, identified specimens taxonomically, carried out data entry and analysis and wrote the first draft of the manuscript. FAO participated in the study design, enhanced the literature survey, and edited the manuscript. AOO participated in acquisition of climate data, advised on data analysis and reviewed the manuscript. DNA coordinated fieldwork and reviewed the manuscript. BAE and IKN conceived the idea for the study and participated in the study design. All authors read and approved the final manuscript.

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