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Research article

Description of malaria epidemics and normal transmissions using rainfall variability in Gondar Zuria highland District, Ethiopia

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ABSTRACT

Background: Rainfall is one of the climate variables most studied as it affects malaria occurrence directly.
Objective: This study aimed to describe how monthly rainfall variability affects malaria incidence in different years.
Methods: A total of 7 years (2013/14–2019/20) retrospective confirmed and treated malaria cases in Gondar Zuria district were used for analysis in addition to five (2013/14–2017/18) years retrospective data from Dembia district.
Results: The annual rainfalls in the study years showed no statistically significant difference (p = 0. 78). But, variations in rainfalls of the different months (p = 0.000) of the different years were the source of variations for malaria count (incidences) in the different years. Malaria was transmitted throughout the year with the highest peak in November (mean count = 1468.7 ± 697.8) and followed by May (mean count = 1253.4 ± 1391.8), after main Kiremt/Summer and minor Bulg/Spring rains respectively. The lowest transmission was occurred in February (338 ± 240.3) when the rivers were the only source of mosquito vectors. Year 2013/14 (RF = 2351.12 mm) and 2019/20 (RF = 2278.80 mm) with no statistically significant difference (p = 0.977) in annual rainfalls produced 10, 702 (49.2%) and 961 (20%) malaria counts for the Bulg (spring) season respectively due to 581.92 mm (24.8%) higher total Bulg/Spring rain in 2013/14 compared to 124.1 mm (5.45%) in 2019/20. Generally, above normal rainfalls in Bulg/Spring season increased malaria transmission by providing more aquatic habitats supporting the growth of the immature stages. But heavy rains in Summer/Kiremt produced low malaria counts due to the high intensity of the rainfalls which could kill the larvae and pupae. Spearman's correlation analysis indicated that the mean rainfalls of current month (RF) (0 lagged month) (P = 0.025), previous month (RF1) (1 month lagged) (p = 0.000), before previous months (RF2) (2 months lagged) (p = 0.001) and mean RF + RF1 + RF2 (P = 0.001) were positive significantly correlated with mean monthly malaria counts compared to negative significant correlations for temperature variables. Temperature variables negative correlations were interpreted as confounding effects because decreased malaria counts in dry months were due to a decrease in rainfalls. Conclusion: rainfall distribution in different months of a year affects malaria occurrences.

1. Introduction

Despite World Health Organization's global malaria elimination plan for a malaria-free world by 2030 [1], 228 million cases of malaria occurred worldwide in 2018 when Africa shared 93% of the total cases including 962, 087 cases in Ethiopia [2]. Malaria elimination program, particularly in northwest Ethiopia, challenged by the seasonal migration of adult male laborers to Metema – Humera lowlands, mostly from highland areas. Their return is usually associated with malaria and kala-azar infections, the two most important vector-borne diseases in the areas [3, 4, 5]. The roles of returnees, in transmitting these vector-borne diseases in highland homes, were higher during some epidemic years (anomalous climate years) [4, 5]. Recently, it has also been indicated about a threat of ongoing warming of Ethiopian highland areas which could increase mean Temperature by 4 C^o in 2100 and transform the areas into moderate malaria transmission zones [6]. Global warming has already been blamed for malaria territorial expansion to originally malaria-free East African highland areas [7]. Such man-made global warming can also affect human life in different ways, outside the increase of vector-borne disease transmission [8, 9]. Naturally, transmission

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dynamics of malaria in Ethiopia are diverse due to the effect of different topographies and climatic variability in different parts of the country which requires geospatial malaria distribution-specific intervention after conducting operational researches to understand the different epidemiological parameters. On top of these, Ethiopia is one of the East African countries subjected to the cyclic El-Nino and La-Nina events [10, 11].

The role of climate variability in highland (above 1500 m asl) malaria epidemiology remained controversial and poorly understood [12]. Inter-annual temperature and rainfall variations due to El Nino and La Nina have played significant roles in the past for the manifested recurrent epidemics in highland areas of Ethiopia [7]. Such kind of cyclic nature of El-Nino or La-Nina events in low transmission zones could prevent the maintenance of the immunity acquired during previous epidemic exposure [8]. Thus, the highland epidemic could have bad consequences in the next cycle.

Malaria epidemic associated with highlands started to be reported by soldiers returning from the first World War in 1918 in Kenya before several epidemics reports in East Africa [7]. Following the 1953 catastrophic malaria epidemic in the Dembia plains which had killed more than 7000 individuals [13], Ethiopia experienced another highland epidemic in 1958 which extended up to 2600 m asl throughout highland areas of Ethiopia and killed 150,000 people in addition to 3 million malaria-related morbidities [14]. The only highland endemic area not affected by the 1958 epidemic was the Dembia district which took the attention of the WHO during the previous epidemic and was receiving regular DDT sprayings [15]. The more recent 1998 and 2003 highland malaria epidemics in Ethiopia have affected more than 1 million and 15 million people respectively [16]. In 2016, there were El-Niño related climatic hazards for drought and floods in Ethiopia which caused drought in northern parts and flooding in Eastern and Southern Ethiopia [11]. The overall effect of El-Niño related climatic change in 2016 has passed with relatively higher annual malaria incidence in northwest Ethiopia which was unnoticed due to the ongoing organized intervention effort to eliminate malaria [5].

Highland malaria epidemiology remained unclear due to a lack of knowledge on how climate anomalies affect malaria transmission by affecting the biology of mosquito vectors in highland areas. A study conducted in the central highlands of Ethiopia indicated the recent mean change in temperature as a reason for territorial expansion to 1600–2400 m asl where approximately 43% of Ethiopia's total population currently lives [17]. The shortcoming of this study could be the inability to consider rainfall which has a direct effect on the survival of mosquito vectors and play a direct role in malaria transmission. Different studies in Ethiopia also showed the association (positive correlation) of lagged months of rainfalls and malaria incidences [18, 19, 20]. The problem to understand the role of rainfall in malaria epidemiology is related to its ability either to support or reduce transmission by affecting the survival of immature stages positively or negatively depending on the intensity of rainfalls as tried to be explained by previous investigators [21, 22].

In Gezira state (agricultural area in Sudan), linear positive correlations among the number of malaria cases and the relative humidity, the amount of rainfall, and the Blue Nile's level ($p < 0.05$) were observed compared to a non-linear relationship with the minimum temperature [23]. In South Africa, a significant positive correlation between malaria logarithmic count (log count) and rainfalls was observed using 30 years of malaria case data [24]. Despite the effective malaria control program in five districts of Limpopo Province (South Africa), the epidemic occurred in 2017 when malaria cases increased from 1377 in 2016 to 30, 558 cases in 2017 [25]. Rainfall was the most important climate driver during this recent epidemic in South Africa [26]. A positive correlation between the previous month's rainfalls (one month lagged) or before the previous month's rainfall (two months lagged) and malaria case counts were reported across all the districts in Limpopo province (South Africa) [25]. A major role of rainfall compared to the minor role of temperature in malaria transmission was also indicated in stable malaria-endemic lowland areas of Sudan [23] and South Africa [26]. Heavy summer rain could also affect malaria transmission due to its killing effect of the aquatic immature mosquito stages. This kind of negative effect is due to high rainfalls in previous and before previous months reported in India [27], Uganda [28], Botswana [29], and Swaziland [30].

The malaria control interventions in Ethiopia resulted in significant reductions from 12.4 million malaria cases and 41,000 annual deaths in 2006 to 5 million cases and 3,000–6,000 annual malaria deaths in 2013 [31]. Six years (2012–2017) retrospective analysis of malaria cases in Batu (Ziway) town also indicated 3.4 fold decline in 2017 compared to 2012 [32]. The impact of intervention in Ethiopia is also evident from the statistics or the situation on the ground.

Above 2000 m highland malaria-endemic areas in Ethiopia are not priority areas for malaria intervention. Highland areas are places where the majority of Ethiopian people live in a crowded manner. To achieve malaria elimination goals and prevent a possible epidemic, highland malaria transmission should also be a priority for the intervention. This study aimed to describe the major role of rainfalls on the highland malaria transmission dynamics (Epidemic and normal transmission) before recommending regular surveillance to monitor malaria cases based on precipitation information particularly in Bulg/Spring season where intervention can be conducted cost-effectively.

2. Methods

2.1. Study area

Gondar Zuria district is one of the districts in the Central Gondar zone (Amhara region). Gondar Zuria district is bordered by the Gondar town and North Gondar (northerly), Libo-KemKem district (Southerly), Belessa district (Easterly), and Lake Tana and Dembia district (westerly) (Figure 1). Maksegnit town is the capital of the Gondar Zuria District and found around 12°23′ latitude and 37° 33′ longitude with an elevation of around 2000 m above sea level. The study area was known historically by the name Dembia plane which covers all the areas affected by the 1953 malaria epidemic. Most of the localities (Kebeles) which were worst affected during the 1953 epidemic are now located in Dembia and Gondar Zuria districts.

2.2. Study design and data collection

Retrospective data of confirmed and treated malaria cases for 7 years (2013/14–2019/20) were obtained in Gondar Zuria district Health Bureau (Maksegnit), malaria expert desk. The malaria PHEM paper and excel reports for confirmed and treated malaria cases were analyzed for annual parasite incidences starting from July 1, 2013/14 to June 30, 2019/20 (7 years). In the documents, parasites were identified by species and patients identified in different age groups (under 5 years, 5–14 years, and above 15 years) for every malaria WHO week. The information on the documents was tallied to obtain meaningful information like monthly malaria count (incidence). Retrospective data of confirmed and treated malaria cases of five years (2013/14–2017/18) were also obtained from Dembia district Health Bureau located in Kola Diba (the capital city of Dembia district). The aim of analyzing the Dembia district was to make for comparison of malaria incidences during the five years as the two neighboring districts share similar malaria ecology. Google search of weather conditions data from a global meteorological website for Maksegnit district has provided monthly mean for average, the minimum and maximum temperature in addition to humidity and rainfalls for the different years. Due to the lack of epidemiologically meaningful effect of temperature variables on the rate of malaria transmission, all emphasis was given to the 0–2 month lagged rainfalls to describe the transmission dynamics of malaria in the study area. The temperature in the study district was neither lethal for mosquitoes at different stages or parasite development inside parous females.

2.3. Statistical analysis

Spearman's correlation was conducted to see a statistically significant correlation between mean monthly malaria count (incidences) and the different climatic variables (rainfalls on current (RF), previous (RF1), before previous (RF2) months, mean RF + RF1 + RF2, mean monthly maximum temperature, mean monthly minimum temperature, mean monthly average temperature and humidity). Man Whitney u - test and Kruskal Wallis tests were also used to see the existence of significant differences in malaria counts and incidences in Dembia and Gondar Zuria districts and different years. Negative binomial log link analysis has been used to show the correlation between monthly malaria count and different years and seasons for Gondar Zuria districts. P-vales below 0.05 were considered as statistically significantly different. IBM SPSS Statistics software (version 25) was used for the analysis of the data.

2.4. Quality control

To reduce malaria-related death to near zero, health personnel in the districts of Maksegnit Health bureau facilitate the malaria screening and treatment process seriously with a chain of supervision by the District and Zone malaria desk officers. Malaria screening and treatment are conducted for free in all government health facilities.

3. Result

3.1. Malaria incidence in Gondar Zuria and Dembia Districts

A total of 145, 073.00 confirmed malaria cases were treated in Dembia district (89, 499.00) and Gondar Zuria Districts (55, 574.00) during 2013/14–2017/18. The Median (mean ± SD (range)) of monthly malaria incidence per 1000 people was 4.35 (5.25 ± 3.3) (1.1–17.04) for Dembia compared to 3.95 (4.74 ± 3.85) (1–21) for Gondar Zuria District during these five years. The overall mean annual parasite incidence (API) during 2013/14–2017/18 for the Dembia district (63.9/1000 people) was higher than GZD (56.7). Both the highest API (110.9/1000 people) and the lowest API (32.6/1000 people) were found from GZD in 2013/14 and 2017/18. Mann-Whitney U-test showed no statistically significant difference ($p = 0.185$) during 2013/14–2017/18 for monthly malaria incidence in these two neighboring districts which are bordered by lakeTana, Foggera district (mountainous kebeles), and Gondar town (Figure 1). But statistically significant difference ($p = 000$) was found for overall monthly confirmed malaria counts in these districts due to the high population in Dembia district (280,000) compared to Gondar Zuria district (196, 229). In both districts, malaria transmission occurred throughout the year with two peaks in May/June and November with declined transmission following these peaks.

3.2. Monthly malaria counts and incidences in Gondar Zaria District (GZD)

A total of 63, 504.00 confirmed malaria cases treated in health posts and clinics during the 7 years in Gondar Zaria district during July (4, 225.00), August (4, 768.00), September (5, 720.00), October (5,244.00), November (10, 281.00), December (4, 283.00), January (3, 177.00), February (2,366.00), March (2,743.00), April (3, 616.00), May (8,774.00) and June (8, 307.00). The highest mean monthly malaria count (1468.7 ± 697.8) and monthly incidence (7.5 ± 3.6) were found in November. The second highest mean monthly count (1253.4 ± 1391.8) and monthly incidence (6.4 ± 6) were found in May while the third-highest mean monthly count (1186.7 ± 1163.6) and monthly incidence (6.1 ± 6) were found in June. February had the lowest monthly count (338 ± 240.3) and incidence (1.7 ± 1.2) compared to the second-lowest in March count (391 ± 387.4) and incidence (1.9 ± 0.1).

The annual incidences per 1000 people for Gondar Zuria district were 110.7 (21730/196229) for the year 2013/14, 61.7 (12117/196229) for the year 2014/15, 43.4 (8509/196229) for the year 2015/16, 34.8 (6829/196229) for the year 2016/17, 32.6 (6389/196. 229) for the year 2017/18, 24.5 (4802/196, 229) for the year 2018/19, and 15.9 (3128/196, 229) for the year 2019/20. The average annual incidences for the 7 years were 46.29 with the continuous decline from 110 cases/1000 people to the lowest 15.96 cases/1000. Similarly, the average monthly malaria incidence in the Gondar Zuria district showed continuous decline starting from 2013/14 to 2019/20. The first three years such as 2013/14 (Inc = 9.24), 2014/15 (5.14), and 2015/16 (3.6) showed relatively high incidences compared to 2016/17 (2.9), 2017/18 (2.7), 2018/19 (2) and 2019/20 (1.3).

3.3. Monthly rainfall and temperature and malaria count

During the 2013/14–2019/20 study period, the median (mean ± SD (range) rainfalls for June, July, and August were 292.8 (291 ± 98.4) (160.35–438.8) mm, 500.8 (451.05 ± 111.7) (191.13–576.01) mm and 465 (454.6 ± 79.02) (308.4–548.4)) mm respectively. The July–August heavy rainfall months were found for a sudden reduction in malaria count compared to May and June. After the June–August main rainy months, there was slight lower rainfalls in September (median (mean ± SD (range)) = (173.9) (198.5 ± 103.6) (101.7–390)), October (median (mean ± SD (range)) = 129.8 (115.6 ± 52.04) (54.17–172.6)), and November ((median) (mean ± SD (range)) = 40.74 (38.7 ± 41.2 (0.7–120)) before further decline in December (0.8 (5.1 ± 10.1) (0–27.5)) and January ((median) (mean ± SD (range)) = 0.1 (0.8 ± 1.2 (0–3.2))). The least malaria transmission occurred in February when median (mean ± SD (range)) rainfall was equal to 0.9 (3.2 ± 4.2 (0.4–12.1)) mm. The median rainfall for March (mean ± SD (range)) was 3.6 (28.4 ± 54.02) (0–148.5) mm. The amount of rainfall increased in April when the Median (mean ± SD (range)) was 19.1 (31.2 ± 34.9) (0.6–95.73) mm. The amount of rainfall further increased in May with Median (mean ± SD (range)) = 126.0 (140.3 ± 75.9 (59.7–289.6)) mm. The rainfalls in March–June were responsible for malaria counts in the Bulg season with a peak in May/June. During the study period, the highest mean maximum temperature ($31C^o$) was found in March and April while the lowest temperature (11 C^o) was recorded in December and followed by January (12 C^o). Mean ± SD (range) for monthly maximum, average and minimum temperature were 24.58 ± 2.4 (15–31), 20.2 ± 2.3 (16–25), and 15.2 ± 2.3 (11–25) respectively for the study period.

3.4. Description of the transmission dynamics of mean monthly malaria cases

3.4.1. Spearman's correlation, Spearman's correlation coefficient, and shared variance between mean monthly malaria case counts and mean monthly rainfalls (RF, RF1, RF2, and RF + RF1 + RF2)

Spearman's correlation analysis indicated that the mean rainfalls of current month (RF) (0 month lagged) ($r = 0.244$; $p = 0.025$), previous month (RF1) (1 month lagged) ($r = 0.347$; $p = 0.001$), before previous months (RF2) (2 months lagged) ($r = 0.345$; $p = 0.001$) and mean RF + RF1 + RF2 ($r = 0.350$; $P = 0.001$) were positive significantly correlated with mean monthly malaria counts similar to humidity ($r = 0.33$; $p = 0.002$) during all months (January–December) in the study period (Table 1). Mean malaria counts shared 6% variance with mean RF (0 month lagged rainfall), 12% with mean RF1 (1 month lagged rainfall), 11.9% with mean RF2 (2 month lagged rainfall) and 12.30% with mean RF + RF1 + RF2. Spearman's correlation also showed negative significant correlation of mean minimum monthly temperature ($r = - 0.305$; $p = 0.005$) and mean average monthly temperature ($r = - 0.359$; $P = 0.001$) with mean monthly malaria count. No correlation was observed for mean monthly maximum temperature ($r = 0.201$; $p = 0.067$).

When rainfalls of July–October heavy Kiremt/summer rainy months, November–December low Kiremt/summer rainy months, January–February dry months (little rain) and March–June Bulg/Spring months

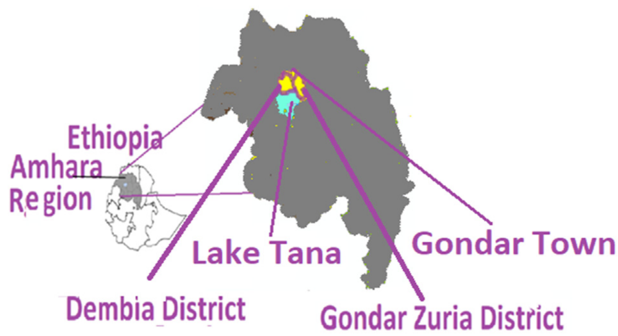

Figure 1. Map of GondarZuria District study area in Central Gondar zone, Amhara Regional State.

compared, only March–June Bulg/Spring rainfalls showed statistically significant spearman's correlation ($p \leq 0.001$). Rainfalls of July–October heavy Kiremt/summer rainy months, November–December low Kiremt/summer rainy month, and January–February dry months did not show statistically significant Spearman's correlation with mean monthly malaria case counts (Table 1). Mean monthly malaria counts during March–June Bulg/Spring months shared 43% variance with mean RF, 43% variance with mean RF1, 33% variance with mean RF2, and 48% variance with Mean RF + RF1+ RF2.

The beginning of the normal Bulg/spring rainfall in the study area was March. The role of rivers as larvae habitats stops more or less starting from March due to frequent heavy rains related flooding in the rivers which could kill the immature stages. Malaria transmission has not been interrupted in March (Figure 2). The slight increase in malaria transmission in March could indicate that mosquitoes could complete their life cycle and feed twice on human blood meals within 1 month in hot March to keep the transmission continues. This might be the reason why rainfall on the month or 0 months lagged month (RF) showed a statistically significant correlation ($p = 0.025$) with the mean malaria counts (Table 1).

The mean rainfall on the month (RF) of January was 0.8 mm but produced malaria cases counts (3, 177.00) greater than March (2,743.00) with higher mean rainfall on the month (RF) (28.4 mm) due to the effect of mean rainfalls in previous (RF1) and before previous (RF2) rainy months which favored January to have more mean monthly malaria cases. Similarly, due to the effect of RF1 and RF2, December (4, 283.00 cases counts) and November (10, 281.00 cases) with mean 5.1 mm and 38.7 mm lower rainfalls on the current months (RF) respectively produced higher malaria case counts compared to higher April (31.2 mm) and May (140.3 mm) rainfalls on the current months (RF) with lower mean monthly malaria cases (April = 3, 616.00 cases; May = 8,774.00 case) during the study period. To obtain, best correlation, it might not be ideal to use RF alone. Similarly, it is not good to use RF1 or RF2 alone to find the highest possible shared variance. In March or February, for example, there might be no rain in RF1 and RF2 and, therefore, it is appropriate to use the mean of RF + RF1 + RF2 to include the impact of all during spearman's correlation analysis to get the maximum result (Table 1).

The gradual increase in mean of RF + RF1 + RF2 from 9.1 mm to 462.5 mm (during February, March, January, April, December, May, November, and June) (8 months) increased the mean malaria count. When the intensity and frequency of rainfall increased in June (Mean RF + RF1 + RF2 = 462.48 mm), the proportional increase in mean monthly malaria started to be affected. In Figure 2H, the mean monthly malaria count mean graph joined the RF + RF1 + RF2 graph at a point between June and July (somewhere between 462.48 – 899.06 mm) before the mean monthly malaria count reached the lowest point in July. Following the decline in this heavy rain season, the mean monthly malaria count started to increase and joined again the mean RF + RF1 + RF2 graph exactly in October (RF + RF1 + RF2 = 768.6 mm and mean monthly count = 749.1). The two points where the graph of mean monthly count joined the mean RF + RF1 + RF2 graph during declining or increasing looked the same (Figure 2H).

Similarly, the graph of mean monthly count bisected the mean RF + RF1 + RF2 graph twice for the year 2016/17 (Figure 2D) and 2017/18 (Figure 2E) at about similar points. For a typical bell-shaped normally distributed rainfall, the two points where the mean monthly count graph meets the mean RF + RF1 + RF2 graph could be the same. In 2019/20 (Figure 2G), monthly rainfall distribution was not favoring malaria transmission (3128 cases). There were no enough rainfalls during the Bulg/Spring season for the start of good transmission. Malaria transmission remained low until sudden heavy June rains further declined malaria transmission. The transmission remained low until November due to continuous heavy rains. The other year which did not flavor malaria transmission was 2018/19 (Figure 2F). The rainfall distribution in this year was not favoring Bulg/spring malaria transmission. During the 2015/16 El-Nino drought year (Figure 2C), the annual rainfall (1083.56 mm) was the lowest. In this year, the total annual cases were 8509 cases (Bulg/Spring season (19.2%), July–October heavy Kiremt/Summer (37%), November–December low kiremt/summer (29.5%), and January–February dry months (14.2%)). The very low rain in the Spring/Bulg season lowered transmission in this season compared to the relatively moderately high rainfalls during the heavy rain months which favored relatively high malaria transmission. But years with high amount rainfalls during Bulg/Spring season such as the year 2013/14 (Figure 2A) and 2014/15 (Figure 2 B) were malaria transmission favoring years and showed the first two top total malaria counts during the study period.

3.4.2. Mean monthly malaria case counts and rainfall variability and anomalies

Very low rainfalls in January ((median) (mean ± SD (range)) = 0.1 (0.8 ± 1.2 (0–3.2)) and February = 0.9 (3.2 ± 4.2 (0.4–12.1)) mm) resulted in the reduction of the drains of the rivers (larvae habitats in dry season) and mean malaria counts. The mean maximum temperature (mean ± SD (range) = 24.58 ± 2.4 (15–31)), mean average temperature (mean ± SD (range) = 20.2 ± 2.3 (16–25)) and mean minimum temperature (mean ± SD (range) = 15.2 ± 2.3 (11–25)) during 7 years study period in the study areas could not affect the survival of any stages of the mosquito vectors or the malaria parasite development inside. But, mean monthly malaria case counts in January and February months showed –48.4% and -55% variance (opposite) with mean average and mean minimum Temperature in these two months (Table 1). Mean maximum temperature showed no statistically significant correlation with mean monthly malaria count (Table 1). Thus, temperature related spearmans' correlations were due to confounding effects.

The ANOVA (Kruskal Wallis) test showed no statistically significant difference ($p = 0.78$) in annual rainfalls in the different years. But, the random variations in rainfalls ($p = 0.000$) of the different months of the different years were the source of variations for malaria count (incidences) in different years. Years with relatively higher Bulg/Spring rainfalls have a higher annual malaria count. For example, year 2013/14 (RF = 2351.12 mm) and 2019/20 (RF = 2228.80 mm) with no statistically significant difference in annual rainfall ($p = 0.977$), produced 21, 730 malaria annual count (Mean ± StD = 1810.8 ± 1145.4) in 2013/14 while 3, 128 count (260 ± 182.04) were produced in 2019/20. The difference is related mainly to the difference in Bulg/Spring rainfalls. Monthly rainfalls in these two years showed a statistically significant difference ($p = 0.000$). During 2013/14, 430.1 mm mean Bulg/Spring RF + RF1+ RF2 rainfall produced 10, 702 (2675.5 ± 1553.4) malaria case counts compared to 181.9 mm Bulg/Spring rainfall which produced 1,360 (340 ± 280.5) in 2019/20. In this study, mean RF + RF1+ RF2 and mean malaria counts in Bulg/Spring season during the study period showed a very high correlation coefficient ($r = 0.69$) or shared variance (48%) (Table 1). Mean monthly RF + RF1+ RF2 was direct proportionality to mean monthly malaria count in Bulg/Spring season. The overall malaria cases counted during March–June

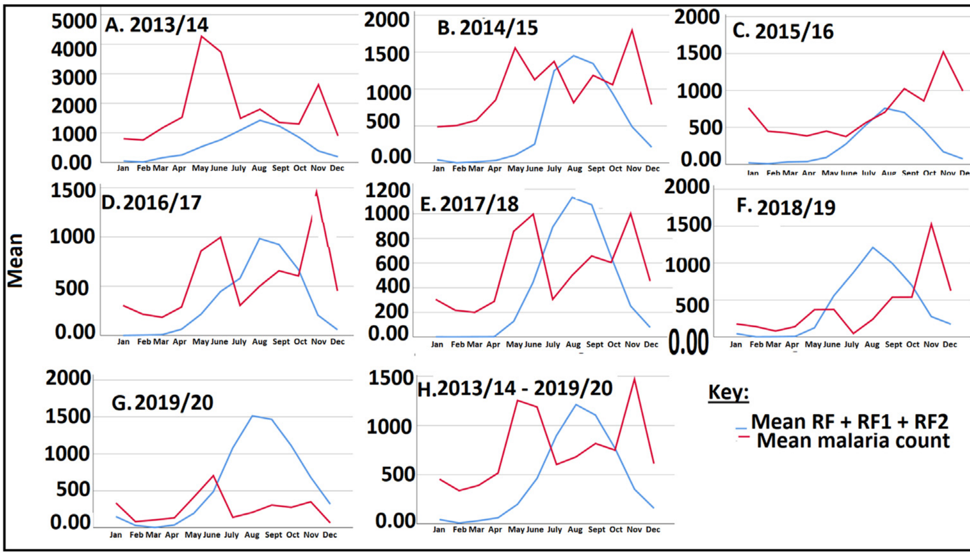

Figure 2. Graphs (A–H) indicated a relationship between mean monthly malaria counts and mean monthly RF + RF1+RF2 for different months in different years (2013/14–2019/20).

was 23, 440 (36.9%) during the study period. Lack of correlation during July–October heavy rain Kiremt/Summer, November–December low rain Kiremt/Summer and January–February dry months (Table 1) most probably were due to extremely varying rainfalls (random variation). It did not mean the contribution of these seasons to malaria transmission was low. Despite the heavy intensity of rainfalls in August–October heavy rain Kiremt/Summer, this season contributed 19, 957 cases (31.4%) during the study period. The contribution of the November–December low rain Kiremt/Summer was also very high (14, 564 or 22.9%). The total contribution of the 6 months of the Kiremt/Summer season was 54.3%.

Negative binomial regression showed a statistically significant difference ($p < 0.05$) for mean monthly malaria counts for different years when compared with 2013/14 highest transmission year. Compared to 2013/14, the mean monthly malaria count decreased by 0.44 in 2015/16, by 0.32 in 2016/17, by 0.30 in 2017/18, by 0.23 in 2018/19, and by 0.15 in 2019/20. Negative binomial regression also indicated malaria count during dry season decreased by 0.5 when compared to Bulg season.

Table 1. Table showing spearman's correlation, coefficient of determination, and shared variance between mean monthly case counts (dependent variable) and climate variables (independent variable).

Mean monthly malaria counts			Monthly	Humidity	RF	RF1	RF2	F1+F2+F3	Max. T	Ave. T	Min T
	Jan.–Feb. (dry season)	correlation co-efficient	1	0.299	0.14	0.37	0.21	0.289	0.35	-0.696**	-0.74**
		Sig. (2-tailed)		0.299	0.64	0.2	0.46	0.317	0.23	0.006	0.002
		N	14	14	14	14	14	14	14	14	14
		co-efficient of determination	-	-	-	-	-	-	-	-0.48	-0.55
		Shared Variance	-	-	-	-	-	-	-	- 48.48%	-0.55%
	March–June (Bulg/Spring)	correlation co-efficient	1	.581**	0.657**	0.657**	0.572**	0.692**	0.17	0	
		Sig. (2-tailed)		0.001	0.000						
		N		28	28	28	28	28	28	28	28
		co-efficient of determination		0.34	0.43	0.43	0.33	0.48	-	-0.21	-
		Shared Variance		34%	43%	43%	33%	48%	-	21%	-
	July–Oct. (Heavy rainKiremt/summer)	correlation co-efficient	1	0.082	-0.17	-0.01	0.261	0.054	0.548**	-0.356	-0.534**
		Sig. (2-tailed)		0.677	0.39	0.95	0.18	0.785	0.000	0.063	0.003
		N		28	28	28	28	28	28		
		co-efficient of determination		-	-	-	-	-	0.3	-	-0.285
		Shared Variance		-	-	-	-	-	30%	-	-28.5
	Nov.–Dec. Low rain Kiremt/Summer	correlation co-efficient	1	0.362	0.36	0.41	0.15	0.213	0.48	-0.521	-0.314
		Sig. (2-tailed)		0.204	0.21	0.14	0.61	0.464	0.08	0.068	0.295
		N		14	14	14	14	14	14	14	14
		co-efficient of determination		-	-	-	-	-	-	-	-
		Shared Variance		-	-	-	-	-	-	-	-
	January–December (All months)	correlation co-efficient	1	0.329**	0.244*	0.347**	0.345**	O.350**	0.2	-0.359**	-0.305**
		Sig. (2-tailed)		0.002	0.03	0.000	0.001	0.001	0.07	0.001	0.005
		N	84	84	84	84	84	84	84	84	84
		co-efficient of determination		0.11	0.06	0.12	0.119	0.123	0.04	-0.129	-0.09
		Shared Variance		11%	6%	12%	11.9%	12.30%	4%	-12.90%	-9%

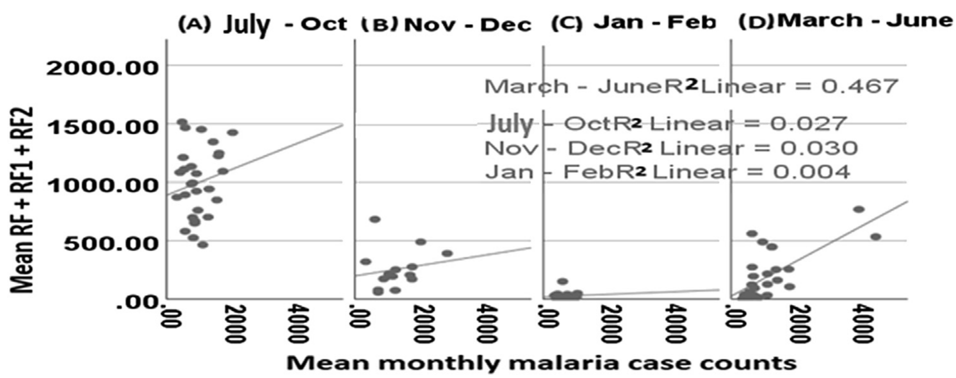

Figure 3. Scattered distribution of mean malaria cases counts and July–October heavy Kiremt/Summer rain (A), November–December Low Kiremt/Summer rain (B), January–February dry (C), and March–June Bulg/spring rain (D) seasons during 2013/14–2019/20.

4. Discussion

Until recently, districts above 2000 m above sea level were considered malaria-free based on the classical knowledge which negatively correlates low temperature with mosquito biology and parasite development inside [33]. But, recently, malaria transmission zones extended to highland areas above 2500 m based on evidence of annual parasite incidences obtained from weekly malaria reports (Public Health Emergency reporting system for Malaria (PHEM)) obtained from all health service facilities in the country for all WHO weeks since 2013 [5,34,35]. In this study, malaria incidence in Dembia and Gondar Zuria neighbor districts during five years (2013/14–2017/18) showed no statistically significant difference ($p = 0.185$). This could be due to the similarity of malaria ecology (geographical location) of the districts. Unlike these two districts, neighbor districts in previous studies could not show similar malaria incidences [20, 36].

Of the 3 types of rainfall patterns in Ethiopia [37], the study area showed the typical northwest (west/southwest) pattern with only one peak rainfall in August. June was also a heavy rainy month making rainfall graph ball-shaped starting from January and end in December. The other rainfall pattern in the Amhara region is the one that is typical in central (east/northeast) Ethiopia which is similar to the northwest rainfall pattern except for low rainfall in June. The third type of rainfall pattern is found in Southern (Southeast) Ethiopia with two rainy seasons (March–May main and September–November minor rain seasons) and is not found in the Amhara region. The study was conducted using 16 districts in the Amhara region to see associations between malaria transmission and climate drivers, May/June and October–November peak transmissions were reported as the characteristics of malaria transmission in western districts of the Amhara region compared to July and September–November peak transmissions in eastern districts [20]. These differences were related to the two types of rainfall patterns in the Amhara region. For eastern districts where June rainfalls decreased from what was in May, malaria transmission could increase continuously until the heavy rain in July or August which affects malaria transmission negatively. The malaria transmission pattern in the study area was similar to the three nearest districts (Libo--KemKem, Mecha, and South Achefer) in the western districts of the Amhara region in the previous study [20]. Malaria transmission existed throughout the year in the study district. There was no month when an absent malaria case was reported. The role of rivers in maintenance parasites or malaria transmission during the dry season has been described before [5]. A total of 5, 543 cases or 8.7% were counted during January–February dry season during the 7 years study period. In highly populated highland areas of Ethiopia often with rivers nearby, dry season malaria transmission cannot be ignored.

There was no correlation between mean monthly rainfalls and mean malaria counts during July–October heavy Kiremt/summer, November–December low Kiremt/summer rainy months, and January–February dry Months ($p \geq 0.05$). But, Bulg/spring months rainfalls (RF + RF1 + RF2) and mean monthly count showed highest 48% shared variance and strong positive correlation ($r = 0.69$; $p = 0.000$) (Table 1). The correlation ($r = 0.35$; $p = 0.001$) between mean monthly rainfalls (RF + RF1 + RF2) and mean malaria counts for overall all the 12 months (January–December) with 12.30% shared variance and 0.123 coefficient of determination was due to the strong correlation effect of Bulg/spring season. Analysis based on the overall 12 months could be misleading in malaria-endemic areas.

The effect of rainfalls on malaria transmission during March's first rain in the Bulg/Spring season was observed in the same month (RF). This might be the reason why spearman's correlation showed a statistically significant correlation ($p = 0.025$) for the current month rainfall (RF) and mean monthly malaria count. Generally, in this study, 0–2 lagged months rainfalls were responsible for the change in mean monthly malaria case counts. Other studies, however, reported the occurrence of malaria incidence on the same month (0 months lagged) of rainfall change [37] or after 1 month lagged [38] or 2 months lagged [39] or 1–2 months lag [24, 25].

Due to the strong spearman's correlation (correlation coefficient = 0.69) between mean monthly malaria cases and mean RF + RF1 + RF2 during Bulg/Spring season, an increase or decrease in rainfall could also show the corresponding increase or decrease in mean monthly malaria cases. Using the correlation graph (scatter distribution graph) which relates mean monthly malaria cases and mean RF + RF1 + RF2 for the study area, it could be possible to predict Bulg/Spring season using future rainfall forecasting for possible intervention (Figure 3D).

During the study period, only one officially recognized 2015/16 El-Nino drought Year was recognized which produced 8509 total cases during the study period (the third-highest). This 2015/16 El-Nino year has passed working against the occurrence of malaria cases in the Bulg/Spring months as it caused relative drought in March–June. But, the effect of anomalous low rains in Kiremt/summer main rainy season in 2015/16 El-Nino drought year resulted in higher malaria counts in September (1025) and October (859) compared to the 7 years 817.1 and 749 average counts respectively. In this year, the anomalous low rainfalls occurred in July (291.13 mm) and August (308.4 mm) compared to 451.04 mm July and 454.6 mm August 7 years averages. Thus, 755.44 mm (69.4%) during July–October heavy Kiremt/Summer rains produced 3149 total cases in this season (37%). Thus, monitoring rainfalls in Kiremt/summer main rainy season for anomalous low rainfalls is also recommended in addition to Bulg/Spring season targeted intervention.

During the historic 1953 malaria epidemic which started in May, the University of Gondar Medical team, which was providing health service, documented a total of 4789 malaria-related deaths from June to December [15]. The catastrophic epidemics in 1958 [14], 1997/98, and 2003 [16,36] were related to April/May–December epidemic period due to rainfall anomalies indicating additional intervention during

Bulg/Spring season. But, in Ethiopia, malaria interventions, including insecticidal residual spraying, are conducted once a year which primarily targets the main rainy season for areas below 2000m asl [33]. The role of March–June Bulg/spring malaria season was 23, 440 (36.9%) in this study. Despite addressing about 50% annual malaria reported cases during high transmission year like 2013/14 or about average 36.9%, Bulg/Spring intervention strategy also reduce the existence of infection in human reservoirs for Kiremt/Summer transmission. Bulg/spring larviciding could also be possible for cost-effective intervention during this low mosquito population season. Unless high malaria cases due to rainfall anomalies, especially during Bulg/Spring season, are properly addressed, there could be malaria outbreaks in Ethiopia similar to Limpopo Province (South Africa) where malaria control program could not stop the 22 fold increase in malaria cases that occurred in 2017 compared 2016 [24].

For Kiremt/Summer season, special attention is needed when the rainfall level is lower than normal. High rainfall by itself controls malaria transmission due to its impact on the survival of the immature stages. Several investigators have indicated the negatively associated relationship of heavy rain with malaria counts (incidence) due to the heavy rain-killing effect of the immature stages [21, 22].

5. Conclusion

Malaria transmission was continuous throughout the year with the highest peaks in May/June and November during Bulg/Spring and Kiremt/Summer rainy season respectively. March–June Bulg/spring months alone showed a statistically significant correlation ($r = 0.69$; $p = 0.000$) between mean monthly rainfalls and mean malaria counts.

Using direct proportionality between rainfall and mean monthly count during Bulg/Spring season (Figure 3D), forecasted rainfall information will have significant value to predict and prevent epidemic or high transmission. Locally specific rainfall (RF + RF1+ RF2) and mean monthly malaria case count scattered distribution graph could be used in all malaria-endemic areas. Bulg/Spring intervention could have also an indirect effect on Kiremt/Summer transmission by reducing the infectivity of humans to mosquitoes. Thus, additional March–June Bulg season targeting intervention is recommended.

Significant Statement: This study discovered the directly proportional relationship between mean monthly malaria confirmed cases counted and mean monthly RF, RF1, RF2 and mean RF + RF1 + RF2 during the March–June Bulg/Spring season that can be beneficial for control of malaria transmission in this season. This study will help the researchers to focus on the impact of rainfalls as the main source of highland malaria epidemics or normal transmission in the Bulg/Spring season. A correlation graph (scattered plat graph) at the district level can predict the relationship between mean rainfalls and the mean monthly malaria count.

5.1. Limitation

Due to lack of previous knowledge on how rainfalls affect mean monthly malaria case counts and mosquito vectors Biology, it was difficult to specifically mention how the different stages of mosquito vectors (the larvae, pupae, and adult stages) are affected by mean RF, RF1, RF2, and RF + RF1 + RF2. The observation of the effect of rainfall variability on mean monthly malaria counts could be affected by the limited years of the study period (7 years).

Declarations

Author contribution statement

Wossenseged Lemma: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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Ethics and consent to participate

All study procedures were conducted by and by approval of the internal review board of the Vice President for Research and Community Service of the University of Gondar.

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