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RESEARCH ARTICLE

ANALYSES OF TEN-YEAR MALARIA TRANSMISSION DYNAMICS IN RELATION TO METEOROLOGICAL VARIABLES IN JABI TEHNAN DISTRICT, NORTHWEST ETHIOPIA

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ABSTRACT: Retrospective studies of malaria cases from health facilities and the impact of meteorological factors provide insight into the dynamics of malaria transmission and the effectiveness of malaria control interventions. This study aimed to analyze inter-annual and monthly trends in malaria cases and determine the correlations between meteorological variables and prevalence of malaria. Retrospective data on malaria cases were extracted from 11 health centres and 39 health posts in Jabi Tehnan district, northwest Ethiopia, for 10 years (July 2011–May 2021). Trends in monthly and annual malaria cases were analyzed and correlated with meteorological data. Of 1,500,868 individuals with febrile complaints examined at the health facilities in the district, 13.4% were diagnosed as clinical malaria cases. Furthermore, 12.6% of those with febrile symptoms had malaria confirmed with microscopy and with rapid diagnostic test (RDT). *Plasmodium falciparum* comprised 56.48%, with 36.56% *P. vivax*, and with 6.96% mixed (*P.f* + *P.v*) infections. There were significant variations in inter-annual and monthly malaria cases ($P<0.001$; $P = 0.004$, respectively). Malaria cases peaked in 2011–2013, and 2015–2016, with reduced and relatively lower malaria cases in 2017–2021. Two malaria peaks in May-June, and in October-November were recorded. Inter-annual and monthly malaria trends were closely correlated with relative humidity and average temperatures. *Plasmodium falciparum* was predominant compared to *P. vivax*. Understanding trends in malaria transmission in relation to climatic variables, and monitoring the effectiveness of malaria control interventions are needed to reduce malaria in the area.

Key words/phrases: Malaria cases, Meteorological variables, *Plasmodium falciparum*, *Plasmodium vivax*, Mixed infection.

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INTRODUCTION

Though there are several reports on the decline in malaria cases in the past two decades, the disease still causes massive morbidity and mortality; and poses a high global disease burden (WHO, 2021a). According to the latest world malaria report, malaria caused an estimated 241 million clinical cases and 627,000 deaths globally in 2020 (WHO, 2021a). The World Health Organization (WHO) Africa region had 95% of all malaria cases and 96% of deaths carrying the largest burden of 35.4 million disability-adjusted life years (WHO, 2021b). Children aged under 5 years were the most vulnerable group affected by malaria in 2021, they accounted for an estimated 80% of all malaria deaths worldwide (WHO, 2021a). The malaria mortality rate globally ranges from 0.3–2.2%, and cases of severe forms of malaria in the tropics are estimated to range from 11–30% (White *et al*., 2014).

Malaria is caused by five species of *Plasmodium* parasites namely *P. falciparum*, *P. vivax*, *P. ovale*, *P. malariae*, and *P. knowlesi* which are transmitted by female mosquito vectors belonging to the genus *Anopheles* (Sato, 2021). *P. falciparum* and *P. vivax* are widely distributed malaria parasites that pose serious public health threats globally (WHO, 2021b). *P. falciparum* is the most prevalent species with nearly 99% of the malaria cases and 94% of all malaria deaths in Africa. *P. vivax* is dominant in most countries outside of sub-Saharan Africa (Snow and Omumbo, 2006). In Ethiopia, *P. falciparum* and *P. vivax* are the predominant malaria parasite species (FMoH, 2016; FMoH, 2017a; Deress Teshiwal and Mekonnen Girma, 2019). These two species are the major malaria parasites responsible for about 70% and 30% of national malaria cases, respectively (FMoH, 2017b). *Anopheles arabiensis* is the primary malaria vector in Ethiopia (O'Connor, 1967; White *et al*., 1980), with *An. funestus*, *An. pharoensis*, and *An. nili* playing secondary roles in malaria transmission (Krafsur, 1971; FMoH, 2014).

The two parasite species coexist in almost all malarious areas at different levels of co-endemicity. A large proportion of infections reported is due to *P. falciparum* (~60%) followed by *P. vivax* (~40%) with micro-epidemiological and seasonal variations (Hiwot Taffese *et al*., 2018). Previous studies have shown an increase in malaria cases since 2015 with a significant burden of asymptomatic *P. falciparum* and *P. vivax* infections in Ethiopia (Fitsum Tadesse *et al*., 2015; Ashenafi Assefa *et al*., 2020). Despite the decrease in mortality and morbidity, malaria has continued to be a public health threat with 75% of the country being malarious, and about 68% of the total population at risk of contracting malaria (Awoke Derbie and Megbaru Alemu, 2017).

In Ethiopia, malaria transmission is seasonal and largely unstable (Rodó *et al*., 2021). Altitude and climate are the most important determinants of malaria transmission in the country. Malaria usually occurs at altitudes <2,000 meters above sea level (masl) (Taye Gari and Lindtjørn, 2018). Areas between 1,000 and 2,200 meters above sea level experience the seasonal transmission of malaria and sporadic malaria epidemics every 5 to 8 years. Occasionally, the transmission of malaria occurs in areas previously free of malaria, including areas >2,000 masl. The peak malaria transmission season in Ethiopia occurs between September and December following the main rainy season, while a second minor peak transmission between March to May is also common in many parts. Both peaks are preceded by rainy months which create a conducive environment for the proliferation of malaria vectors (Wossenseged Lemma, 2021).

Malaria is mainly known to be a climate change-sensitive disease (Omumbo *et al*., 2011). In the recent past, there have been changes in meteorological variables such as temperature, rainfall, humidity and precipitation. These variables are major determinants of malaria transmission and influence both malaria parasites and vectors by modifying the behaviour and geographical distribution of vectors and changing the length of the sporogonic cycle of the parasite (Patz *et al*., 2003; Afrane *et al*., 2012).

Ethiopia embarked on malaria elimination from low transmission districts by 2030. There are about 835 districts with different levels of malaria transmission with an estimated 50.6 million people at risk of infection (Finda *et al*., 2020; Gessessew Bugssa and Kiros Tedla, 2020). Currently, the country has adopted and is implementing the WHO-recommended intervention tools and malaria elimination plan (Hemingway *et al*., 2016). Recent malaria control efforts in Ethiopia have led to progressive changes in the prevalence of malaria infection due to efforts implemented by using effective malaria prevention and control measures in malaria-prone areas with remarkable progress in achieving malaria-related millennium development goal (MDG) targets, as evidenced by reduced prevalence and death rates (Yibeltal Assefa *et al*., 2017).

Despite efforts to control malaria and reduce malaria incidences to a lower level, the disease is still a major public health concern in Ethiopia and elsewhere in tropical Africa. There is a gap in information on the correlation between meteorological variables and malaria transmission in the study area and other malaria-endemic parts of Ethiopia. Thus, this study aimed to analyze retrospective malaria data from health facilities and assess the trend of malaria transmission in relation to changes in meteorological variables in the study area.

MATERIALS AND METHODS

Description of the study area

The study was conducted in Jabi Tehnan district, a malaria-endemic area in West Gojjam zone, Northwest Ethiopia, which is located about 387 km from Addis Ababa, and 176 km southwest of Bahir Dar City (Fig. 1). The area lies between 10° 24′ 36″ to 10° 55′ 48″N latitude; and 37° 4′ 12″ to 37° 30′ 36″E longitude. The altitude ranges from 1,345 to 2,572 masl (Abebe Animut and Yohannes Negash, 2018). A considerable part of the area lies in ranges closer to 2,000 masl where malaria is endemic. The area receives a rainfall of about 1,250 mm per annum, and the mean minimum and maximum temperatures are 14°C and 32°C, respectively. The rainfall distribution in the area is unimodal, and the rainy season lasts from June to mid-September (Seble Ayalew *et al*., 2016). The total population of the district was about 225,769 of which 112,341 were male, and 113,428 were female (CSA, 2013). Malaria transmission in the area is low, seasonal, and unstable and though the epidemiology has been described, there is relatively little data on the meteorological determinants of malaria transmission (Abebe Animut *et al*., 2014).

Study design

A ten-year health facility-based retrospective study was conducted to determine the trends of malaria morbidity with meteorological variables from the National Meteorology Agency (NMA) over ten years (2011–2021) in Jabi Tehnan district, West Gojjam zone, Northwest Ethiopia. The study used monthly and annual precipitation (in mm), relative humidity (% RH), and maximum and minimum temperature (in °C) data obtained from the nearest weather stations.

Source of malaria data

Data on reported malaria cases were extracted from laboratory registry logbooks in the Jabi Tehnan district malaria control program for ten years (July 2011–May 2021). The 11 health centres and 39 health posts that provided malaria diagnosis and treatment services were included in the study. These facilities used the same standard operating procedure (SOP) with the national malaria control program and WHO protocols so that the variables captured were similar irrespective of the type of health facilities.

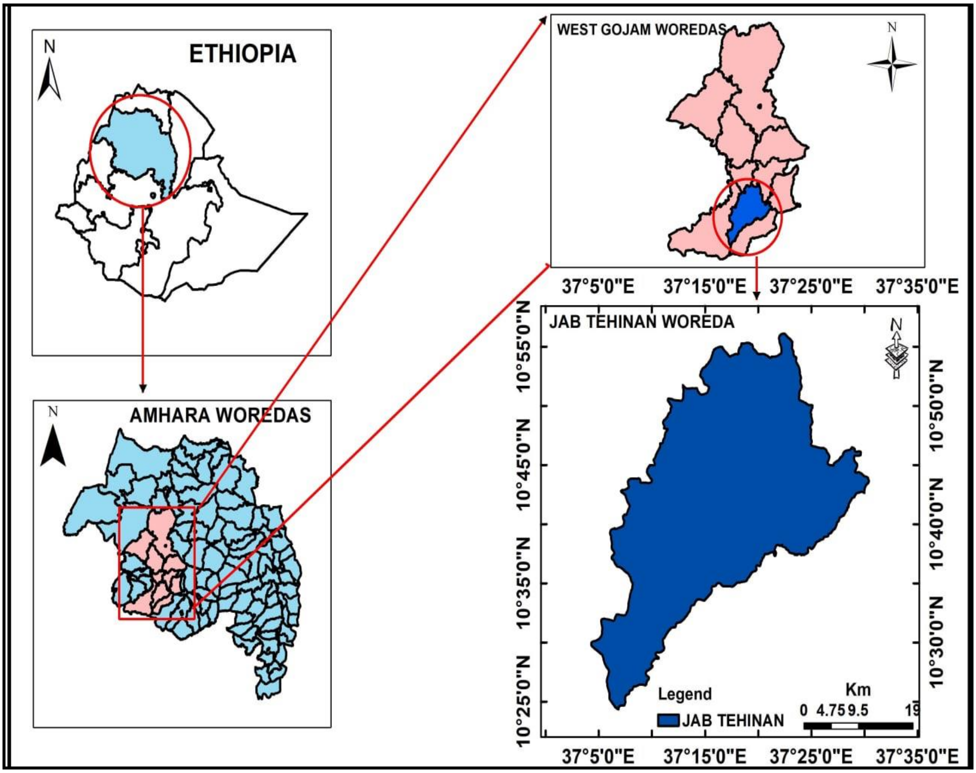

Fig. 1. Map of the study area indicating Jabi Tehnan district ('woreda' means 'district').

Data analysis

All data from meteorological and clinical records were checked for completeness and cleaned for any inconsistencies, and analyzed using Microsoft Excel 2019 version 2110, and IBM SPSS Statistics version 20 (IBM Corporation, Armonk, New York). The correlations between meteorological variables and malaria cases were computed with monthly malaria cases as the dependent variables, and meteorological variables as independent variables.

RESULTS

Trends in annual malaria suspected patients and confirmed malaria cases

Out of 1,500,868 individuals with febrile complaints that visited the district health facilities from July 2011 to May 2021 (10 years), 13.4% (201,051) were malaria suspected patients with malaria symptoms. These were further examined by microscopy or Rapid Diagnostic Test (RDT) in which 12.6% (189,085) were positive for malaria parasites (Table 1).

Inter-annual variations in confirmed and clinical malaria cases were statistically significant (P<0.001) (Table 1). The percent confirmed malaria cases in 2011 (36.3%) and in 2012 (40.8%), were followed by a substantial decline in 2013 (26.6%) and 2014 (10.3%). A surge in the number of confirmed malaria cases was recorded in 2015 (20.6%) followed by a sharp decline starting from 2017, and then steadily decreased by 2021 (Table 1). Similar trends in the number of malaria suspected patients were recorded in 2011 (48.5%) and in 2012 (46.7%) with a sharp decline in 2013 (26.7%) and in 2014 (10.3%), with an increase in 2015 (20.9%) followed by a marked decrease to 2% in 2021.

Table 1. Annual malaria suspected patients and microscopic/RDT confirmed malaria cases in Jabi Tehnan district health facilities (July 2011 to May 2021).

Year	No. examined	Malaria suspected patients		Microscopic/ RDT confirmed malaria cases	
		no.	%	no.	%
2011	37,112	18,009	48.5	13,454	36.3
2012	130,181	60,806	46.7	53,172	40.8
2013	112,447	30,009	26.7	29,925	26.6
2014	94,325	9,688	10.3	9,707	10.3
2015	165,331	34,139	20.9	34,488	20.6
2016	193,396	23,255	12	23,226	12.0
2017	174,087	7,625	4.4	7,619	4.4
2018	181,340	6,340	3.5	6,378	3.5
2019	182,841	5,144	2.8	5,074	2.8
2020	166,294	4,767	2.9	4,773	2.9
2021	63,514	1,269	2	1,269	2.0
Total	150,0868	201,051	13.4	189,085	12.6

Monthly trends in the numbers of malaria suspected patients and confirmed malaria cases

There were significant variations in monthly percent malaria suspected patients and confirmed malaria cases (P = 0.016) (Table 2). Trends in monthly number of confirmed malaria cases consistently showed two peaks in May to June (21,557 and 32,954 malaria cases), and October to November (21,460 and 27681 malaria cases) over the ten-year retrospective study. The highest percent of confirmed malaria cases were recorded in June (19%) and October (16.3%), which correspond to months after the short and long rains, respectively. The lowest percent malaria cases were recorded in the dry season from January (7.9%) to March (6.9%) (Table 2).

Table 2. Cumulative monthly malaria suspected patients and microscopic/RDT confirmed malaria cases over 10 years in Jabi Tehnan district health facilities (July 2011 to May 2021).

		Malaria suspected patients		Microscopic/ RDT confirmed malaria cases	
Month	**No. examined**	**No.**	**%**	**no.**	**%**
January	91,738	7822	8.5	7,206	7.9
February	98,585	6,698	6.8	6,308	6.4
March	141,530	10,506	7.4	9,766	6.9
April	122,779	11,690	9.5	11,342	9.2
May	126,847	22,524	17.8	21,557	17.0
June	173,578	35,554	20.5	32,954	19.0
July	115,362	16,337	14.2	14,703	12.7
August	99,698	12,358	12.4	11,289	11.3
September	106,643	14,837	13.9	13,267	12.4
October	131,929	22,291	16.9	21,460	16.3
November	171,942	27,839	16.2	27,681	16.1
December	120,237	12,595	10.5	11,552	9.6
Total	150,0868	201,051	13.4	189,085	12.6

Trends in *Plasmodium* species prevalence

Of the 189,085 confirmed malaria cases, 56.48% (106,798) were positive for *P. falciparum*; *P. vivax* accounted for 36.56% (69,125); and mixed infections of both species were 6.96% (13,162) (Table 3). *Plasmodium falciparum* was predominant accounting for ≥58.9% malaria cases distributed in most of the years of the study (July 2011–May 2021). Mixed infections with *P. falciparum* and *P. vivax* were more prevalent in 2011 (48.2%), but steadily declined and became very rare from 2012 to 2021.

The prevalence of malaria cases varied among different months ranging from 2% to 36.3%, and there was a statistically significant variation in confirmed malaria cases and parasite species prevalence (P = 0.016). The trends in monthly malaria cases and *Plasmodium* species in the ten-year retrospective study (July 2011–May 2021) showed a statistically significant variation in confirmed malaria cases and parasite species prevalence (P = 0.016) (Table 3). Percent confirmed malaria cases markedly increased in May (11.4%) and June (17.4%), with another peak in October to November (11.3% and 14.6%, respectively), trends that were observed following the short and long rainy seasons. *Plasmodium falciparum* was the predominant malaria parasite during the two peak malaria season following short rains (April/June), and to some extent after the long rains (July to September) (Table 3). *Plasmodium vivax* malaria were common (48%–51%) during the dry season (December to March). Mixed infections with *P. falciparum* and *P. vivax* persisted at much lower levels in all the months with some increase in October (14.3%).

Table 3. Annual *Plasmodium* parasite prevalence among microscopic/RDT confirmed malaria cases in Jabi Tehnan district health facilities (July 2011 to May 2021). NOTE: Pf: *Plasmodium falciparum*, Pv: *Plasmodium vivax*, and Pf/Pv mixed: co-infection of *P. falciparum* and *P. vivax*.

Year	Confirmed malaria +ve (no.)	*P. falciparum*		*P. vivax*		Mixed (P.f + P.v)	
		no.	%	no.	%	no.	%
2011	13,454	2,561	19.0	4,410	32.8	6,483	48.2
2012	53,172	27,916	52.5	20,126	37.9	5,130	9.6
2013	29,925	14,932	49.9	13,604	45.5	1,389	4.6
2014	9,707	5,714	58.9	3,833	39.5	160	1.6
2015	34,488	24,616	71.4	9,872	28.6	-	-
2016	23,226	14,929	64.3	8,297	35.7	-	-
2017	7,619	4,545	59.7	3,074	40.3	-	-
2018	6,378	4,489	70.4	1,889	29.6	-	-
2019	5,074	3,272	64.5	1,802	35.5	-	-
2020	4,773	2,989	62.6	1,784	37.4	-	-
2021	1,269	835	65.8	434	34.2	-	-
Total	189,085	106,798	56.48%	69,125	36.56%	13,162	6.96%

Correlation between confirmed malaria cases with meteorological variables

Pearson correlation analysis of monthly malaria cases to monthly meteorological variables such as rainfall, relative humidity (%RH), maximum temperature (T_{max}), minimum temperature (T_{min}), and average temperature ($T_{average}$) is presented in Table 4. The monthly malaria cases for the 2011–2021 period were ln-transformed and subjected to correlation with these meteorological variables for 0 to 4-months lag effect (Table 4). There was significant correlation of malaria cases with monthly relative humidity at zero-month lag (r = 0.214, P = 0.019); with minimum temperatures at 2-months lag (r = 0.276, P = 0.003), and 3-months lag (r = 0.203, P = 0.029); and with mean temperatures at 2-months lag (r = 0.203, P = 0.028), and 3-months lag (r = 0.202, P = 0.029). The correlations of malaria cases with any of the meteorological variables were not significant at 1-month and 4-months lag time (Table 4).

Table 4. Correlation between monthly malaria cases (log transformed) and meteorological variables over 10 years at different months lag in Jabi Tehnan district, northwest Ethiopia (July 2011 to May 2021).

Variable	Rainfall		RH		T_{Max}		T_{Min}		T_{Mean}	
Lag in months	(r)	P value	(r)	P value	(r)	P value	(r)	P value	(r)	P value
0	0.091	0.326	0.214	0.019*	-0.060	0.519	-0.032	0.732	-0.063	0.494
1	0.058	0.532	0.126	0.175	0.043	0.644	0.179	0.052	0.124	0.118
2	0.015	0.870	0.049	0.599	0.084	0.371	0.276	0.003**	0.203	0.028*
3	-0.010	0.913	-0.030	0.745	0.126	0.178	0.203	0.029*	0.202	0.029*
4	-0.069	0.463	-0.154	0.103	0.126	0.183	0.022	0.815	0.112	

Note: Rainfall = monthly precipitation (mm); RH = relative humidity (%); T_{Max} = monthly maximum temperatures (°C); T_{Min} = monthly minimum temperatures (°C); and T_{Mean} = monthly mean temperatures (°C), r = Pearson correlation coefficient. * = significant at P = 0.05, ** = significant at P = 0.01

The monthly and annual selected meteorological variables and malaria data from the district health facilities over the ten-year period are presented in Fig. 2. The variations in the distribution meteorological variables and confirmed malaria cases indicate consistent seasonal malaria transmission in the area. The area experienced two peak malaria seasons closely associated with the short rains (May-June) and end of the long rainy season (September-October) (Fig. 2A). The annual number of malaria suspected patients and confirmed malaria cases declined from 2012 to 2015 and further dropped to lower levels from 2016 to 2020 (Fig. 2B). Annual meteorological and malaria data were not complete for 2011 (6 months' data) and 2021 (5 months' data) and could not be assertively compared.

DISCUSSION

The ten-year retrospective malaria analysis undertaken in this study indicated that malaria is a major public health concern in Jabi Tehnan district with 13.4% clinically diagnosed as having malaria symptoms (clinical malaria cases) and 12.6% were positive for malaria parasites. There were monthly and inter-annual variations in clinical and confirmed malaria cases during the July 2011−May 2021 period. These results are similar with 11.5% reported in Arsi Negelle health centre by Mengistu Hailemariam and Solomon Gebre (2015), and 11.8% malaria cases in Boricha district, southern Ethiopia by Desalegn Dabaro *et al*. (2020); and closer to the 16.34% prevalence in Dembecha health centre, west Gojjam (Desalegn Haile *et al*., 2020), and 17% prevalence reported in Metema Hospital, west Gondar (Getachew Ferede *et al*., 2013) health facilities in northwestern Ethiopia.

These results were lower than 21.2% reported in East Wollega (Zelalem Babure *et al*., 2021), 32.6% prevalence reported in Woreta town, Amhara Region (Amir Alelign *et al*., 2018); 36.1% malaria cases reported in Adi Arkay Health Centre, North Gondar (Habtie Tesfa *et al*., 2018); 39.6% malaria reported in Kola Diba Health Centre, north Gondar (Abebe Alemu *et al*., 2012); and still much lower than 51.04% malaria cases reported in Guba district, western Ethiopia (Shemsia Alkadir *et al*., 2020).

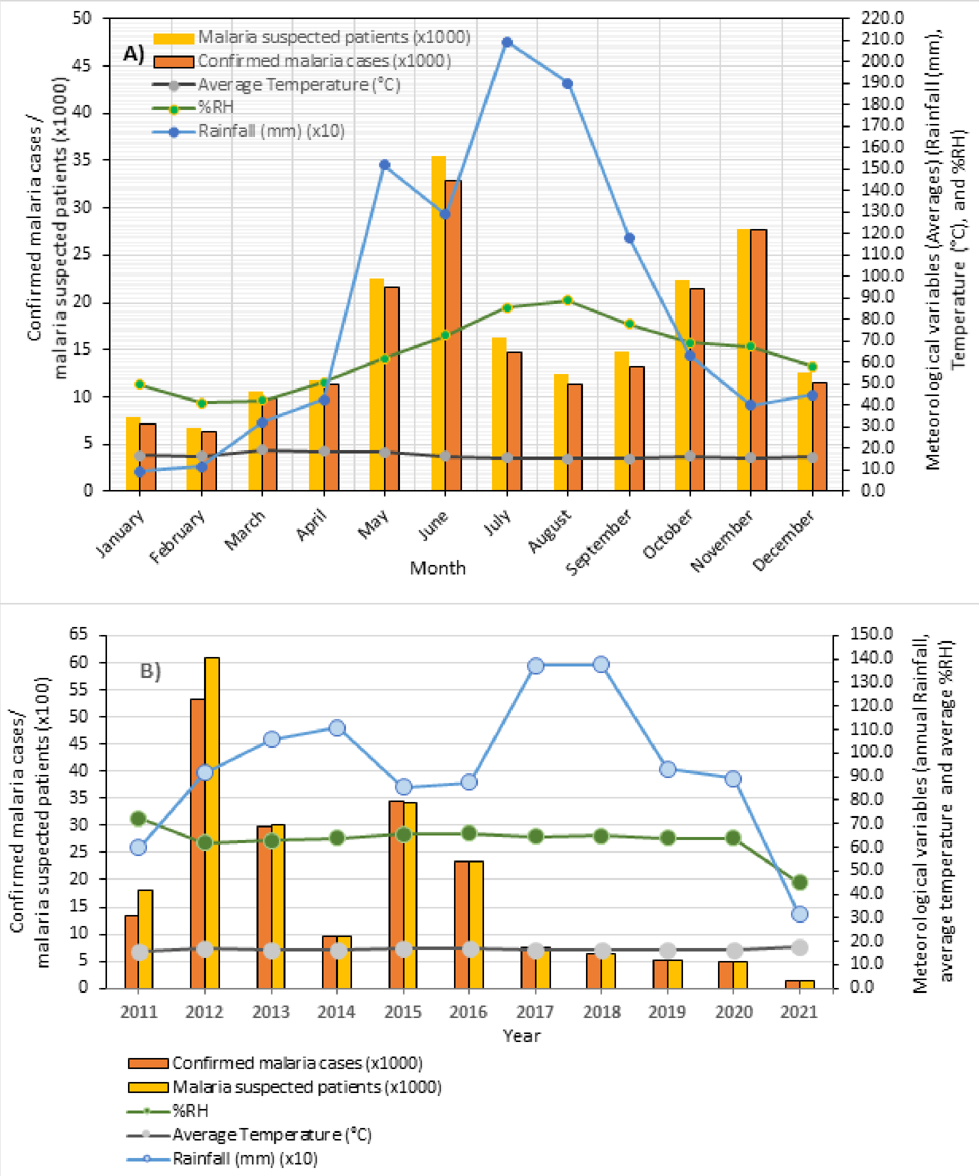

Fig. 2. Trends in monthly fluctuations of confirmed malaria cases and malaria suspected patients over 10 years (A); and variations in annual malaria cases and malaria suspected patients, with fluctuations in selected meteorological variables (B) in Jabi Tehnan district health facilities, northwest Ethiopia (July 2011 to May 2021).

The results in this study are characterized by reduced malaria case prevalence consistent with other studies conducted elsewhere in northwestern Ethiopia (Toyama *et al*., 2016). However, the results in the present study were still higher than the 7.5% malaria cases in Kombolcha Health Centre (Daniel Gebretsadik *et al*., 2018), and the 5% prevalence reported in Felege Hiwot Referral Hospital (Mulat Yimer *et al*., 2017). The differences might be due to time variations of the studies, difference in insecticide application in the areas, variations in geographical locations, differences in population awareness about malaria bed net application, its transmission, and health seeking behaviour.

P. falciparum and *P. vivax* accounted for 56.48% and 36.56%, respectively, with mixed infections comprising 6.96% of the overall confirmed malaria cases reported in the present study. *P. falciparum* was predominant in most of months and years throughout the study period except in 2011. In our study, *P. falciparum* was the predominant species followed by *P. vivax*. This is in agreement with the national malaria reports that highlighted *P. falciparum* as the predominant malaria parasite species. This is also in line with the malaria parasite species distribution in different parts of Ethiopia where malaria is endemic (Asnakew Yeshiwondim *et al*., 2009; Eyob Gebreyohannes *et al*., 2017, Habtie Tesfa *et al*., 2018; Absra Solomon *et al*., 2020). The higher prevalence of falciparum malaria in the study area might be due to climatological differences and altitudinal variations as similar findings were reported in Tanzania and other countries (Bødker *et al*., 2003).

The annual malaria prevalence was initially high (36.3% in 2011 and 40.8% in 2012), but this dropped to 26.6% in 2013, followed with sharp declines in subsequent years (4.4% in 2017 down to 2% in 2021). The steady reduction in annual malaria prevalence in the health facility might be attributed to the effectiveness of national malaria control strategies. The scale-up of malaria control efforts in the district could explain the marked reductions in malaria burden over the ten-year study period (Falaho Kalil *et al*., 2020).

Malaria prevalence in the health facilities were low during the dry season which extend from December to February. Two peaks in malaria prevalence (in May-June after the short rains, and a second peak in October-November following the heavy rainy season) observed in the current study are in agreement with studies in different parts of Ethiopia (Abebe Alemu *et al*., 2012; Awoke Derbie and Megbaru Alemu, 2017; Fitsum Tigu *et al*., 2021). This bimodal trend in peak malaria transmission could be associated with availability of mosquito breeding habitats formed and the build-up of vector populations during the preceding short and heavy rainy seasons in the study area. Our findings are similar to those reported in previous studies in South Africa (Ikeda *et al*., 2017).

The fluctuating trends in season and inter-annual malaria cases were positively correlated with monthly relative humidity, monthly minimum temperatures (T_{Min}), and monthly mean temperatures (T_{Mean}). Monthly malaria cases were associated with prevailing monthly relative humidity (RH), while there were 2- to 3-months lagged effects with monthly minimum temperatures (T_{Min}), and monthly mean temperatures (T_{Mean}). The meteorological factors and variations in malaria cases need to be correlated on larger area-wide scales for more meaningful interpretations (Ikeda *et al*., 2017; Umer *et al*., 2019). The trends in the monthly malaria data revealed two peak malaria seasons and most of the malaria cases occurred following the short and long rainy seasons implying malaria cases peaks lagged behind the rainy seasons (Hussien, 2020). Climatic factors such as temperature, relative humidity, and rainfall are closely associated with the occurrence and magnitude of malaria cases and influence the transmission dynamics of malaria in a given area. Different factors might contribute to the fluctuation of malaria cases including other climatic factors, ecological and socio-economic variables, and malaria interventions implemented in the area.

CONCLUSION

The prevalence of clinical and confirmed malaria cases from the health facilities shows that malaria is a major public health problem in the district. The retrospective trend analysis over the ten-year period (2011−2021) indicated seasonal and inter-annual fluctuations with a consistent reduction in malaria cases. This low-level and declining trend in malaria prevalence may be an essential prerequisite for efforts toward malaria elimination in the district. The observed reduction in malaria prevalence to such low levels over the years could also be an indicator for initiating malaria control strategies appropriate for malaria elimination. Both *P. falciparum* and *P. vivax* are important parasite species in the area and need to be considered in the choice of anti-malarial drugs for malaria elimination. Malaria interventions should be strengthened to sustain control and move towards elimination in the area. Area-wide seasonal and inter-annual meteorological variations are factors that need to be incorporated with core malaria interventions for launching long term malaria elimination undertakings.

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