Djedanem *et al. BMC Infectious Diseases* (2026) 26:455
https://doi.org/10.1186/s12879-025-12286-3

BMC Infectious Diseases

RESEARCH **Open Access**

Burden of malaria among children aged 5–10 years in the Sahelian area: do we need to adapt seasonal malaria chemoprophylaxis?

Médard Djedanem[1,2,3], Mamane Aminou Yacoudima Yacoubou[2,3,4], Abdoussalam Zakari[1], Idi Issa[3], Mahamadou Yahaya[5], Mamane Zaneidou[6], Issaka Mody[6], Daniel Bikele Onana[7], Jean Testa[2,8] and Ronan Jambou[3,8,9*]

Abstract

Background Despite its Sahelian context, Niger is one of the sub-Saharan countries reporting the highest number of malaria cases. Currently, preventive measures such as seasonal malaria chemoprophylaxis (SMC) target children under the age of five during the rainy season. However, malaria is increasingly affecting older children, even during the dry season. Therefore, strategies need to be adapted. To this end, this study analyzed data from 35 dispensaries across seven provinces in Niger to evaluate the impact of malaria on different age groups according to ecological context.

Methods This retrospective study used routine monthly district data from 2018 to 2021. The collected monthly variables were fever, uncomplicated malaria, severe malaria, and deaths, broken down by sex, age group, and region. A forecasting package under R 4.3.3 was used for SARIMA modeling. Multiple linear regression was performed to identify factors associated with malaria.

Results Malaria transmission was highly seasonal, with an annual peak observed between July and October during the four-year study period. During this peak period, children aged 12 to 59 months accounted for an average of 33.2% of cases, followed by those aged 10 to 14 years (26.0%) and 2 to 11 months (22.6%).Older children (5–14 years) together accounted for over one-third of all cases. Geographic disparities were marked: southern districts bordering irrigated agricultural zones reported the highest incidence (3,000–7,500 cases per month), while savanna and Saharan districts reported fewer than 2,500 cases. The Niamey V district recorded peaks of 11,000 monthly cases. SARIMA projections indicated a likely increase in cases after 2022.

Conclusion The results confirm seasonal malaria transmission, with peaks concentrated between July and October. While children aged 12 to 59 months are the most vulnerable, a significant burden was also observed in older children over five years of age. Additionally, geographical disparities were observed, with higher incidences in southern districts close to irrigated agricultural areas and lower transmission rates in Sahelian and Saharan districts. These trends highlight the importance of expanding interventions beyond the traditionally targeted groups.

Clinical trial number Not applicable.

Keywords Malaria, Chemoprevention, Niger, Sahel, Children, Seasonal transmission

---

*Correspondence:
Ronan Jambou
rjambou@pasteur.fr

Full list of author information is available at the end of the article

Background

Malaria remains a major public health issue in many tropical and subtropical regions worldwide. This parasitic disease is transmitted through the bites of mosquitoes belonging to the Anopheles genus and affects millions of people each year, particularly in sub-Saharan Africa. It continues to cause significant morbidity and mortality, particularly among children under five and pregnant women. The persistence of malaria reflects challenges related to access to care, vector control, and growing resistance to drugs and insecticides [1].

Despite the significant resources mobilised to combat malaria and the substantial decline observed over the past decade, the disease is experiencing a resurgence globally. In 2023, there were 11 million more malaria cases than in 2022, and 31 million more than in 2019, bringing the total to 263 million cases and 597,000 deaths [1–3]. The African region bears most of the global burden of the disease, accounting for 94% of cases and 95% of deaths [1]. More than half of all malaria deaths worldwide occurred in four African countries: Nigeria, which accounted for 26.8% of deaths, followed by the Democratic Republic of Congo with 12.3%, Uganda with 5.1% and Mozambique with 4.2% [1]. However, Niger, despite its large arid zones, is one of the top ten African countries reporting the highest number of malaria cases [3].

Niger is located in Sahel, south of the Sahara, a semi-arid region which stretches for some 5,900 km, from Senegal in West Africa to Sudan and Ethiopia in East Africa [2]. Although the ecological context of this region might suggest otherwise, malaria remains highly endemic, with a significant impact on children under five and a growing burden among those aged 5 to 10 [3]. This gradual re-increase in transmission is the result of a number of factors, including (i) a return to rainfall levels comparable to those of the 1970s, (ii) increasing anthropization disrupting rainwater run-off and causing flooding, and (iii) a global change in the ecosystem that is more favorable to vectors [4–6].

Niger's climate is globally dry and very hot, but the country is divided into three main climatic zones according to latitude: a Saharan zone with less than 200 mm of annual rainfall, a Sahelian zone receiving between 200 and 600 mm, and a Sudanian zone with more than 600 mm [5]. Two main seasons alternate in the year: a long dry season lasting eight to nine months, and a short rainy season varying from three to four months. Niger's climatic and geographical conditions make malaria a public health problem in most of the country [7, 8]. The effects of global warming are modifying rainfall patterns, creating environments supporting continuous mosquito breeding through stagnation zones, even during the dry season [9–11]. This contributes to extending the geographic distribution of malaria vectors and increasing their reproduction rate.

The National Malaria Control Program (NMCP) set-up several control strategies, such as the distribution of Long-Lasting Impregnated Mosquito Nets (LLINs), indoor spraying of insecticides, epidemiological surveillance and Seasonal Malaria Chemoprophylaxis (SMC) for children under 5 years [11]. SMC is based on administration of a single dose of sulfadoxine-pyrimethamine (SP) and three doses of amodiaquine over three days, in four to five monthly cycles, depending on the epidemiological strata [12]. Currently, children over the age of five are not included in the SMC target group because children under the age of five account for approximately 76% of malaria deaths in Africa [13]. This justifies their priority in prevention strategies. Over the age of five, children are supposed to be already exposed to malaria and to have develop partial immunity. In areas where malaria transmission remains intense but seasonal, this protection seems not always acquired at the age of five and data show a significant burden of malaria cases among these children. Exclusion of children over five years, from the SMC can thus be debated [14–17].

In light of the gradual changes in malaria transmission, the study aimed to evaluate the malaria burden across different age groups and ecological contexts. The goal was to determine if older children should be included in SMC and if an additional dose should be administered during the dry season.

Methods

Study design

This longitudinal, retrospective study is based on routine clinical data collected from health centers from January 2018 to December 2021, through DHIS2. Five health facilities were selected by simple random sampling in each health district included in the study. First, the complete list of health facilities in each district was obtained from local health authorities. Then, five health facilities per district were selected using a random number generator in Excel without replacement. This method ensured that each health facility had an equal probability of being included in the sample, thus ensuring the representativeness and reproducibility of the selection.

Study sites

The transmission of malaria in Niger depends heavily on bioclimatic zones. According to the National Office for meteorology forecasting, there are three types of climatic zones in Niger (i) the Saharan zone covering the northern part of the country, with less than 200 mm of rainfall per year, corresponds to the hypo-endemic malaria zone; (ii) the Sahelian zone, with rainfall between 200 and 600 mm, corresponds to the meso-endemic zone which a short seasonal transmission; (iii) the Sudanese zone, with more than 600 mm of rainfall, corresponds to the hyperendemic zone in the southern part of the country, experimenting a highly seasonal transmission.

This study was conducted in seven health districts: Niamey V, Balleyara, Boboye, Dakoro, Arlit, Matameye, Damagaram Takkaya all belonging to different epidemiological strates of malaria transmission.

Balleyara (Tillabéri)

This district is located approximately 95 km northeast of Niamey and features a savanna landscape with hills and plains. Annual rainfall ranges from 400 to 600 mm and is concentrated between June and September. The district covers 1,314 km^2 and has a population density of 121 inhabitants per km^2. 80% of the population has access to healthcare. Transmission of malaria is meso-endemic .

Arlit (Agadez)

Located in the northern Sahara region of Niger, Arlit is 240 km far from Agadez and has an arid climate with less than 300 mm of rainfall per year. With 156,467 km^2, the population density is low (92 inhabitants/ km^2) and with 91% health coverage. Transmission of malaria is hypo-endemic.

Boboye (Dosso)

Located 180 km southwest of Niamey, Boboye (4,794 km^2) has a Sudano-Sahelian climate with annual rainfall between 400 and 600 mm and a population density of 78 inhabitants/ km^2. Only 54.22% of the population has access to healthcare. Transmission. is here hyperendemic.

Dakoro (Maradi)

Located approximately 620 km from Niamey, Dakoro is situated in a Sahelian zone with an annual rainfall of 300 to 500 millimeters. The district covers 11,861 km^2 and has a population density of 82 inhabitants/km^2. It is a hyperendemic zone for malaria transmission.

Damagaram Takaya (Zinder)

This southeastern Niger district is 850 km from Niamey and has a semi-arid climate with a short rainy season (three months) and 400 to 600 mm of rainfall. The district has low health coverage (29.53%) and a population density of 34 inhabitants per km^2. Transmission of malaria is meso-endemic.

Matameye (Zinder)

Located about 900 km east of Niamey, Matameye has a Sahelian climate with a long dry season and a short rainy season (400–600 mm per year). The town covers 2,381 km^2 and has a population density of 194 inhabitants/km^2. Meso-endemic transmission zone.

For Niamey only the 5th arrondissement was considered, located on the right bank of the Niger River. The district covers 40 km^2 and has a Sahel-Sudanese climate with temperatures ranging from 15 °C to 45 °C and an average rainfall of 600 mm. The district is a hyperendemic malaria transmission zone [17, 18].

Data source

This study analyzed routine malaria data extracted from the District Health Information System (DHIS2) for thirty-five health facilities in seven districts. Daily consultations are recorded, including information on gender, age group, area of residence, malaria laboratory tests, cases of mild and severe malaria, and malaria-related deaths. The data are aggregated monthly by age group and transmitted to the Ministry of Health's Directorate of Surveillance and Epidemic Response (DSRE). The data were linked to the district population for the corresponding age groups.

All health facilities in Niger are equipped with rapid diagnostic tests (RDTs) for malaria. Therefore, all malaria cases were confirmed by RDTs or Giemsa-stained thick smears at health facilities. Severe malaria cases were defined according to World Health Organization (WHO) criteria updated in 2020 [19].

Inclusion and exclusion criteria

The data for this study were extracted from healthcare facility consultation records; no primary data collection was involved. Children with fever and no obvious respiratory, digestive, or viral causes were included. Confirmed cases concerned suspected malaria plus a positive test for malaria. The analysis included all confirmed cases of malaria in children aged 0–5, 5–9, and 10–14 years who presented to health facilities. This corresponds to a comprehensive retrospective sampling of malaria cases according to facility records. Non-inclusion criteria were children with obvious cause of infection, or with no biological diagnostic of malaria available.

Statistical analysis

Data analysis was carried out using R software version 4.3.3 to manipulate, visualize and import variables (tidyverse/ dplyr packages) or to to produce graphs (ggplot2 package). Scripts were developed for data management and analysis, and were stored on GitHub.

We performed descriptive statistics, followed by a multifactorial analysis using the general linear model (GLM) to assess the effects of factors such as region, age group, and gender on the quantitative variables of interest. This approach allows us to test the main effects, as well as the interactions between factors, while accounting for possible imbalances in sample sizes.

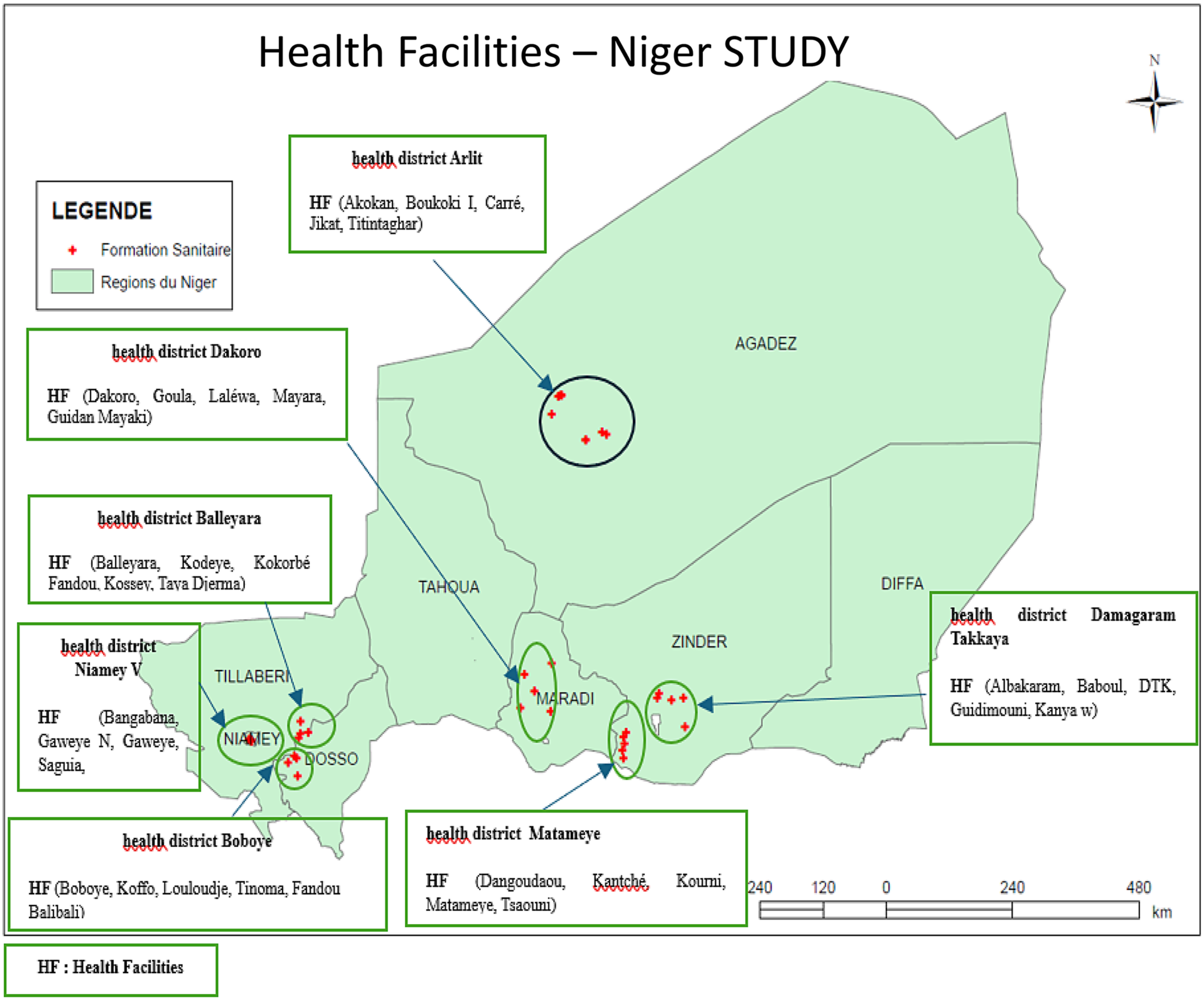


Fig. 1 Administrative map of Niger. The 35 dispensaries are located on the map by district

Time periods and time zones in the time series were determined by segmentations using Residual Sum of Squares (RSS) and the Bayesian Information Criterion (BIC, lubridate package). The RSS expressed as $RSS = \sum_{i=1}^{n}(y_i - \widehat{y}_i)^2$quantified the deviation between observed values (y_i) and predicted values ($\widehat{y}_i$), while the BIC, defined as BIC=-2·ln(L)+k·ln(n). was applied as a statistical criterion that compared the goodness of fit of competing models or clusters, where L represented the likelihood of the model, k the number of parameters, and n the sample size [20, 21].

The Data on fevers, mild malaria, severe malaria, and number of deaths were aggregated by month or by year, by district or by dispensary to perform principal component analysis (PCA FactoMineR package and Factoextra package [20–22]. Each dispensary-month or district-month data were considered as the individuals for the Principal Component Analysis (PCA). However, before analysis, for one place (dispensary of district) each data (total dispensary-month or total district-month) was normalized and centered in accordance with data collected over the four years using $Normalized\ values = \frac{(\text{total/month}) - (\text{total 48 months})}{(\text{total 48 months})}$. Distances between points were calculated using Euclidean distance (Distance = $\sqrt{(PC1_2 - PC1_1)^2 + (PC2_2 - PC2_1)^2}$). The first two axes (PC1 and PC2) were determined based on the percentage of cumulative variance.HAC was applied using Euclidean distance as the measure of dissimilarity between points to explore the data structure and identify the optimal number of clusters, followed by K-means clustering on the same PCA coordinates to group dispensaries or districts into homogeneous clusters [21].

A SARIMA (Seasonal Autoregressive Integrated Moving Average) model, suitable for modeling time series with seasonal components, was applied by fitting the model to data from the first three years (2018–2020). Data obtained in the fourth year were compared with data predicted by the model. Model parameters were estimated using the maximum likelihood method. Each district was analyzed and modelled separately. This approach was also used to capture trends and seasonal patterns in the data.

To test autocorrelation in the residuals, a Box-Pierce test was performed [22], indicating that the model adequately captures the underlying dynamics. The Seasonal Autoregressive Integrated Moving Average (SARIMA) model was denoted as SARIMA(p, d,q) (P, D,Q)s, where p represented the order of the non-seasonal autoregressive (AR) terms, d the degree of non-seasonal differencing, and q the order of the non-seasonal moving average (MA) terms. Similarly, P indicated the order of the seasonal autoregressive terms, D the degree of seasonal differencing, and Q the order of the seasonal moving average terms, while s denoted the length of the seasonal cycle (e.g., s = 12 for monthly data with yearly seasonality). was used to generate forecast for 2021 for each district. Predictive performance of the models was evaluated by comparison of the predicated and real data. Forecasts for a fifth year (year 2022) were then predicted to assess the medium-term robustness of the model defined by $\Phi p(Bs)\phi p(B)(1\text{-}B)d(1\text{-}Bs)DYt = \Theta q(Bs)\theta q(B)\epsilon t$.

Multiple linear regression was finally used to analyze link between explanatory variables (region, month, fever, sex, age group, etc.) and the dependent variable (number of uncomplicated malaria).

Ethical considerations

This study was conducted in collaboration with the Statistics Directorate (DS) and the Epidemic Surveillance and Response Directorate (DSRE), in strict compliance with the Declaration of Helsinki for epidemiological studies. The data were anonymized and extracted from DHIS2 in a disaggregated, raw format. The quantitative analysis used only routine surveillance data collected at health facilities, and the data were stored securely, accessible only to authorized personnel. No changes were made to the source data received. This work was conducted on behalf of the health Ministry authority and ethical control.

Study outcomes

The primary expected outcome of the study was to compare the burden of malaria in young (0–5 years) and older (5–10 years) children, to give arguments of the Ministry of Health to include these later in the SMC. The secondary outcomes were, (i) to evaluate transmission of malaria during winter, to propose a fifth round of treatment SMC during this period, (ii) to evaluate the difference of transmission in the different climatic area of the country (iii) to evaluate the impact of these differences on the burden of malaria in older children and (iv) to explore heterogenicity of the transmission inside districts.

Results

Overall trends in malaria in Niger from 2018 to 2021

To better understand heterogenicity of the data collected in the 35 structures, the data collected over the whole country were summarized to get ideas on the national malaria trends,

For the whole country. The malaria incidence rate per 100,000 inhabitants was 16,620 in 2018, 18,700 in 2019, 19,058 in 2020, and 17,222 in 2021. This takes into account the rapid increase of the population in Niger which doubles every twenty years. Indeed, according to the DSRE, the number of malaria cases in Niger increased by 29% over the past four years, rising from 2,367,989 cases and 2,756 deaths in 2017 to 4,937,676 cases and 4,182 deaths in 2021 [23–25].

Fever by age and gender

For the 35 healthcare facilities, data from the four years of analysis revealed that 577,349 children suffering from febrile attacks attended dispensaries. The number of fever cases was higher among children under 5 years of age (453,879 cases, 78.61%) than among older children aged 5 to 9 and 10 to 14 years (123,470 cases, 21.39%, $X^2 \approx 15.14$; $p < 0.0001$) (Table 1, S2). Among the 5–9 and 10–14 age groups, girls had a consistently higher number of fever episodes than boys, with 291,752 cases (50.53%) among girls and 285,597 cases (49.47%) among boys. This difference was statistically significant ($X^2 = 64.8$, $p = 5.48 \times 10^{-16}$). (Table 1, S2).

Uncomplicated malaria, by age and gender

Confirmed cases of uncomplicated malaria peak between July and October (Fig. 2A, S1), coinciding with the rainy season. The proportion of confirmed malaria cases among children with fever varied according to age and sex. The proportion was lowest among younger infants (63.7%) and highest among children aged 5–9 years (97%), suggesting that other causes of fever are more prevalent among younger ones. Among children aged 2–11 months, 84.6% of girls and 75.6% of boys had confirmed malaria ($X^2 = 25{,}5$, $p < 0.001$). Severe forms and deaths remained rare in this age group (1.8% and 3.2%, respectively). Among 5- to 9-year-old children, the proportion of confirmed cases was higher for girls (57.3%) than for boys (42.7%) but was similar for older ones (50.3% vs. 49.7%). (Table 2)

Severe malaria, by age and gender

Overall, children aged 5 to 14 years (who were not covered by SMC) accounted for twice as many consultations

Table 1 Data collected for the seven districts summarized by year (2018–2021)

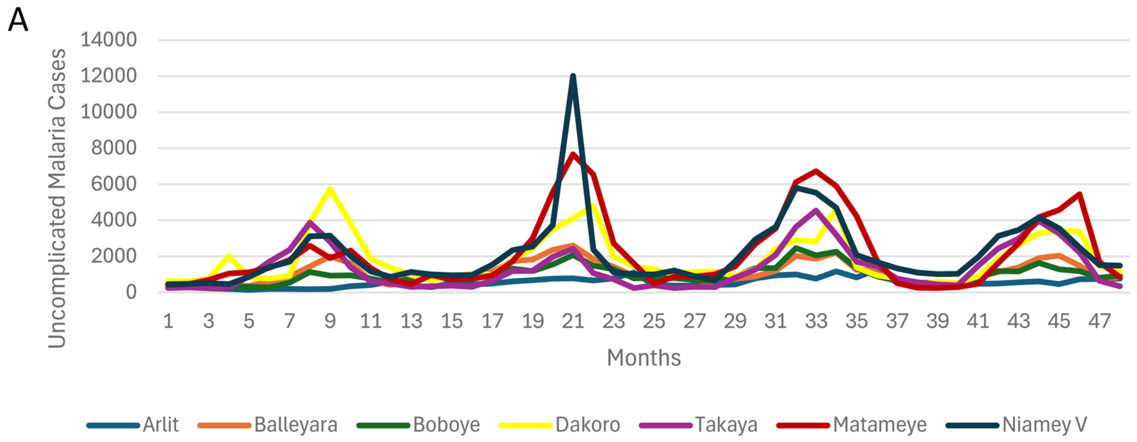
Years	Age range	Sex	Fever	confirmed uncomplicated N (%)	P-values	Confirmed severe malaria N (%)	P-Values	Deaths* N (%)	P-value
2018	< 2 mois	F	11586	8788 (75,85)	0.62	68 (0,77)	1	1 (1,47)	1
		M	19 342	18644 (96,39)		53 (0,28)		3 (5,66)	
	2-11 mois	F	8041	6938 (86,28)	0.59	319 (4,59)	0,4	12 (3,76)	0,8
		M	7342	5183 (70,59)		339 (6,54)		11 (3,24)	
	12-59 mois	F	20718	20066 (96,85)	0.34	861 (4,29)	0,3	35 (4,06)	0,7
		M	21798	19260 (88,35)		824 (4,27)		38 (4,61)	
	5-9 ans	F	9268	8122 (87,63)	0,66	131 (1,61)	0,0005	0	N/A
		M	9295	8067 (86,78)		205 (2,54)		0	
	10-14 ans	F	3182	2767 (86,95)	0,37	58 ()	0,01	0	N/A
		M	3595	2701 (75,13)		35 ()		0	
2019	< 2 mois	F	17797	14236 (80.00)	0.62	153 (1,07)	0,9	0	0,002
		M	18531	15149 (81,74)		152 (1.00)		9 (5,92)	
	2-11 mois	F	17900	16845 (94,10)	0.88	321 (1,90)	0,1	11 (3,42)	0,33
		M	17137	14755 (86,10)		286 (1,93)		16 (5,59)	
	12-59 mois	F	18486	17585 (95,12)	0.57	823 (4,68)	0,1	40 (4,86)	0,06
		M	16984	15814 (93,11)		890 (5,62)		58 (6,51)	
	5-9 ans	F	15271	14531 (95,15)	0.46	142 (0,97)	0,19	0	N/A
		M	7723	7126 (92,26)		121 (1,69)		0	
	10-14 ans	F	5607	4446 (79,29)	0,5	69 (1,55)	0,03	0	N/A
		M	5461	4396 (80,49)		96 (2,18)		0	
2020	< 2 mois	F	34788	28565 (82,11)	0.47	270 (0,94)	0.05	0	0.0003
		M	30630	22265 (72,69)		316 (1,41)		13 (4,11)	
	2-11 mois	F	20834	18259 (87,64)	0.54	379 (2,07)	0.0003	13 (3,43)	0.84
		M	19539	14536 (74,39)		287 (1,97)		12 (4,18)	
	12-59 mois	F	21502	18472 (85,90)	0.77	1047 (5,66)	0.001	22 (2,10)	0.75
		M	20636	17787 (86,19)		1197 (6,72)		20 (1,67)	
	5-9 ans	F	9004	8679 (96,39)	0.95	75 (0,86)	0.0000	3 (4.00)	0.08
		M	7720	7405 (95,91)		131 (1,76)		0	
	10-14 ans	F	7026	6777 (96,45)	0.48	177 (2,61)	0.56	0	N/A
		M	6770	6025 (89,00)		188 (3,12)		0	
2021	< 2 mois	F	14256	13175 (92,41)	0.61	82 (0,62)	0.000	6 (7,31)	0.76
		M	20961	16514 (78,78)		39 (0,23)		5 (12,82)	
	2-11 mois	F	25100	18766 (73,76)	0.50	253 (1,34)	0.0001	5 (1,97)	0.47
		M	25399	17996 (71,02)		175 (0,97)		3 (1,71)	
	12-59 mois	F	13262	12137 (91,51)	0.38	726 (5,98)	0.4	15 (2,06)	0.49
		M	13794	12732 (92,30)		758 (5,95)		19 (2,50)	
	5-9 ans	F	11780	10585 (89,85)	0.28	295 (2,78)	0.01	0	N/A
		M	7980	7337 (91,94)		241 (3,28)		0	
	10-14 ans	F	7704	7172 (93,09)	0.95	781 (10,88)	0.0004	0	N/A
		M	7540	6804 (90,23)		648 (9,52)		0	

* among severe malaria cases

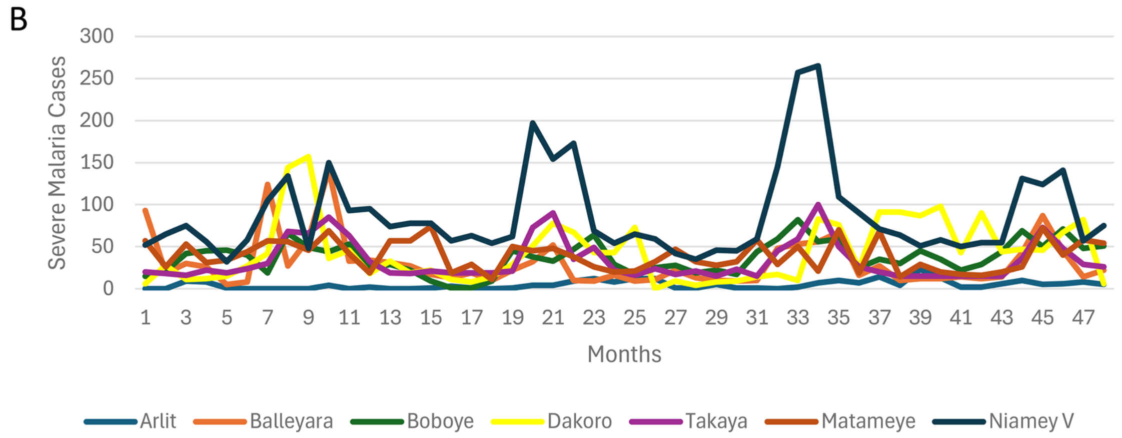
for uncomplicated malaria as children aged 0 to 5 years (410,174 vs. 192,049). However, the proportion of severe cases was higher among younger children (9.8% vs. 1.6%). Among older children, the mortality rate for severe cases was higher than for younger children (2.2% vs. 0.9%, $P = 0.05$).

Uncomplicated and severe malaria and deaths by district

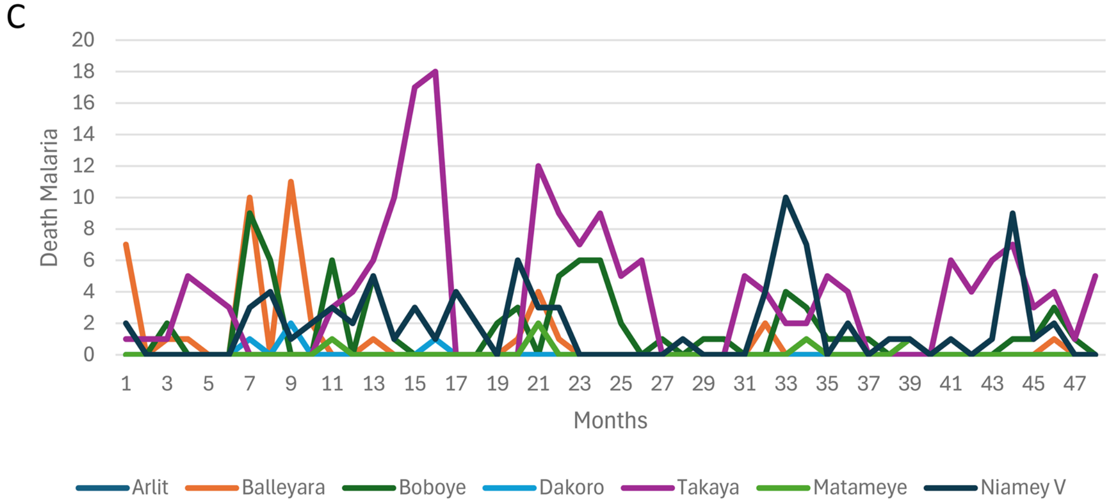
A comparison of the seven health districts (Fig. 2A, S1, and S2) reveals that Niamey V recorded the most confirmed cases of uncomplicated malaria, with 11,000 consultations per month. The southern districts (Matameye, Damagaram Takaya, Boboye, Niamey, and Dakoro), which are located near irrigated land, had high transmission rates (3,000 to 7,500 cases per month). In contrast,



Mild malaria



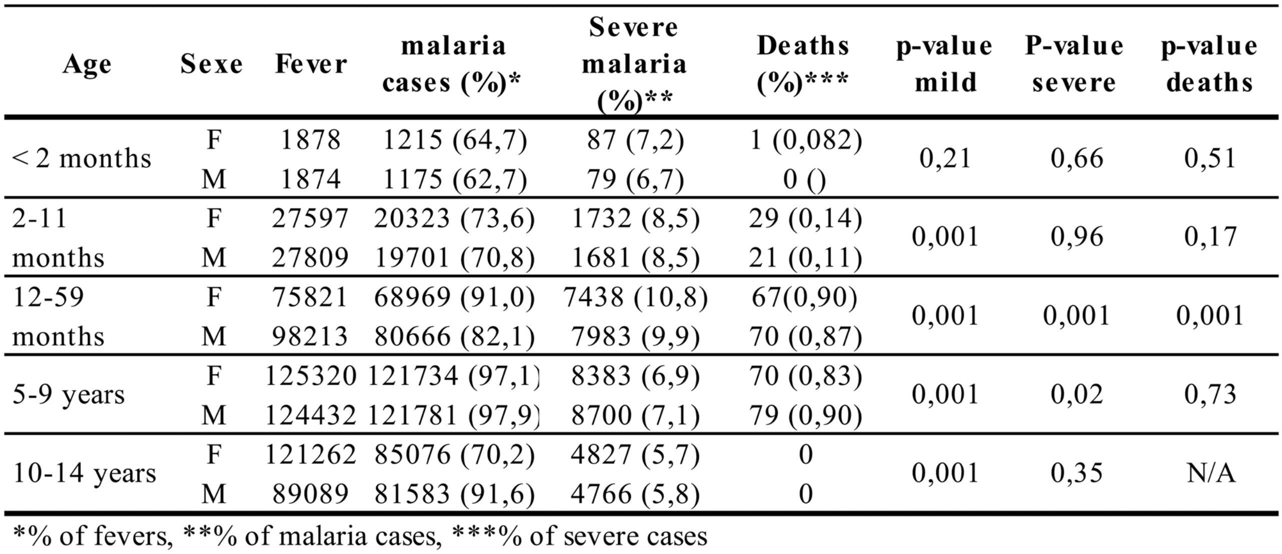
Severe malaria



Death / malaria

Fig. 2 Cumulative number of cases registered by the five dispensaries of each district from 2019 to 2021. A/ number of cases of confirmed mild malaria spotted by month for the seven districts. A seasonal pic of number of cases can be seen each year during the rainy season. During the dry season, number of accesses can be still identified. (start at 1 = January). B/ number of cases of severe malaria spotted by month for the seven districts. A season pic can be seen as in A) however severe cases can be seen almost all over the year. C/ number of deaths due to malaria spotted by month for the seven districts. The cases followed the appearance of the severe disease with lot of deaths even during winter. Three districts of the South part of the country registered most of deaths (Takaya, Matameye, Niamey)

Table 2 Data collected for the seven districts summarized by age (2018–2021)



Age	Sexe	Fever	malaria cases (%)*	Severe malaria (%)**	Deaths (%)***	p-value mild	P-value severe	p-value deaths
< 2 months	F	1878	1215 (64,7)	87 (7,2)	1 (0,082)	0,21	0,66	0,51
	M	1874	1175 (62,7)	79 (6,7)	0 ()			
2-11 months	F	27597	20323 (73,6)	1732 (8,5)	29 (0,14)	0,001	0,96	0,17
	M	27809	19701 (70,8)	1681 (8,5)	21 (0,11)			
12-59 months	F	75821	68969 (91,0)	7438 (10,8)	67(0,90)	0,001	0,001	0,001
	M	98213	80666 (82,1)	7983 (9,9)	70 (0,87)			
5-9 years	F	125320	121734 (97,1)	8383 (6,9)	70 (0,83)	0,001	0,02	0,73
	M	124432	121781 (97,9)	8700 (7,1)	79 (0,90)			
10-14 years	F	121262	85076 (70,2)	4827 (5,7)	0	0,001	0,35	N/A
	M	89089	81583 (91,6)	4766 (5,8)	0			

*% of fevers, **% of malaria cases, ***% of severe cases

the districts in the savanna areas (Arlit and Balleyara) had lower case numbers (1,000 to 2,500 cases per month). The number of cases increased in 2019 and 2020, with a slight decrease in 2021 (Fig. 2). Severe cases followed the same seasonal trend, peaking in 2020 (Fig. 2B). Deaths shifted towards the end of the October–November rainy season (Fig. 2C), with higher numbers in the Damagaram Takaya district.

A principal component analysis (PCA) was performed to account for fever, uncomplicated malaria, severe malaria, and deaths simultaneously. The data were centered and reduced to compensate for the effect of population size and allow comparison between districts. First principal axis (1), which explains 34.5% of the variance, contrasts uncomplicated malaria and fever with severe malaria and deaths. Axis 2, which explains 27.6% of the variance, contrasts fever with deaths (Fig. 3A-B).

The PCA revealed considerable heterogeneity between districts and between years within the same district (Fig. 3C). For instance, Balleyara exhibits significant variability, as indicated by its large ellipsoid (Fig. 3D). In Damagaram Takaya, a district covered by SMC in 2019, a shift along first principal axis illustrates a relative reduction in severity without any notable improvement in mortality (axis 2). This suggests better community monitoring without any change in health center performance. Overall, the Sahelian districts' ellipsoids are elongated on the second axis (severity-death), while the agricultural districts are elongated on first principal axis fever-simple illness). This reflects potentially more effective protection against malaria in the latter.

PCA showed that for one district, data collected during the different years do not cluster together, (Fig. 3C). For Balleyara, for example, ellipsoid of data is very large (Fig. 3D). Similarly, for Damagaram (included in SMC strategy in 2019), a shift in severity (change on the position on first axis) can be seen but without real improvement in the mortality (no movement on the second principal axis), supporting an improvement in the community health, without any improvement in the performance of the dispensary itself (Fig. 3C).

Intra-district variation of malaria burden (suppl Fig. 1, suppl Fig. 2, S3 suppl. data)

In previous analyses, data from the five health facilities within each district were aggregated. Although each district generally shares a homogeneous ecological context, micro-ecological heterogeneity may lead to differences between facilities within the same district. Therefore, data from each facility were analyzed using Principal Component Analysis (PCA), hierarchical classification, and K-means clustering (Supplementary Fig. 4). Annual data from each facility were also aggregated, and districts were analyzed collectively by year (Supplementary Fig. 2, supplementary Table 3). PCA axis 1 separates fever and uncomplicated malaria cases from severe cases and deaths, while the second axis distinguishes malaria cases from other causes of fever and deaths.

This intra-district analysis revealed significant annual variability in patient recruitment and facility performance, with well-defined clusters. Standardizing patient recruitment is therefore challenging, as intra-district variability often exceeds inter-district variability. Several facilities showed a decline in performance after 2018, notably Balleyara, Kodeye (Boboye district), and Koffo, with increased mortality. Conversely, despite a high proportion of severe cases, fewer deaths were recorded in Niamey, likely due to the proximity of several hospitals.

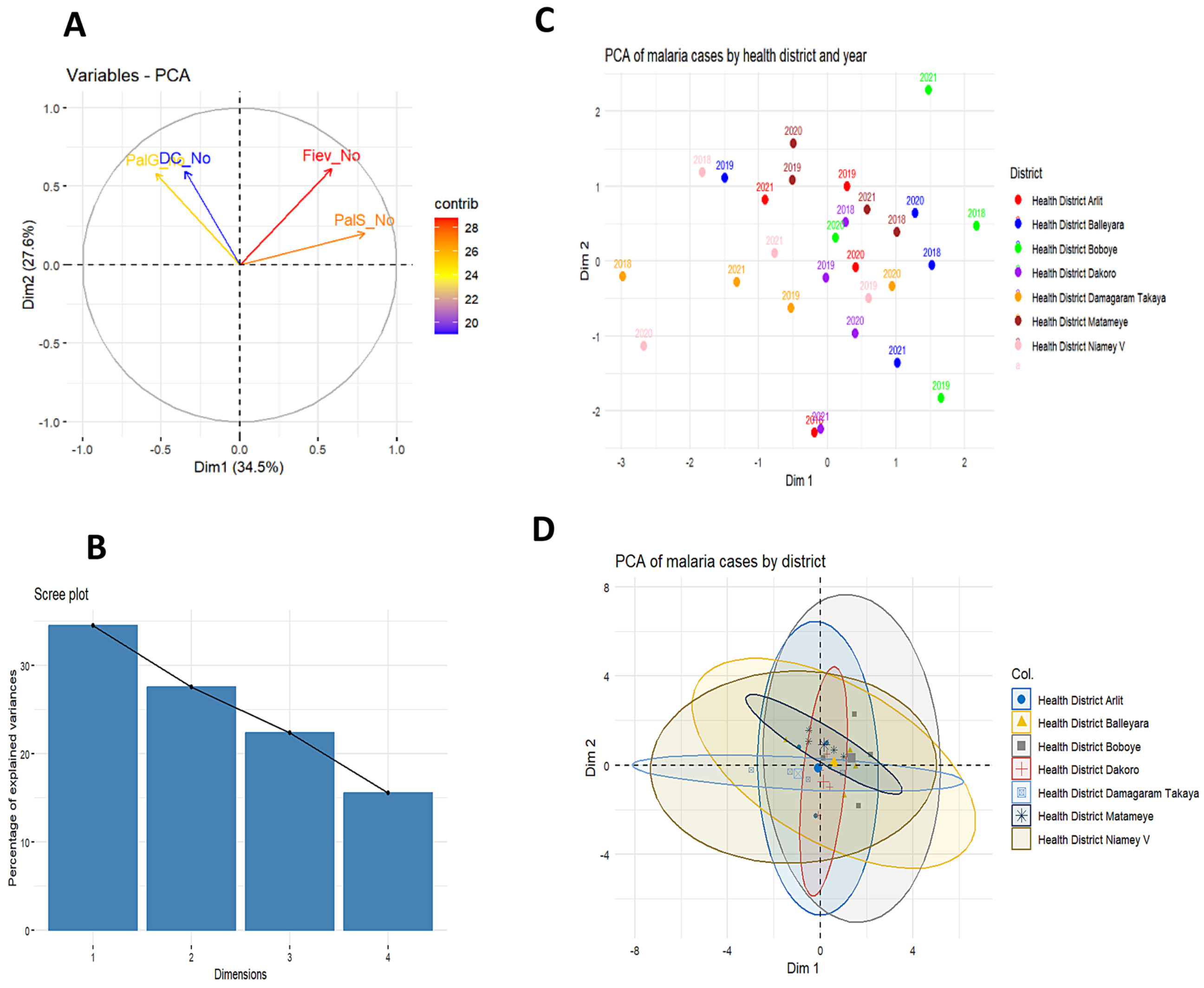


Fig. 3 Principal component analysis of annual data of the seven districts. Data of each district were grouped yearly after normalization with the total number of cases registered for the seven districts in all over the study period. A/ projection of the variables on the first two axis. Axis 1 contrasts uncomplicated malaria and fever with severe malaria and death. B/PCA of the 7 × 4 points (7 districts – 4 years, yearly data of each district). C/Variance explained by the first four axis. D/same data as A/ but expressed as centroids of the 4 sets of data of the one district

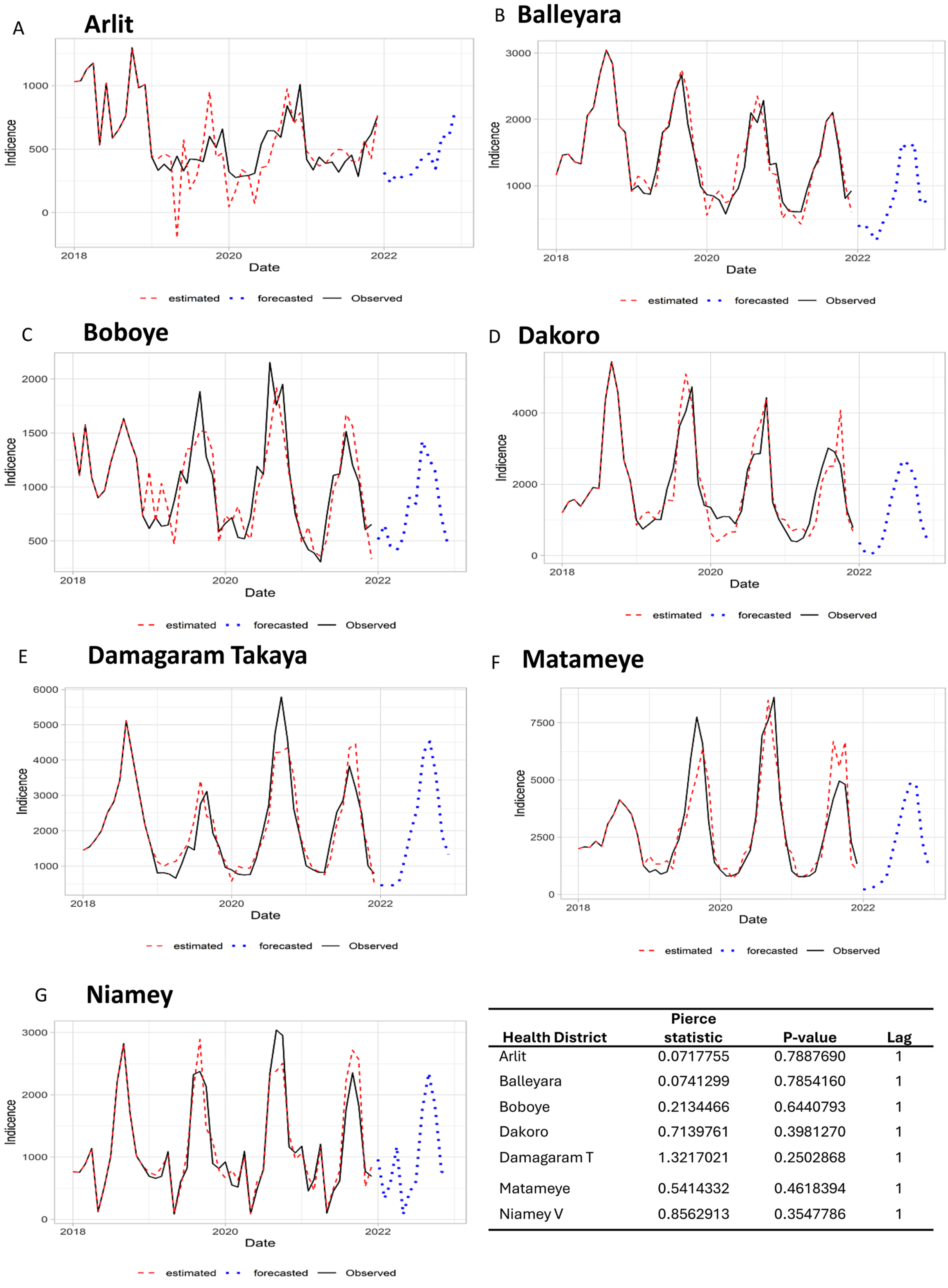
Due to inter-annual fluctuations, a second analysis was conducted by year across all 35 facilities. This approach allowed for tracking the overall evolution of the situation. In 2018, conditions varied widely between districts and even between facilities within the same district. The analysis revealed a progressive deterioration, with a more pronounced impact from severe cases and deaths (axis 2), particularly during the COVID-19 pandemic period. These findings suggest that cumulative district-level analysis may not be the most appropriate method for operational monitoring.

Modeling annual variations in cases of uncomplicated malaria

Cases of uncomplicated malaria recorded in each district were treated as separate time series. Seasonality was analyzed by identifying breakpoints in each series relative to a stationary model (Fig. 4). Residual sum of squares (RSS), which decreases as the number of segments increases, was used to evaluate the model's fit to the observed data.

Time series analysis revealed that districts exhibited different behaviors in terms of malaria transmission. The districts of Balleyara, Arlit, and Damagaram Takaya exhibited complex seasonal patterns reflecting significant temporal variability in consultations, likely due to local ecological variations. In contrast, the districts of Boboye and Dakoro exhibited simpler patterns, indicating more straightforward transmission dynamics.

The time series analysis of malaria across seven health districts in Niger reveals heterogeneous epidemiological dynamics, characterized by structural breaks, seasonal



Health District	Pierce statistic	P-value	Lag
Arlit	0.0717755	0.7887690	1
Balleyara	0.0741299	0.7854160	1
Boboye	0.2134466	0.6440793	1
Dakoro	0.7139761	0.3981270	1
Damagaram T	1.3217021	0.2502868	1
Matameye	0.5414332	0.4618394	1
Niamey V	0.8562913	0.3547786	1

Fig. 4 Time series analysis of the number of mild malaria cases. For each district data are plotted monthly. Black line: data collected; red line: data estimated by the model (one specific model for each district); blue line: forecasted data for an additional year (SARIMA model). Each district harbored a specific seasonal pic of cases during the year, with a more erratic pattern in the Saharan area (Arlit) and more cases during winter in areas by the Niger river (Niamey V).

variations, and distinct trends. The fitted models demonstrated strong statistical performance (optimal RSS and BIC), enabling the identification of significant breakpoints and reliable forecasting (see Supplementary Table S4).

The districts of Boboye, Dakoro, Balleyara, and Niamey V exhibited recurrent structural breaks and a projected increase in case numbers after 2022, indicating intensified transmission. These districts show unstable endemicity, with notable intra- and inter-annual fluctuations, highlighting the need to strengthen surveillance systems.

In contrast, the districts of Damagaram Takkaya and Matameye displayed more stable profiles, although Matameye showed high variability in seasonal peaks. Damagaram Takkaya is characterized by two distinct transmission seasons, with well-defined peaks, particularly in 2019, illustrating a structured seasonal pattern.

Arlit stands out due to continuous fluctuations without clear structural breaks, suggesting an epidemiological profile influenced by environmental and climatic factors. Despite this variability, forecasts also indicate an increase in cases starting in 2022.

These findings underscore the diversity of malaria transmission profiles across Niger's districts, with important implications for health planning. The presence of temporal breakpoints and upward trends in several districts suggests the need for tailored intervention strategies that account for local seasonality, environmental factors, and social dynamics (see S2_suppl_Table).

Predictability of cases using the SARIMA (Seasonal autoregressive integrated moving Average) model

Health facility data, aggregated by district and by month over a four-year period, were modeled using a seasonal ARIMA model (see Fig. 4). Box-Pierce tests indicated that the residuals were consistent with white noise ($p > 0.05$), and all coefficients were statistically significant ($p < 0.05$), confirming the validity of the models. The autoregressive coefficients of order 1 and 2 (AR1 and AR2) quantify the influence of past values on current values: AR1 reflects the effect of the previous month, while AR2 captures the influence of data from two months prior, illustrating long-term persistence.

District-level analysis revealed distinct temporal dynamics. In Arlit, both AR1 and SAR1 coefficients were negative (-0.43), indicating a negative influence from previous seasons, with low seasonality but a projected increase in cases starting in 2022. In Balleyara, AR1 (0.21), AR2 (0.16), and SAR1 (-0.70) suggest persistent transmission despite a negative influence from the previous seasonal cycle, with forecasts indicating rising case numbers for 2022–2023. In Dakoro, high interannual variability is reflected by a drift coefficient of -29.09, suggesting an overall downward trend, although recent forecasts show a resurgence in cases. In Boboye, positive AR1 and AR2 coefficients, combined with negative AR3 and SMA1 values, indicate moderate autoregressive influence with a downward trend, yet the model predicts future increases.

In Damagaram Takaya, AR1 is high (0.82) and SAR1 is negative (-0.55), indicating strong short-term autocorrelation and negative long-term seasonal correlation. Matameye (AR1 = 0.73) and Niamey V (AR1 = 0.56) show strong dependence on past values, supporting short-term predictability.

Overall, most districts particularly Boboye, Balleyara, Arlit, and Dakoro are expected to experience an increase in malaria cases starting in 2022. Forecasts indicate high incidence levels in Dakoro, Damagaram Takaya, and Matameye, with peaks exceeding 6,000 cases; moderate levels in Boboye and Balleyara (1,500 to 2,500 cases); and lower levels in Niamey V and Arlit (fewer than 2,000 cases). These results reflect the diversity of malaria transmission dynamics and underscore the need to tailor interventions to the local epidemiological profiles of each district.

Impact of geographical area on the evolution of malaria cases by age

Children aged 12 to 59 months were the most vulnerable to malaria across all health districts (see Fig. 5 and Supplementary Table 2). However, the number of severe cases was similar among children under 5 years and those aged 5 to 14 years. Severe cases were observed in children aged 2 to 11 months in Balleyara, but most often affected children aged 12 to 59 months in Boboye (10%), Dakoro (5–10%), and Niamey V (20%). In Matameye district, which is covered by the seasonal malaria chemoprevention (SMC) strategy, severe cases were less frequent (under 10%), as were deaths (under 2%), suggesting good effectiveness of the intervention.

Analysis of uncomplicated malaria cases by age and month showed that in agricultural districts, children under 11 months remained the majority throughout the year, with a particularly high proportion of cases among infants under 2 months. Seasonal peaks were mainly associated with this age group, and mortality was highest among children under 5 years, especially in agricultural districts. In Damagaram Takkaya, children aged 2 to 11 months accounted for 28% of severe cases.

In Sahelian districts, children aged 12 to 59 months were predominant, but the proportion of older children (5–9 years and 10–14 years) became significant, with a marked increase in Arlit after 2019. These older children were the majority among malaria cases at the end of the rainy season and during the winter months. In the semi-urban district of Niamey, which includes irrigated areas, case distribution was balanced across age groups,

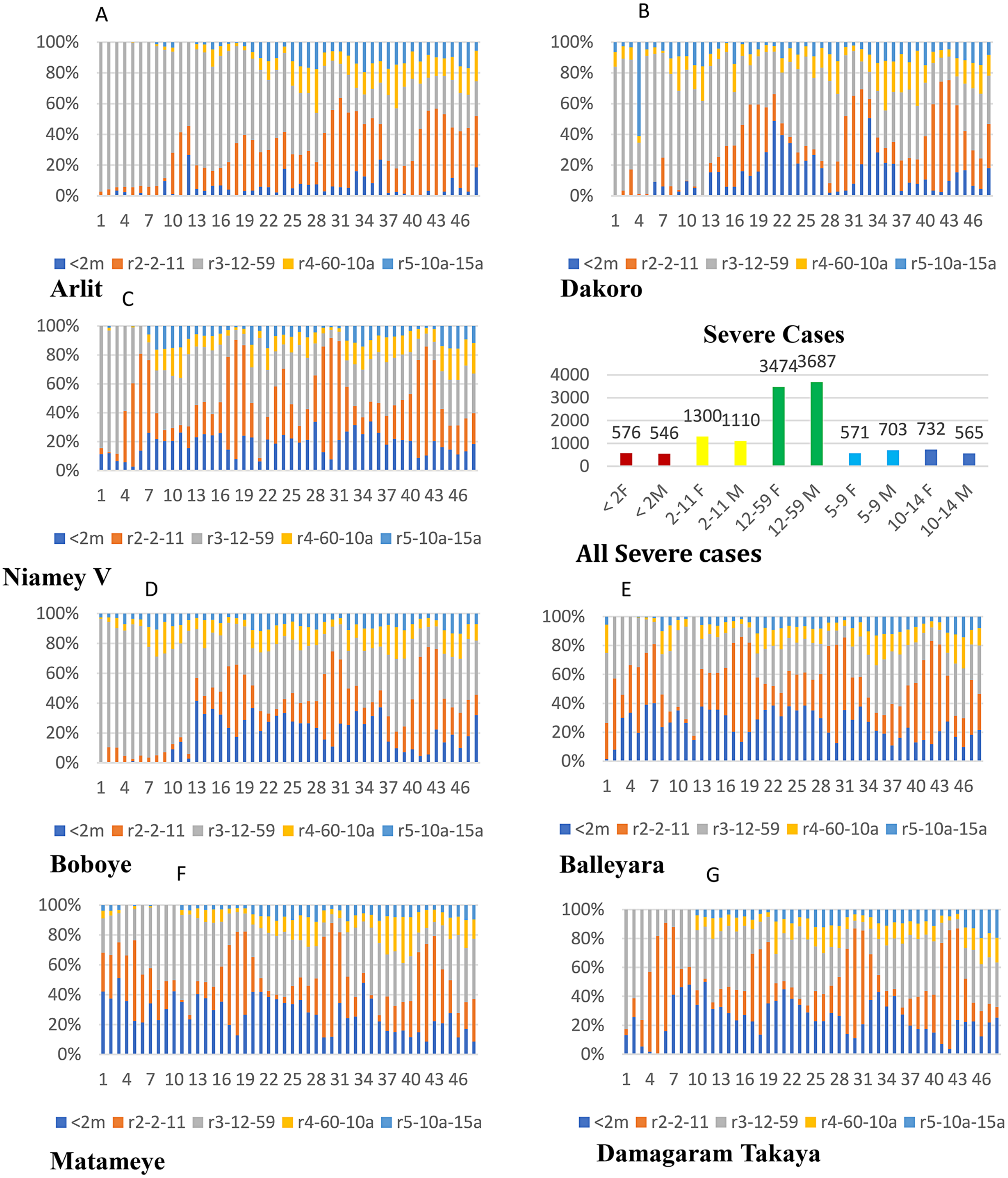


Fig. 5 Part of each age group in the mild malaria cases registered in each district during the study period. Each district is plotted separately. For one month the percent of each age group is calculated among the total number of cases of the month (total 100%). D) cumulative data of the 35 dispensaries, by age group. The part of cases observed in higher age group (light blue / yellow / grey) increased in dry area (**A** and **B**). when younger children were more prevalent in the south of the country. (**E**, **F** and **G**)

although seasonal peaks remained primarily associated with children aged 2 to 11 months.

Risk factors for malaria occurrence

A multiple regression analysis was conducted using monthly data from seven districts over four years to identify predictive factors for uncomplicated malaria and to anticipate resource allocation needs. The final model showed a high adjusted R^2 of 0.993, indicating that 99.3% of the variance in case numbers was explained by the included variables. Fever was a major predictive factor (*estimate* = 0.670, $p < 2e\text{-}16$), as was male sex, which was significantly associated with an increased number of cases (*estimate* = 8.169, $p < 6.82e\text{-}09$). Children aged 2 to 11 months were particularly vulnerable (*estimate* = 11.103, $p < 4.96e\text{-}07$), but all other age groups (12–59 months, 5–9 years, and 10–14 years) also had significant coefficients ($p = 0.000$), confirming that all children remained at risk, with no reduction in risk among older age groups.

Southern districts (Damagaram Takaya, Balleyara, Boboye, Dakoro, and Matameye) accounted for the majority of cases ($p = 0.000$), while Niamey V and Arlit were less affected ($p = 0.064$), suggesting that other causes of fever may be more prevalent in these areas. Certain months showed higher risk, particularly August 2020 ($p = 0.000$) and April 2018 ($p = 0.000$), as well as dry season months such as December 2021 ($p = 0.01$) and September 2020 ($p = 0.003$). Consistent with SARIMA models, each district exhibited specific dynamics that could lead to interactions between the "district" and "period" variables. However, the small number of districts ($n = 7$) limited the ability to analyze these interactions. Similarly, the impact of preventive strategies such as seasonal malaria chemoprevention (SMC) and the use of insecticide-treated nets could not be assessed due to lack of available data.

Overall, this analysis confirms that consultations for uncomplicated malaria were more frequent among boys and in southern districts, and that all children remained exposed, with no decline in risk as age increased.

Discussion

The study covered 35 health facilities across seven districts. As observed in other studies conducted in Sahelian regions [26–28], the data show strong malaria seasonality in most districts, with case peaks beginning in July, coinciding with the onset of the rainy season. The Arlit health district, located in the Saharan zone with less than 300 mm of annual rainfall, does not follow this seasonal pattern and is also the least affected by malaria [28].

Breakpoint analysis of the time series revealed shifts in uncomplicated malaria incidence at different times depending on the district, suggesting the influence of external factors. The months identified as breakpoints ranged from June to August, following the northward movement of the Intertropical Front from the Gulf of Guinea [29], initially affecting southern districts.

Malaria case dynamics also varied within districts, from one facility to another, highlighting the importance of tailoring malaria control strategies to local conditions, considering geographic, climatic, and demographic factors [31]. The start date for seasonal malaria chemoprevention (SMC) is coordinated with the Ministries of Health in the three Sahelian countries (Mali, Burkina Faso, Niger), with all teams intervening simultaneously to treat children in villages [30].

A persistence of malaria cases between February and April was also observed, indicating off-season transmission. This persistence, reported in other regions [32–35], has important implications for malaria management and suggests the need for a fifth SMC cycle during the dry season, likely linked to the continued presence of breeding sites favored by human activity and climatic conditions [35].

SARIMA models indicate an upward trend in uncomplicated malaria cases for the 2022–2023 period in several districts, despite seasonal variations and some declines observed in 2021. The autoregressive coefficients show temporal and seasonal links with previous periods—common in arboviruses but unusual for malaria—supporting the hypothesis of ecosystem changes. In most countries, temperature is a key factor in malaria increases, especially in African highlands and Southern Europe [36–38]. In the Sahel, however, this trend appears to be driven by increased rainfall over the past decade [35, 37], which affects flooding, breeding sites, and other diseases such as influenza [38, 39].

The reappearance of *Anopheles funestus* in Niger after 40 years of absence may also contribute to this trend [39, 40]. Additionally, urbanization and irrigated agriculture in West Africa may expand transmission, a phenomenon expected to continue over the next 30 years with the growth of medium-sized cities favorable to malaria [41–43].

During the study, older children (5–9 and 10–14 years) accounted for an equal or greater share of cases compared to children under five. Despite free healthcare and preventive strategies, the 12–59 months and 5–9 years age groups were most affected by severe malaria-related deaths, with gender-based differences. In contrast, districts included in the SMC strategy, such as Balleyara and Boboye, showed a decline in incidence after 2018, confirming the strategy's effectiveness, as demonstrated in other studies in Senegal [44–49].

However, after 2019, incidence remained steady among children over five, indicating insufficient protection for older children, as also observed in Mali [14, 15]. These findings highlight the vulnerability of children aged 5 to

14 years, with high incidence of both uncomplicated and severe malaria, and suggest that current prevention strategies should be expanded to include these age groups [44–51].

Limits

Our study is limited to malaria cases reported in health facilities, which likely underestimates the actual incidence, especially in remote rural areas. We did not analyze the interaction between district and season due to insufficient data. Additionally, the ratios were calculated using the total district population, but only data from five selected health centers per district were considered, which leads to an underestimation of the actual incidence.

Conclusions

This study, conducted in seven health districts in Niger using data from 35 health facilities between 2018 and 2021, highlights the persistence and complexity of malaria transmission in the country. Malaria remains highly seasonal, with case peaks linked to the rainy season, except in Saharan zones like Arlit, where transmission dynamics are less pronounced. Children aged 5 to 14 years, who are not covered by seasonal malaria chemoprevention (SMC), bear a burden comparable to that of children under five, who benefit from national preventive strategies, and show notable morbidity from severe malaria. Age-specific differences by sex were also observed, suggesting potential social factors that warrant further investigation.

District and facility-level analyses revealed significant inter and intra-district heterogeneity, with marked year-to-year variations and performance declines after 2018 particularly during the COVID-19 pandemic associated with increases in severe cases and deaths. SARIMA models identified structural breakpoints and predicted a rise in uncomplicated malaria cases from 2022 onward in several districts, likely driven by increased rainfall, expanding urbanization, and the reappearance of *Anopheles funestus*.

To strengthen results of this study, a yearly study based on incidence could be organize as a new step, taking into account the data registered to all the dispensaries of the district. However, informal population not registered and migrants will still be missing in the count of the reference population of the districts.

These findings confirm the effectiveness of SMC in covered districts, while underscoring the insufficient protection for older children. They call for adapting malaria control strategies to local contexts and expanding prevention efforts to include children aged 5 to 14 years. This could involve pilot extensions of SMC to children aged 5–10 years in high-burden districts and the addition of a fifth SMC cycle during the dry season in areas with persistent transmission. The study provides essential data to guide the National Malaria Control Program's interventions and strengthen protection for the most vulnerable communities.

Abbreviations

ANOVA	Analysis of Variance.
AQ	Amodiaquine.
AR	Autoregressive Coeficcient.
BIC	Bayesian Information Criterion.
DHIS2	District Health Information Sofware.
DSER	Direction of Surveillance and Epidemic Response.
IHC	Integreted Health Center.
LLIN	Long-Lasting Insecticidal Net.
NMCP	National Malaria Control Program.
PCA	Principal Component Analysis.
PC1	First Principal Component.
PC2	Second Principal Component.
RSS	Residual Sum of Square.
SARIMA	Seasonnal Autogregressive Integreted Moving Average.
SD	Statistics Direction.
SMC	Seasonnal Malaria Chemoprevention.
SP	Sulfadoxine-Pyrimethamine.
TBS	Thick Blood Smear.
WHO	World Health Organization.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12879-025-12286-3.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Supplementary Material 5

Acknowledgements

We thanks the Direction de la Surveillance et de la Riposte aux Epidémies (DSRE) and Direction des Statistiques (DS) for their support in collection of data on DHIS2; The Science for Africa Foundation to the Developing Excellence in Leadership, Training and Science in Africa (DELTAS Africa) programme [DEL-22-012].

Author contributions

DJEDANEM Médard: conducted the study, analyzed data and wrote the draft of the manuscript Yacoudima Yacoubou: collected data ZAKARI Abdoussalam: collected data, conducted a part of statistical analysis ISSA Idi: collected data YAHAYA Mahamadou: collected data ZANEIDOU Mamane: conducted a part of statistical analysis MODY Issaka: collected data Daniel Bikele ONANA: collected data TESTA Jean: reviewed the final manuscript JAMBOU Ronan: defined the protocol, supervised the study analyzed data, co-wrote and corrected the manuscript

Funding

This study was partially supported by the OPT SMC from EDCTP; MD.

Data availability

The dataset supporting the conclusions of this article is(are) included within the article and its additional files.

Declarations

Ethics approval and consent to participate

Data were obtained from the National Central Health System of Niger (DHIS2), as CERMES is a part of the Health Ministry. The data were anonymized and used under the national health surveillance mandate, in accordance with Niger's public health regulations. Ethical approval is thus unnecessary according to national regulations. However, information about the study was given to the Niger National Ethic Committee by CERMES, Niger. This study as well as the management of data by the offices of the Health Ministry adhered to the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Epicentre Niger, BP 13330, Niamey, Niger
[2]Université Nazi Boni, Bobo Dioulasso, Burkina Faso
[3]Centre de Recherche Médicale et Sanitaire, Ministère de la Santé Publique, Niamey, Niger
[4]Service de Santé Garde Républicaine, Niamey, Niger
[5]Direction des Statistiques (DS), Ministère de la Santé Publique, Niamey, Niger
[6]Direction de la Surveillance et de la Riposte aux Epidémies (DSRE), Ministère de la Santé Publique, Niamey, Niger
[7]Université Evangélique du Cameroun BP127, Bandjoun, Cameroun
[8]Laboratoire RETINE, Faculté de Médecine de Nice, Nice, France
[9]Département Santé Globale, Institut Pasteur, 25 rue Dr Roux, Paris 75015, France

Received: 14 May 2025 / Accepted: 28 November 2025

References

1. World Heath Organisation. World malaria report. https://www.who.int/fr/teams/global-malaria-programme/reports/world-malaria-report-2024 (2024). last connexion 1.4.25.
2. Organisation Mondiale de la Sante. Paludisme. https://www.who.int/fr/news-room/fact-sheets/detail/malaria (2024). Last connexion 1.4.25.
3. Organisation Mondiale de la santé. Paludisme: 619.000 décès enregistrés dans le monde en 2021. https://www.aa.com.tr/fr/monde/paludisme-619000-décès-enregistrés-dans-le-monde-en-2021-oms/2759547 (2022). Last connexion 1.4.25.
4. Relief web. Moving from Reaction to Action: Anticipating Vulnerability Hotspots in the Sahel - Burkina Faso. https://reliefweb.int/report/burkina-faso/moving-reaction-action-anticipating-vulnerability-hotspots-sahel (2022). Last connexion 1.4.25.
5. Bulletin Prévisions Saisonnières Niger. 2024. DMN n.d. https://www.niger-meteo.ne/nos-publications/bulletin-previsions-saisonnieres-niger-2024. Last connexion 20.8 25.
6. CNSC Niger Bulletin Bilan 2023 Climat-RRC. DMN n.d. https://www.niger-meteo.ne/nos-publications/cnsc-niger-bulletin-bilan-2023-climat-rrc/. Last connexion 20.8 25.
7. Medard N, Yacoudima YMAE, Emeline P, Yacoubou M, Yacoubou A, Ibrahim A, et al. Paludisme grave Chez Les grands Enfants En zone saharo-sahélienne: Une révision des stratégies de lutte est à Envisager avec Le changement climatique. Rev Neurol. 2024;180:S112.
8. Pages F, Orlandi-Pradines E, Corbel V. Vecteurs du paludisme: biologie, diversité, contrôle et protection individuelle. Médecine Mal Infect. 2007;37:153–61.
9. Besancenot JP, Handschumacher P, Ndione JA, Mbaye I, Laaidi K. Climat, eau et santé Au Sahel ouest-africain. Sécheresse. 2004;15:33–41.
10. Alan, Beier K, Claus B, David D, Markus S, Melinda D, et al. Consequences of more extreme precipitation regimes for terrestrial ecosystems. Bioscience. 2008;58:811–21.
11. Office National D'Edition de Presse. Lutte contre le paludisme: En attendant la mise à l'échelle de la vaccination, le renforcement des moyens traditionnels de lutte contre le fléau. https://www.lesahel.org/lutte-contre-le-paludisme-en-attendant-la-mise-a-lechelle-de-la-vaccination-le-renforcement-des-moyens-traditionnels-de-lutte-contre-le-fleau/ (2023). Last connexion 1.4.25.
12. Salissou I, Moustapha LM, Yerima B, Alkassoum I, Hadiza D, Ibrahim ML. Perception de La chimioprévention du paludisme saisonnier Au Niger. Int J Biol Chem Sci. 2016;10:2710–5.
13. Cissé B, Ba EH, Sokhna C, NDiaye JL, Gomis JF, Dial Y, et al. Effectiveness of seasonal malaria chemoprevention in children under ten years of age in Sénégal: A Stepped-Wedge Cluster-Randomised trial. PLOS Med. 2016;13:e1002175.
14. Cairns ME, Sagara I, Zongo I, Kuepfer I, Thera I, Nikiema F, et al. Evaluation of seasonal malaria chemoprevention in two areas of intense seasonal malaria transmission: secondary analysis of a household-randomised, placebo-controlled trial in Houndé District, Burkina Faso and Bougouni District, Mali. PLOS Med. 2020;17:e1003214.
15. Druetz T. Evaluation of direct and indirect effects of seasonal malaria chemoprevention in Mali. Sci Rep. 2018;8:1–9.
16. Mahamar A, Issiaka D, Barry A, Attaher O, Dembele AB, Traore T, Sissoko A, Keita S, Diarra BS, Narum DL, Duffy PE, Dicko A, Fried M. Effect of seasonal malaria chemoprevention on the acquisition of antibodies to plasmodium falciparum antigens in Ouelessebougou, Mali. Malar J. 2017;16:289.
17. Système national d'information sanitaire. Annuaire statistiques 2023. https://snis.ne/download/annuaire-statistiques-2017/(2022). Last connexion 20.8.25.
18. Système national d'information sanitaire. Annuaire statistiques 2024. https://snis.ne/download/annuaire-statistiques-2017/(2022). Last connexion 20.8.25.
19. Juba. Introduction à R et au tidyverse. https://juba.github.io/tidyverse/07-import.html (2023). Last connexion 1.4.25.
20. Grolemund G, Wickham H. Dates and times made easy with lubridate. J Stat Softw. 2011;40:1–25.
21. Husson F, Josse J, Le S, Mazet J, Husson M. F. Package 'factominer'. R Package. 2016;96:698.
22. Irnawati I, Riswanto FDO, Riyanto S, Martono S, Rohman A. The use of software packages of R factoextra and factominer and their application in principal component analysis for authentication of oils. Indonesian J Chemometrics Pharm Anal. 2021; 1–10.
23. Ghosh J, Acharya A. Cluster ensembles. Wiley Interdisciplinary Reviews: Data Min Knowl Discovery. 2011;1:305–15.
24. Horowitz JL, Lobato IN, Nankervis JC, Savin NE. Bootstrapping the Box–Pierce Q test: a robust test of uncorrelatedness. J Econ. 2006;133:841–62.
25. Système national d'information sanitaire. Annuaire statistiques 2017. https://snis.ne/download/annuaire-statistiques-2017/(2022). Last connexion 1.4.25.
26. S Système national d'information sanitaire. Annuaire statistiques 2022. https://snis.ne/download/annuaire-statistiques-2017/(2024). Last connexion 1.4.25.
27. Legendre E, Landier J, Lehot L, Dieng S, Thu A, Drae, et al. Classification de dynamiques temporelles de paludisme à l'échelle du village Dans Le cadre d'un programme d'élimination du paludisme. Rev Épid Santé Publique. 2021;69:S20.
28. Legendre E, Landier J, Lehot L, Dieng S, Thu A, Drae J, et al. Classification de dynamiques temporelles de paludisme à l'échelle du village Dans Le cadre d'un programme d'élimination du paludisme. Rev Épid Santé Publique. 2021;69:S20.
29. Ndiaye O, Hesran JYL, Etard JF, Diallo A, Simondon F, Ward MN, et al. Variations climatiques et mortalité attribuée Au paludisme Dans La zone de Niakhar, Sénégal, de 1984 à 1996. Cah Détudes Rech Francoph Santé. 2001;11:25–33.
30. Mahamadou Y, Saley MM, Fode M. Analyse multi-modèle régional de Climat des régimes de précipitations et de températures Au Niger. La Météorologie. 2018;101:50–61.
31. Lele I, Lamb PJ. Variability of the Intertropical front (ITF) and rainfall over the West African Sudan–Sahel zone. J Clim. 2010;23:3984. https://doi.org/10.1175/2010JCLI3277.1.
32. Koko DC, Maazou A, Jackou H, Eddis C. Analysis of attitudes and practices influencing adherence to seasonal malaria chemoprevention in children under 5 years of age in the dosso region of Niger. Malar J. 2022;21:375. https://doi.org/10.1186/s12936-022-04407-z.
33. Nkemngo FN, Raissa WGL, Nebangwa DN, Nkeng AM, Kengne A, Mugenzi LMJ, et al. Epidemiology of malaria, schistosomiasis, and geohelminthiasis amongst children 3–15 years of age during the dry season in Northern Cameroon. PLoS ONE. 2023;18:e0288560.
34. Keita K, Keïta M, Sogoba N, Sangaré D, Keita AC, Cissé B, et al. Evaluation de l'impact d'une pulvérisation intra-domiciliaire En Saison sèche Sur La transmission du paludisme Le long du fleuve Niger, Mali. Antropo. 2017;38:87–97.
35. Charlwood JD, Alecrim WD, Fe N, Mangabeira J, Martins VJ. A field trial with Lambda-cyhalothrin (ICON) for the intradomiciliary control of malaria

transmitted by Anopheles Darlingi root in Rondonia, Brazil. Acta Trop. 1995;60:3–13.

36. Filémon T, Razaki O, Franck Z, Marlène A, Zoulkifilou S, Festus H, et al. Evaluation of malaria transmission and vector control strategies in the dry season in the Cotonou V health Zone, Benin, West Africa. Adv Entomol. 2023;11:156–71.
37. Jambou R, Njedanoun M, Panthou G, Descroix L. Malaria transmission in Sahelian African Regions, a witness of climate changes. Int J Environ Res Public Health. 2022;19:10105.
38. Caminade C, Kovatsc S, Rocklovd J, Tompkinse AM, Morse AP, Colón-Gonzáleze FJ, Stenlund H, Martens P, Lloy SJ. Impact of climate change on global malaria distribution. PNAS. 2014;111:3286–91. https://doi.org/10.1073/pnas.1302089111.
39. Diouf I, Fonseca B, Caminade C, Thiaw WN, Deme A, Morse AP, Ndione JA, Gaye AT, Diaw A, Ndiaye MKN. Climate variability and malaria over West Africa. Am J Trop Med Hyg. 2020;102(5):1037–47. https://doi.org/10.4269/ajtmh.19-0062.
40. Komi K, Neal J, Mark A, Bern Diekkrüger T. Modelling of flood hazard extent in data sparse areas: a case study of the Oti river basin, West Africa. J Hydrology: Reg Stud. 2017;10:122–32. https://doi.org/10.1016/j.ejrh.2017.03.001.
41. Sultan B, Labadi K, Guegan JF, Janicot S. Climate drives the meningitis epidemics onset in West Africa. PLoS Med. 2005;2:e6.
42. Labbo R, Fouta A, Jeanne I, Ousmane I, Duchemin JB. Anopheles funestus in sahel: new evidence from Niger. 2004, 363, Issue 9409p660.
43. Labbo R, Fandeur T, Jeanne I, et al. Ecology of urban malaria vectors in Niamey, Republic of Niger. Malar J. 2016;15:314. https://doi.org/10.1186/s12936-016-1352-0.
44. Denis E, Moriconi-Ebrard F. Urban growth in West Africa. La Chron Du CEPED. 2009;57:1–5. hal-00410475 ff.
45. Bocquier P, Kabulu Mukandila A. African urbanization trends and prospects. Afr Popul Stud. 2011;25:2.
46. Cohee LM, Opondo C, Clarke SE, Halliday KE, Cano J, Shipper AG, et al. Preventive malaria treatment among school-aged children in sub-Saharan africa: a systematic review and meta-analyses. Lancet Glob Health. 2020;8:e1499–511.
47. Coldiron ME, Assao B, Guindo O, Sayinzoga-Makombe N, Koscalova A, Sterk E, Quere M, Ciglenecki I, Mumina A, Atti S, Langendorf C, Grais RF. Prevalence of malaria in an area receiving seasonal malaria chemoprevention in Niger. Malar J. 2021;20:419. https://doi.org/10.1186/s12936-021-03953-2.
48. ACCESS-SMC. Partnership effectiveness of seasonal malaria chemoprevention at scale in West and central africa: an observational study. Lancet. 2020;396:1829–40.
49. Gilmartin C, Nonvignon J, Cairns M, Milligan P, Bocoum F, Winskill P, Moroso D, Collins D. Seasonal malaria chemoprevention in the Sahel subregion of africa: a cost-effectiveness and cost-savings analysis. Lancet Glob Health. 2021;9:e199–208.
50. Ceesay SJ, Koivogui L, Nahum A, Taal MA, Okebe J, Affara M, Kaman LE, Bohissou F, Agbowai C, Tolno BG, Amambua-Ngwa A, Bangoura NF, Ahounou D, Muhammad AK, Duparc S, Hamed K, Ubben D, Bojang K, Achan J. D'Alessandro U. Malaria prevalence among young infants in different transmission Settings, Africa. Emerg Infect Dis. 2015;21:1114–21.
51. Djedanem M, Sale NM, Aminou EYYM, Descroix L, Testa J, Jambou R. Intense rainfalls and floods reshape malaria transmission in Niger. Acta Trop. 2025;268:107699.

Publisher's note