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Malaria Seasonality and Epidemiology in Burundi: A Non-Parametric Approach

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Abstract

Introduction: Malaria is a disease caused by parasites of the Plasmodium genus. It is transmitted to humans through the bites of *Anopheles mosquitoes*, which are themselves infected by the Plasmodium parasite. Malaria is primarily a tropical disease and is most prevalent in Africa. In Burundi, malaria remains a major public health issue and one of the country's top health priorities. The objective of this study is to analyze the time series of confirmed malaria cases to determine its seasonality and epidemic characteristics. **Methods:** The data used in this study consists of monthly confirmed malaria cases in Burundi, reported across all health districts in the country. A non-parametric Haar wavelet decomposition approach was used as the assumptions of the parametric decomposition model were not met. The Haar wavelet model provides two parameters, mean and variation, which can characterize the epidemic magnitude and seasonality of malaria. **Results:** The decomposition model results show that periods of the year, such as February to June and August to December are characterized by high malaria transmission. Similarly, the periods from January to July and October to December record average malaria cases exceeding 500,000. **Conclusion:** The objective of this study was to determine the existence of a seasonal effect on malaria cases in Burundi over a monthly observation period from January 2019 to December 2023. The results show that a seasonal effect exists, which may contribute to malaria epidemics in Burundi. Malaria seasonality follows a cyclical pattern, lasting for four months, followed by a two-month period of decreased cases. The key question that arises is whether the seasonal effect of malaria is uniform across the entire Burundian territory. To address this, a further study could focus on the level of malaria transmission across different geographical strata of the country.

Keywords

Malaria, Decomposition, Coefficients, Seasonality, Epidemiology

1. Introduction

Malaria is a disease caused by parasites of the Plasmodium genus. It is transmitted to humans through the bites of *Anopheles mosquitoes*, which are themselves infected by the Plasmodium parasite. It is primarily a tropical disease and is most prevalent in Africa [1]. According to the World Health Organization (WHO) report, globally, the number of malaria-related deaths decreased from 625,000 to 619,000 between 2020 and 2021 but remained higher than the estimated 568,000 deaths in 2019, before the pandemic struck [1]. Malaria cases continued to rise in 2021, but at a slower rate than during the 2019-2020 period: they were estimated at 247 million in 2021, 245 million in 2020, and 232 million in 2019 [1]. The WHO African region bears a significant and disproportionate share of the global malaria burden. In 2022, approximately 94% of malaria cases and 95% of malaria-related deaths were recorded in this region [2]. Children under five years old accounted for about 78% of malaria deaths in the region [2]. Slightly more than half of the world's malaria deaths were recorded in four African countries: Nigeria (31.1%), the Democratic Republic of the Congo (11.6%), Niger (5.6%), and Tanzania (4.4%) [2]. In Burundi, malaria remains a major public health issue and one of the country's top national health priorities [3]. The country has experienced several epidemics, with the deadliest occurring in 2001 and 2002 in meso- and hypo-endemic areas [3]. The most recent epidemic occurred in 2017 [3]. The epidemic response plan, updated by the Ministry of Public Health and the Fight Against AIDS in Burundi, enabled interventions that led to a decrease in cases in 2020 [3].

Data from the National Health Information System identify malaria as the leading cause of morbidity and mortality, with an incidence of 808 per 1000 inhabitants in 2019 (Statistical Yearbook Report 2019), compared to 815 per 1000 inhabitants in 2020, with an estimated prevalence of 27% [3]. Malaria accounted for 46% of medical consultations and 59.4% of hospital deaths in 2019 (DHIS2) [3]. The case fatality rate in hospitals is 1.2% (Statistical Yearbook Report 2019) [3]. From a socio-economic perspective, malaria morbidity and mortality impose a heavy burden on households and the country, not only due to direct expenses (consultations and hospitalization) but also due to indirect costs related to the patient's and caregiver's travel, absenteeism from work, food, funerals, etc. In 2018, 2019, and 2020, the number of deaths was 2813, 3541, and 2981, respectively [3]. Technical interventions (prevention, case management, epidemiological surveillance) and support interventions are being implemented nationwide to reduce the burden of the disease [3]. The epidemic nature of malaria in Burundi is poorly documented, if at all.

The malaria seasons, or the times of the year when a significant transmission of malaria typically occurs, are not well-known or are poorly understood. Studies already conducted on the epidemiology of malaria in Burundi have been limited to examining epidemic risk factors [4]-[6] or analyzing the temporal evolution of cases [7], without addressing the seasonality and extent of epidemics. However, to carry out an effective fight based on the current situation, it is crucial to understand the seasonality of malaria in order to identify the critical moments when concrete actions for resilience and surveillance should be undertaken to respond to the malaria threats in Burundi. This study aims to examine the time series characterizing the evolution of confirmed malaria cases reported monthly over a period of 5 years, from 2019 to 2023. The main objective of this study is to determine the times of the year during which malaria epidemics occur in Burundi, to understand the magnitude of these epidemics in terms of the number of cases, and to grasp their seasonal pattern.

2. Methodology

2.1. Data Source

The data used to analyze seasonality and detect epidemic periods concern confirmed malaria cases (across all groups) in Burundi. These cases are reported monthly over a 5-year period from 2019 to 2023. These data are collected by the National Integrated Malaria Control Program through the health districts. The raw data are gathered by the health district from the health facilities at the community level. Data are then stored in the District Health Information Software 2 (DHIS2), an information system used by the Ministry of Health and the Fight Against AIDS for data storage.

2.2. Data Pre-Processing

The data on confirmed malaria cases were initially stratified by health districts. To obtain the confirmed malaria cases at the national level, we summed the cases reported in all districts for each month of the observation period. A malaria case is considered confirmed if the result of the thick drop test or rapid test is positive. Missing data at the district level were not imputed. In consultation with the program staff, it was determined that these data are missing primarily because no malaria screenings were conducted during that period.

2.3. Study Period

The study period was primarily selected due to its recency. The epidemiological dynamics of recent periods provide an updated understanding of malaria seasonality and transmission patterns, while also accounting for changes in key influencing factors such as climate particularly in an era marked by the imminent effects of climate change. This allows for a forward-looking perspective on malaria seasonality and epidemiology, using recent trends as a basis for anticipating future patterns. Furthermore, the choice of this study period was also guided by data availability within the DHIS2 database. Only data from the 2019-2023 period met the necessary standards of completeness, reliability, and quality required for rigorous analysis.

2.4. Study Area

Burundi is a landlocked country in East Africa, located 1200 km from the Indian

Ocean and 2200 km from the Atlantic Ocean [8]. It is bordered to the north by Rwanda, to the East and South by Tanzania, and to the west by the Democratic Republic of Congo [8]. It is a country in the Great Lakes region of Africa, located between the meridians 29˚00' - 30˚25' East and the parallels 2˚20' - 4˚25' South [8]. Its total area is 27,834 km^2 [8]. The population, which is predominantly rural with an urbanization rate around 10.4%, was estimated at 8,053,574 inhabitants with an average density of 310 inhabitants/km^2 in the 2008 national population census [8]. According to the preliminary results of the 2024 general population census, the population of Burundi was estimated at 12,332,788 [9].

3. Statistical Analysis

3.1. Descriptive Statistics

To describe the series of confirmed malaria cases in Burundi, we use various descriptive parameters, including the minimum, maximum, mean, and the confidence interval of the mean. These parameters will be used to describe each month of the year for the entire observation period.

3.2. Trend Series Analysis

The trend of our series was evaluated using LOESS (Locally Estimated Scatterplot Smoothing) adjustment. This is a non-parametric smoothing method for the series, based on the smoothing parameter known as the span, which controls the width of the smoothing. In our case, we did not specify a particular value for the span. The function used in R directly provides the optimal span enabling the generation of a relatively well-smoothed series.

3.3. Haar Wavelets Decomposition

The statistical analysis of confirmed malaria cases stratified monthly for the period from 2019 to 2023 aims to decompose the series and primarily extract the seasonal component. To achieve this, the method used is based on Haar wavelet decomposition. This is a non-parametric decomposition method.

The choice of a non-parametric model was based on the fact that the malaria case series does not meet the conditions for applying a parametric decomposition model. This primarily concerns the non-stationarity of the series. The stationarity test used was the Phillips-Perron test due to its robustness compared to other stationarity tests [10]. The null hypothesis of the test is that "the series is not stationary". The p-value found is 0.3018, which suggests that there is evidence in favor of the null hypothesis. Therefore, the series is non-stationary. Secondly, the series is not periodic. This is evident when performing a simple parametric decomposition in R. The decomposition is impossible because the series has less than two periods. This provides little insight into the frequency of seasonal peaks in malaria cases. However, this may be due to the fact that the series of confirmed malaria cases is short, with only 60 observations.

The wavelet model is [11]:

$$\left\{\psi_{u,s}\left(t\right)=\frac{1}{\sqrt{s}}\psi\left(\frac{t-u}{s}\right)\right\}_{(u,s)\in IR*IR_0^+}$$

with:

u the time parameter; s the scale parameter.

A wavelet is an oscillating function with a zero mean, called ψ possessing a certain degree of regularity and having finite support (which explains the term "wavelet," meaning small wave) [11]. We choose the Haar wavelet to study the series with two components: the variation and the mean. The Haar model is given by its two components. The so-called Haar function ϕ and the Haar wavelet ψ given by [11]:

$$\psi\left(x\right)=\begin{cases}-1 & if\ \ 0\leq x<1/2\\ 1 & if\ \ 1/2\leq x<1\\ 0 & if\ not\end{cases},\quad \varphi\left(x\right)=\begin{cases}1 & if\ \ 0\leq x<1/2\\ 1 & if\ \ 1/2\leq x<1\\ 0 & if\ \ not\end{cases}$$

In the definition of a wavelet basis, the function ϕ is called the scaling function, and the function ψ is called the mother wavelet function [11]. These components are respectively provided by the scaling coefficients and the wavelet coefficients. These two coefficients respectively measure the local means and the local variations of a series [12]. These coefficients can describe the series at different levels. The parameter related to this is the decomposition level parameter. We are interested in what happens at the finest scale of our series, that is, at the first decomposition level. To describe a signal Z at level j (at a scale of $j\Delta t$) we use coefficients Vj and Wj which respectively represent the scaling coefficients and the wavelet coefficients of length $N/(2j)$ (if N is even) [12]. In the case where N is odd, the length of the coefficients will be $N-1/(2j)$. Thus, if we consider that 2 consecutive points are spaced by Δt, the first decomposition level corresponds to the scale Δt with wavelet coefficient vectors $W1$ which is proportional to the variations between two segments of width Δt, and with scaling coefficient vectors $V1$ which is proportional to the means over two segments of width Δt [12].

For our series, the coefficients that will be obtained will characterize the pairs January-February; March-April; May-June; July-August; September-October; and November-December of each year during the observation period. However, these coefficients have the drawback of not fitting the values of our series, whether in x or in y, and their length is $N/(2j)$. To address this and obtain coefficients of length N, we will perform an inverse transformation of the wavelet and scaling coefficients in order to obtain, respectively, a detail series Dj and a smoothed series Sj. We can therefore consider that the details Dj and the smooth Sj obtained respectively as the corrected wavelet coefficients and the corrected scaling coefficients [12].

We then obtain, for our series, the coefficients of variations and means for each month, but which still characterize the variations and means of consecutive month pairs. But in reality, we are unsure about the coefficients of the month transitions such as February-March; April-May; June-July; August-September; October-November; and December-January. To address this, we remove the first value of January 2019 from the original series. Thus, the decomposition process will start from February, and the obtained coefficients will correspond to the pairs February-March ; April-May; June-July; August-September; October-November; and December-January (of the following year). In order to maintain 60 observations and to obtain the coefficients for the December 2023-January 2024 month pair, the month of January 2024 was imputed by the average of the January months from the observation period, and the decomposition was performed.

4. Results

4.1. Description of Time Series

Figure 1 shows a general downward trend in malaria cases from month 1 to month 20 (January 2019 to August 2020) and from month 39 to month 60 (March 2022 to December 2023), while an upward trend in malaria cases is observed from month 24 to month 38 (December 2020 to February 2022).

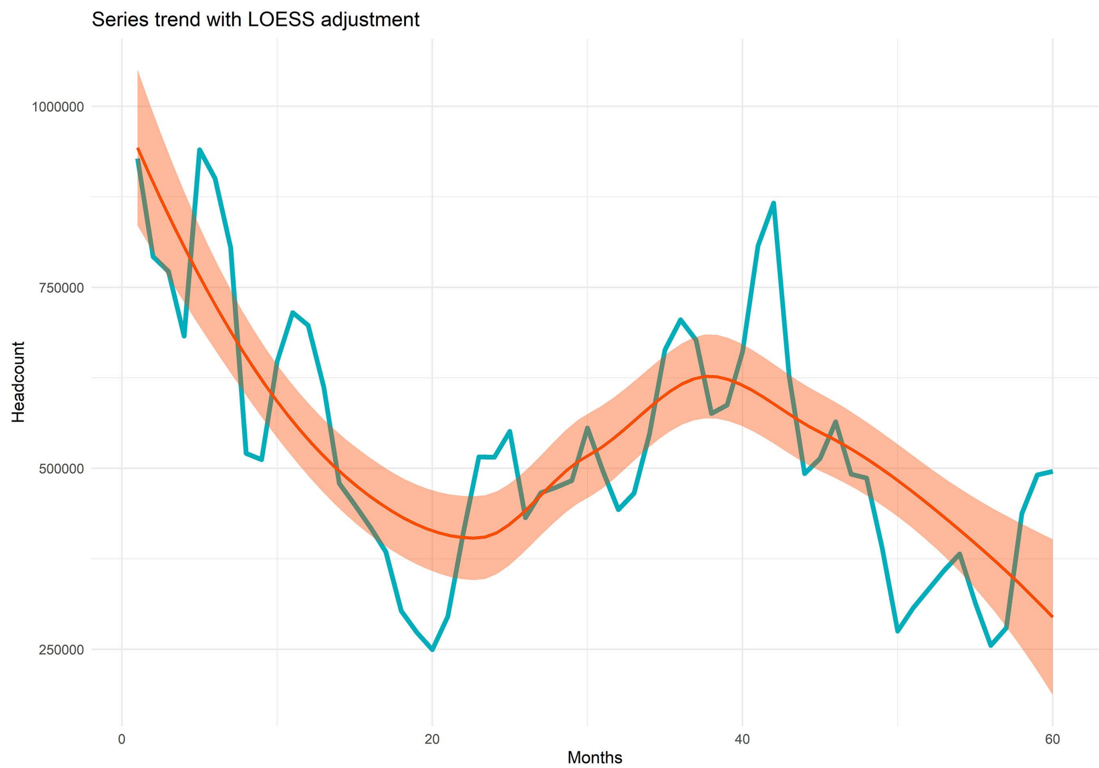

Figure 1. General trend analysis.

Regarding seasonality and epidemiology, this trend helps us to identify, in general terms, the time intervals during which local minima and maxima of malaria cases occur and the seasonal rhythm at which this pattern repeats.

According to Table 1, a total of 31,777,626 malaria cases were recorded over the entire period. The year 2023 had the lowest number of malaria cases, with 4,320,032 cases, while 2019 recorded the highest number of cases throughout the period, with 8,913,210 malaria cases.

Table 1. Confirmed malaria cases over the observation period.

Year	Overall
2019	8,913,210
2020	4,908,980
2021	6,283,144
2022	7,352,260
2023	4,320,032
Total	31,777,626

4.2. Descriptive Parameters

Table 2 indicates that August had the lowest average number of malaria cases, with 392,306 cases, whereas January had the highest, averaging 631,649 cases. This contrast offers an initial insight into the seasonal pattern of malaria, with January showing a peak in cases and August recording comparatively fewer cases than other months.

Table 2. Descriptive parameters of the months.

Month	Minimum number of cases	Maximum number of cases	Average number of cases (rounded)	Confidence interval of the mean (at 95%)
January	389,740	927,875	631,649	[387,045.2, 876,253.2]
February	275,082	792,408	510,891	[273,414.5, 748,367.9]
March	307,222	771,856	516,537	[300,602.7, 732,470.5]
April	333,399	682,731	514,086	[324,372.7, 703,799.7]
May	359,292	940,001	594,974	[268,587.7, 921,360.3]
June	303,179	900,438	601,497	[262,122.2, 940,871.8]
July	273,576	804,587	503,178	[229,219.5, 777,135.7]
August	249,592	520,680	392,306	[230,129.0, 554,483.4]
September	279,492	513,439	413,212	[268,576.3, 557,848.5]
October	410,674	648,124	521,656	[400,906.6, 642,406.2]
November	490,877	715,040	575,473	[443,915.6, 707,030.8]
December	486,728	705,131	580,065	[441,978.7, 718,151.7]

Similarly, all confidence intervals that do not contain zero show that these averages are significantly high. Continuing to discuss the epidemic nature of the months, January recorded the highest maximum number of observed cases, with 927,875 cases, while August has the second-lowest maximum number of cases with 520,680 cases, just behind September, which recorded 513,439 cases. At the same time, it is still the month of August that records the lowest minimum number of malaria cases, with 249,592 cases. In summary, the highest number of malaria cases is observed in the month of January, while the lowest number of malaria cases is observed in the month of August.

4.3. Decomposition of the Series of Confirmed Malaria Cases Stratified Monthly from 2019 to 2023

In Figure 2, the means and variations obtained characterize the pairs of months: January-February; March-April; May-June; July-August; September-October; and November-December. The scale coefficients for certain months in our observation period show very high local means, while others have lower local means.

For illustration, the means for the pairs of the 1st and 2nd months; 3rd and 4th months; 5th and 6th months; 11th and 12th months; and 41st and 42nd months exceed 700,000 cases (Figure 2A). These correspond to January-February 2019, March -April 2019, May-June 2019, November-December 2019, as well as May-June 2022.

As for the variation in malaria cases, month pairs such as January-February 2019, July-August 2019, September-October 2019; January-February 2020, September-October 2020; January-February 2021, January-February 2022, July-August 2022; January-February 2023, and September-October 2023 have a variation in malaria cases greater than or equal to 100,000 (Figure 2B).

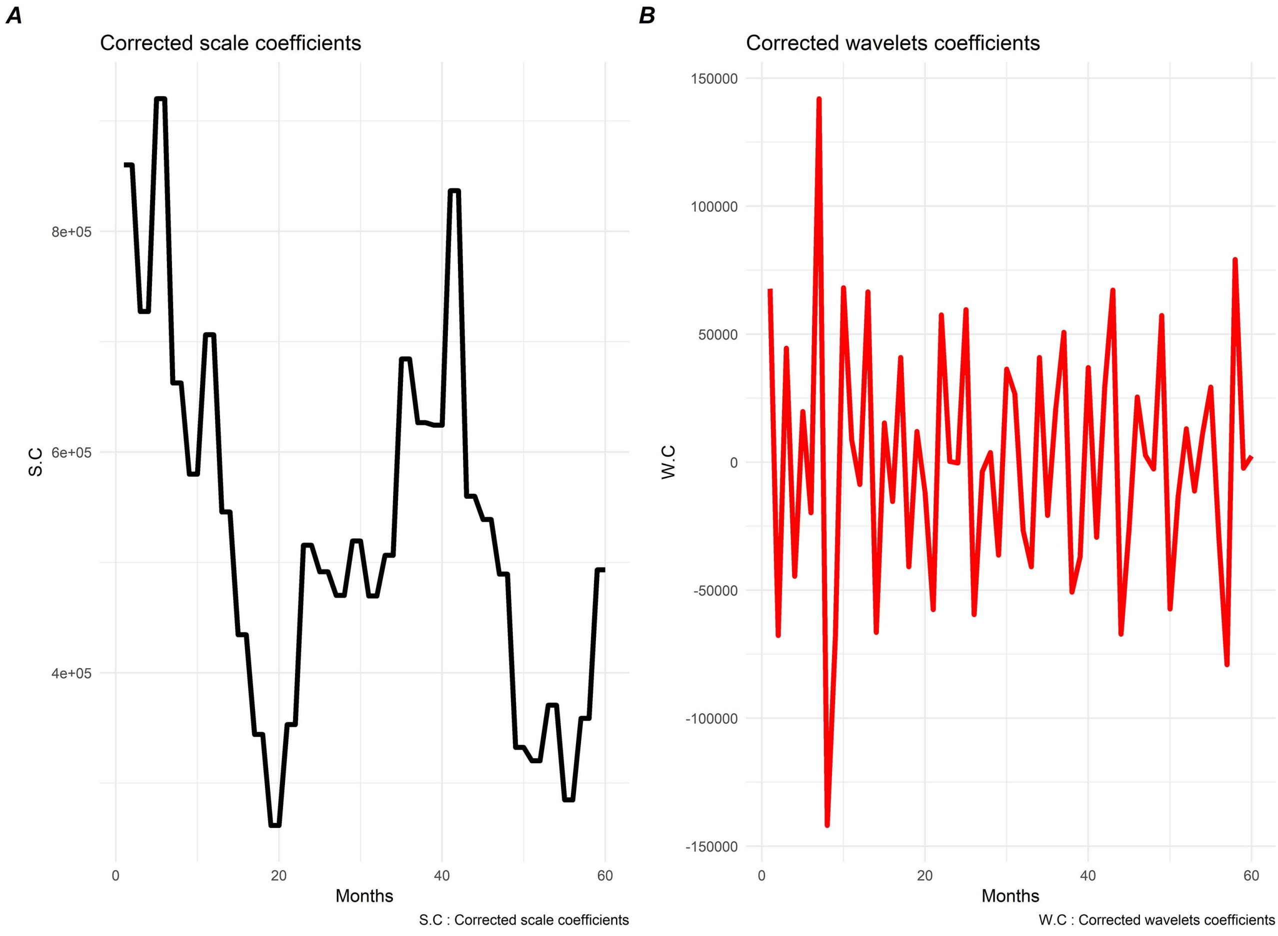

Figure 2. Corrected coefficients of the original series.

Figure 3 represents the coefficients for month pairs such as February-March; April-May; June-July; August-September; October-November, and December-January (of the following year).

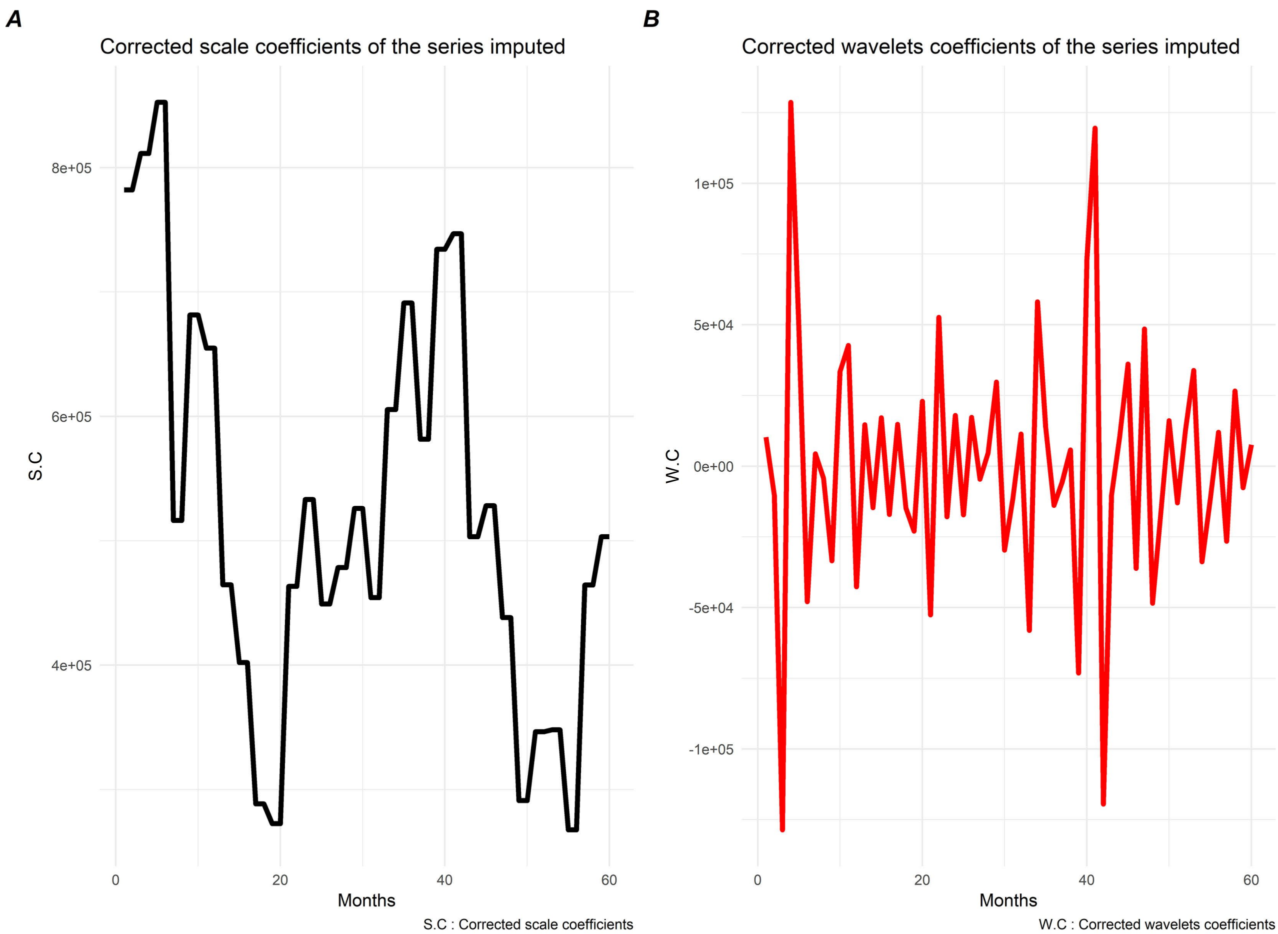

Figure 3. Corrected coefficients of the imputed series.

For the month pairs of February-March , April-May, June-July 2019, as well as April-May and June-July 2022, the average number of cases exceeds the 700,000 mark (Figure 3A). As for the variations, month pairs such as April-May 2019, October-November 2020, October-November 2021, and June-July 2022 record variations in the order of 100,000 (Figure 3B).

The general period from February to June, as well as from August to December, are periods during which an increase in malaria cases is observed, with a more pronounced increase from August to December. In these same periods, the transitions from April-May and September-October show a significant increase in cases, with an increase of 80,888 and 108,444 cases respectively. At the same time, the periods from January to July and from October to December record malaria averages above 500,000 cases. The highest malaria figures are observed from May to June, due to its higher average. The transition from July to August is a turning point, with a notable average decrease of about 110,871 cases and an average of cases below 500,000 (Table 3).

Table 3. Mean and variation analysis.

Period	Average variation over the period	Average of cases
January-February	−120,758	571,270.2
February-March	5645.4	513,713.9
March -April	−2450.4	515,311.4
April-May	80,887.8	554,530.1
May-June	6523	598,235.5
June-July	−98,319.4	552,337.3
July-August	−110,871.4	447,741.9
August-September	20,906.2	402,759.3
September-October	108,444	467,434.4
October-November	53,816.8	548,564.8
November-December	4592	577,769.2
December-January	−31,812.76	564,158.82

5. Discussion

As the goal of this study, the analysis revealed that the series of confirmed monthly malaria cases from 2019 to 2023 exhibits a seasonal effect. The seasonality of malaria is cyclical in nature, consisting of two periods: one from February to June (with a slight decrease in cases from March to April), and the other from August to December, with a two-month gap from June to August marked by a decline in cases. We identified the presence of two peaks during the year in general. This means that Burundi experiences two periods with epidemic potential throughout the year. This analysis has been very useful for a better understanding of the epidemiology of malaria. Indeed, it will enable the Ministry of Public Health and the Fight against AIDS, through the National Integrated Malaria Control Program, to effectively combat this disease, which is a major public health issue in Burundi. Understanding the seasonality of malaria and its epidemic periods throughout the year will help the program take resilience actions to limit the damage caused by this disease. For example, the periods from February to June and from August to December are times when there is a general increase in malaria cases. It is during these periods that a malaria epidemic is most likely to occur. Within these same periods, the periods from April to May and from September to October are high-potential epidemic periods, with an average increase in cases of around 80,888 and 108,444, respectively. Indeed, these periods correspond to the peaks of the variations. Long-lasting insecticidal nets should be distributed just before these periods to control transmission. To effectively monitor the evolution of malaria cases, authorized institutions should engage in continuous screening campaigns, especially before and during these periods with epidemic potential. The added value of this study is that it provides an analysis of variations and averages in malaria cases, offering crucial insights for better planning and intervention. The highest average of malaria cases during the observation period is recorded in the period from May to June. Although this transition falls within the period of epidemic potential, the fact that the average during this period is the highest does not necessarily mean that the average increase in cases was the most significant. This transition only records an average increase in cases of around 6523, although it still falls within the period of epidemic potential. In fact, this could be interpreted as being due to the general average increase observed from February to May. At the same time, the transition from September to October records the largest average increase with 108,444 cases on average, while the average number of cases for this transition is significantly lower than the 500,000 mark (with an average of 467,434 cases). At the very least, it is not one of the months with the highest average malaria cases. This is important because the epidemiology of malaria is generally not well understood, and even less so the magnitude of the epidemic explained by the variations and averages of cases. Ultimately, the National Integrated Malaria Control Program has developed a new stratification based on: annual incidence, malaria incidence among pregnant women, malaria fatality rate, healthcare facility attendance rate, poverty index, and chronic malnutrition rate (by district) to establish a vulnerability score to malaria epidemics [3]. In fact, to analyze the epidemic nature at a given moment (t), one must have the information from $t - 1$ and analyze the variation. Additionally, to understand the scope of the epidemic, one must also have information on the number of cases (or the average number of cases). This leads us to distinguish between two types of epidemic periods in Burundi: the large-scale epidemic period and the small-scale epidemic period.

The large-scale epidemic period corresponds to the period from February to June, with a periodic average of 545,448 malaria cases. The small-scale epidemic period corresponds to the period from August to December, with a periodic average of 499,132 malaria cases. A study on the effect of climate in Burundi suggests a strong positive association between malaria incidence in a given month and the minimum temperature (night temperature) of the previous month [5]. Thus, the monthly minimum night-time temperatures observed from July (the coldest month) are positively and significantly associated with the small-scale epidemic period from August to December, while the minimum night-time temperatures observed from January are positively and significantly associated with the large-scale epidemic period from February to June. Temperature has a significant influence on malaria transmission, with higher temperatures shortening the extrinsic incubation period [13]. WHO reports also indicate that temperate areas that are below the lower end of the suitable temperature range for malaria transmission and are therefore currently malaria free may become suitable for competent vectors to breed if temperatures increase by 1˚C - 2˚C [14]. An epidemiological study on malaria in Africa identified that, in general, there is an association between climate and the epidemiology of malaria [15]. This suggests that as climate change leads to global warming, the frequency of malaria epidemic periods is likely to rise, given that warmer conditions promote both mosquito development and malaria transmission.

Control interventions should also take this root cause into account, particularly by implementing effective and sustainable solutions for environmental protection.

6. Study Limits

This study faced limitations due to the lack of an extensive and detailed database of confirmed malaria cases in Burundi, which could have enabled a more thorough analysis. Access to disaggregated data might have revealed important intra-monthly trends. Although the study addresses malaria seasonality, the lack of up-to-date climate data for Burundi constrained certain aspects of the analysis. Data on climatic variables such as temperature and rainfall would have made it possible to simultaneously highlight the impact of climate on the seasonality and epidemiology of malaria. Future research should focus on a detailed exploration of malaria seasonality and epidemiology alongside climatic seasons, integrating diverse climate indicators to gain deeper insights into their interconnected effects.

7. Conclusion

The objective of this study was to determine the existence of a seasonal effect on malaria cases in Burundi over a monthly observation period from January 2019 to December 2023. The issue at hand was to determine whether there is a seasonal effect causing malaria cases to increase rapidly during one or more periods of the year. We set our research hypothesis that there exists a seasonal effect that could be responsible for malaria epidemics in Burundi. The results show that there is indeed a seasonal effect, which could be the origin of malaria epidemics in Burundi. The seasonality of malaria is cyclical in nature. It lasts for a period of 4 months, followed by a 2-month period marked by a decrease in cases. Peaks in average variations (or outbreaks) are observed during the periods from February to June and from August to December. These periods can be considered as having epidemic potential. In these same periods, the transitions from April to May and from September to October are transitions with a significant increase in cases, and are therefore periods with a high epidemic potential. The question that arises is whether the seasonal effect of malaria is uniform across the entire territory of Burundi. To answer this question, a comprehensive study could focus on the level of malaria transmission in different geographical strata of the country.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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