Indoor residual spraying uptake and its effect on malaria morbidity in Ngoma district, Eastern province of Rwanda, 2018-2021

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ABSTRACT

Background: Indoor residual spraying (IRS) was implemented in Rwanda among districts with high transmission of malaria, including Ngoma District, which received the first IRS (IRS-1) in March 2019 before the peak season, and the second IRS (IRS-2) campaign in August 2020, which targeted 89,331 structures. This study was conducted to assess factors associated with IRS uptake and the effect of IRS intervention on malaria morbidity in the Ngoma district, Eastern Province, Rwanda.

Method: A household survey using a multistage cluster sampling design was used to randomly select households. A well-structured questionnaire was administered to the head of household or the designated household in May 2021. A logistic regression model adjusted for the complex survey design and weighted to account for the sampling design was used to assess factors associated with IRS uptake. A secondary data analysis of malaria cases registered in the Rwanda Health Management Information System (RHMIS) from January 2015 to December 2022 in Ngoma district was used to determine the effect of IRS on malaria morbidity using interrupted time series analysis.

Results: Six hundred thirty-six households headed by self-employed (aOR=0.07; 95% CI: 0.01-0.55) and unemployed (aOR=0.18; 95% CI: 0.03-0.99) individuals were less likely to take up IRS than households headed by farmers. Households receiving information about the IRS via media (aOR=0.01; 95% CI: 0.00-0.17) were less likely to use the IRS than were those receiving information via community health workers. From the RHMIS, 919,843 malaria cases were identified. In the interrupted time series analysis, the baseline number of adjusted malaria cases was approximately 16,920. The first intervention in March 2019 led to a significant reduction of approximately 14,380 patients ($p < 0.001$), while the second intervention in August 2020 led to a decrease of approximately 2,495 patients, although the difference was not statistically significant ($p = 0.098$).
Conclusion: This study underscores the ability of IRS to reduce malaria incidence in Ngoma District. The influence of socioeconomic factors and information sources on IRS uptake calls for targeted strategies, comprehensive IRS education, and an integrated malaria control approach, including bed net usage and other prevention and control interventions.

Keywords: Indoor Residual Spraying, Uptake, Malaria Morbidity, Ngoma, Rwanda

INTRODUCTION

Indoor residual spraying (IRS) is an activity consisting of applying a long-lasting, residual insecticide to potential malaria vector resting surfaces, including internal walls, eaves, and ceilings of houses or structures [1]. IRS, along with long-lasting insecticidal nets (LLINs), is considered the main vector control intervention for malaria prevention[2, 3].

The effect of IRS has been indicated as positive over the past decades in areas with high and low malaria prevalence[4, 5]. Different studies conducted in sub-Saharan Africa, Asia, the Americas, and Europe have indicated that IRS is associated with a dramatic reduction in malaria transmission when combined with other malaria interventions, such as LLINs, and malaria control interventions, including artemisinin-based combination therapy and intermittent preventive treatment of malaria for pregnant women (IPTp)[6–11]. As a result of IRS implementation on the African continent, the number of protected Africans increased from 10 million in 2005 to 124 million in 2013. The population at risk decreased from 10.5% in 2010 to 5.7% in 2015[1, 3, 12].

In Rwanda, the number of reported malaria cases increased from 2.5 million in 2015 to 4.2 million in 2018, an increase of 68%[11]. The whole population in Rwanda is at risk of contracting malaria; an estimated 1.8 million children under the age of five years and 450,000 pregnant women are at high risk of becoming infected with malaria. By September 2016, Rwanda reported an increase in the malaria incidence rate from 112 per 1,000 in 2013–2014 to 308 per 1,000 in 2015–2016. An increase was reported in all provinces of Rwanda; however, the majority of new cases were documented in the eastern and southern provinces, accounting for more than 70% of the malaria cases[13, 14]. Malaria transmission in Rwanda is perennial, with two distinct peaks (May-June and November-December) in endemic zones, including the Huye, Ngoma, Kayonza, Rwamagana, Nyanza, Ruhango, Nyamasheke, Kamonyi, Gisagara, Gatsibo and Bugesera Districts. the following distinct rainy seasons. Malaria infections in Rwanda are influenced not only by climate and altitude but also by other factors, including high population density, population movement, irrigation schemes, and cross-border movement of people[15, 16].

In Rwanda, LLINs, IRSs, case management through home-based management (HBM), and health facility (HF)-based services have been used as the main intervention strategies to control malaria [17]. IRS has been implemented in Rwanda since 2007 through the Africa Indoor Residual Spraying (AIRS Rwanda) Project, which was funded by the United States Agency for International Development (USAID) under the United States President's Malaria Initiative (PMI). In March 2018, AIRS Rwanda transitioned to PMI VectorLink Rwanda, and two districts from the Eastern Province that received IRS (Nyagatare and Kirehe) were the only districts funded by PMI VectorLink[15]. The IRS was also implemented by the Government of Rwanda (GoR) using funds from the Global Fund in the Gatsibo, Rwamagana, Kayonza, Bugesera, and Ngoma districts, which are located in the

Eastern Province, and in the Nyanza, Huye, and Gisagara districts, which are located in the Southern Province[18]. Therefore, in Rwanda, 10 districts are covered by the IRS, 7 of which are from the Eastern province and 3 of which are from the Southern province.

The Ngoma district is in the Eastern Province of Rwanda, and it shares borders with the Kayonza, Bugesera, Rwamagana, and Kirehe districts (see Figure 1). As the IRS focuses on malaria-prone areas, the Eastern Province is a highly endemic area for malaria infections, and the Ngoma district was selected among the districts to be sprayed as one of the top 10 Malaria burden districts in Rwanda. Currently, the Ngoma district benefits from all 3 high-impact malaria control interventions (bed nets, HBM case management, and HF-based services) [17, 19].

Figure 1. Map showing sectors in Ngoma, a district in Rwanda

Several studies have shown that IRS programs in Africa have been successful and beneficial in controlling malaria [2–4, 7, 20–24]. Two rounds of IRS interventions in Ngoma district have been implemented since 2019; the first round occurred in March 2019, and the second round occurred in August 2020, but no data are available on how IRS interventions affect malaria morbidity in this district. In this study, the trend of the malaria disease morbidity rate was analyzed by comparing the period before the IRS intervention, the period during the intervention, and the period after the intervention to identify changes in malaria morbidity over a period affirming the effect of the IRS intervention. Furthermore, this study assessed factors associated with IRS uptake among households in Ngoma District.

METHODS

Study design and setting

This is a household survey that used a multistage cluster sampling method. The sampling frame comprised all households in the Ngoma district. Four of the 15 sectors (Remera, Gashanda, Mutenderi, and Rukumberi) were selected using a simple random sampling method. Each sector was considered a cluster, resulting in four study clusters. In each selected sector, two cells were randomly selected, and in each cell, 2 villages were also randomly selected; additionally, at least 40 households in each village were randomly selected. Therefore, in each cluster, approximately 159 households were interviewed, for a total of 636 households in the Ngoma district that participated in the study.

The Ngoma district benefited from different malaria control interventions, including LLINs, case management through HBM, health facility-based services, and IRS. All areas in the Ngoma district received two rounds of IRS. The first IRS round was conducted in March 2019 (before the high peak season of May-June), and 357,058 people were targeted. The second IRS (IRS-2) spray campaign in Ngoma was implemented in August 2020. During the twenty-day spray campaign in Ngoma District, spray operators targeted 89,331 structures. This study analyzed data collected in the National Health Management Information System (HMIS) between January 2015 and December 2022 to address the first and second objectives of the study, which were to evaluate changes in incidence rates before, during, and after each of the two rounds of IRS interventions. The third objective was to assess factors associated with IRS uptake among households in Ngoma District using a household survey that was conducted in May 2021.

Data Sources and CollectionThe data on patients who were diagnosed with malaria at the community and health facility levels in the Ngoma district were obtained from the HMIS. A structured questionnaire was developed based on previously validated instruments and focused on assessing household-level factors associated with IRS uptake. The content and structure underwent expert review by epidemiologists and staff from Malaria and Other Parasitic Diseases Unit in Rwanda Biomedical Centre (RBC) with experience in conducting malaria-related surveys. The questionnaire was then pilot tested in two villages with 20 households to evaluate question clarity, completion time, and participant comprehension. Minor modifications were made to confusing response options based on feedback before finalizing the questionnaire. This revised and tested questionnaire was administered by trained healthcare workers to the head of household or designate among 636 households across 25 villages. The head of household was preferred; however, in case of his/her absence, any household member who was at least 18 years of age and who had lived in the selected household at the time of spraying was interviewed. The interviewers were trained in questionnaire administration before data collection. Each selected sector was assigned a supervisor to monitor the process of data collection and data accuracy.

Dependent and independent variables

To assess household-level factors associated with IRS uptake, the dependent variable for the household survey was the uptake or lack of household IRS, while the independent variables for the household survey were sociodemographic and household characteristics, which included the head of household's sex, age, occupation, marital status, religion, education level, net mosquito ownership, benefits of, and dissatisfaction with the IRS intervention; socioeconomic category (*Ubudehe*), which is a home-grown socioeconomic categorization system implemented in Rwanda where every household is classified into one of four categories based on a combination of material and social economics factors, including income and vulnerability; knowledge level on malaria prevention and transmission, which was scored using a 0-10 point knowledge scoring system; and the following: 1 point for each correct response on questions testing awareness of IRS, ITNs, malaria symptoms, and malaria transmission mechanisms; and 0 points for each incorrect or "Do not Know" response. Based on this knowledge score, levels were defined as follows: low, 0-3 points; intermediate, 4-6 points; and high, 7-10 points.

However, to assess the effect of IRS interventions on malaria morbidity, the primary dependent variable was monthly new malaria cases, while the main independent variable was the IRS intervention (periods before and after all two IRS interventions) at two different intervention calendar time points.

Sample size and sampling

All data registered in the HMIS during this study period in the Ngoma district were used in this study. The sample size (n) for the household survey to estimate the proportion of IRS uptake in the Ngoma district with a given precision was determined using the formula below:

$$n = \frac{z^2 p(1-p)}{d^2}$$

where *n* = sample size, *d* = precision/standard error: a precision of 5% was used, *and Z* = the z score associated with the confidence level. For a 95% confidence level, z is typically 1.96, *p* = proportion, and *p* was assumed to be 50% since there was no information on IRS uptake in the Ngoma district.

Therefore, the sample size $n = [(1.962)^2 \times 0.5(1\text{-}0.5)]/(0.05)^2$ was estimated to be 385. By adjusting for the design effect of 1.5, the adjusted sample size was (*n* x 1.5), which equals 578. After accounting for a nonresponse rate of 10%, the sample size was 642.

Statistical analysis

The data were collected using EPI Info 7.2.1.0, exported into Microsoft Excel for cleaning and then imported into Stata version 15 for analysis. Frequencies and medians with ranges were calculated. In this study, we utilized an interrupted time series (ITS) analysis to assess the impact of two interventions on malaria morbidity using R software. The dataset consisted of monthly malaria case counts from January 2015 to December 2023 in the Ngoma District. To address the inherent seasonality in malaria transmission, we first applied a seasonal decomposition to the time series data, represented by the following equation:

$$Y_t = T_t + S_t + R_t$$

where Y_t is the observed number of malaria cases at time t, decomposed into its trend component (T_t), seasonal component (S_t), and residual component (R_t). Next, we adjusted the data for seasonality to isolate the impact of the interventions. The seasonally adjusted malaria cases ($Y_{t,adj}$) were calculated as follows:

$$Y_{t,\mathrm{adj}} = Y_t - S_t$$

This adjustment allowed for a clearer analysis of trends and levels unrelated to seasonal fluctuations. For the ITS analysis, we employed a segmented regression model to evaluate the changes in malaria cases before and after the interventions. The model is specified as follows:

$$Y_{t,\mathrm{adj}} = \beta_0 + \beta_1 \cdot I_{t1} + \beta_2 \cdot I_{t2} + \varepsilon_t$$

In this model, β_0 represents the baseline level of adjusted malaria cases before any intervention. β_1 and β_2 are coefficients estimating the immediate change in malaria cases following the first and second interventions, respectively. I_{t1} and I_{t2} are dummy variables indicating the occurrence of the first (March 2019) and second (August 2020) interventions, respectively. ε_t is the error term. This approach provided a robust framework for assessing the effects of public health interventions on malaria morbidity, accounting for both the trend and seasonality in the data.

The IRS coverage among households was calculated as the proportion of sprayed households to the total number of households participating in the study. This study focused on the uptake of IRS by households and their associated factors. Thus, a sprayed household was considered a positive outcome during the data analysis to determine factors associated with IRS uptake. Factors associated with sprayed households were assessed by using a logistic regression model adjusted for the complex survey design and weighted to account for the complex sampling design employing a backward stepwise elimination method to build the multivariable models. Odds ratios (ORs) with corresponding 95% confidence intervals (CIs) and P values were calculated. Variables with P values < 0.05 were considered significant and were included in the final model.

Ethical consideration

Participation in the IRS uptake study was voluntary, a consent form was administered to each participant before the beginning of an interview, and the study was ethically approved by the Institutional Review Board (IRB) of the University of Rwanda, College of Medicine, and Health Sciences. However, for confidentiality reasons, no personally identifiable information was collected or managed by the study team.

RESULTS

Bivariate analysis of the factors associated with IRS uptake among households in Ngoma district.

The results from the bivariate analysis are presented in *Table 1*, which shows the associations between IRS uptake and various factors. The analysis revealed that participants who received information about IRS activities through the media (Radio, TV) and through other sources were less likely to use an IRS than those who received information about IRS activities from community health workers. The odds ratios (ORs) were 0.01 (0.00-0.21) and 0.02 (0.00-0.20), respectively, with p values of 0.017 and 0.013, indicating statistically significant associations.

Similarly, households headed by government employees, self-employed persons, and unemployed persons were found to be less likely to take up IRS than those headed by farmers, with ORs of 0.24 (0.08-0.76), 0.06 (0.01-0.40) and 0.17 (0.04-0.73) and p values of 0.029, 0.018 and 0.030, respectively.

Table 1. Bivariate analysis of the factors associated with IRS uptake among households in 2019–2020 in Ngoma district, Rwanda.

Characteristic		IRS uptake status among 636 households				Bivariate analysis		
		N	Weighted Column %	Yes	Weighted Row %	OR	(95% CI)	P value
		N=636		n=613				
Age groups								
	18-30 years	218	34.3	212	97.2	1.00	-	
	31-60 years	312	49.1	302	96.8	0.77	(0.25-2.35)	0.508
	>60 years	106	16.7	99	93.4	0.40	(0.07-2.34)	0.198
Sex								
	Male	271	42.6	264	97.4	1.86	(0.61-5.61)	0.174
	Female	365	57.4	349	95.6	1.00	-	
Marital status								
	Married	353	55.5	337	95.5	1.00	-	
	Not married	283	44.5	276	97.5	2.39	(0.56-10.30)	0.153
Education level								
	Never attended school	89	14.0	88	98.9	1.00	-	
	Primary	457	71.9	447	97.8	0.32	(0.01-11.87)	0.393
	Secondary	61	9.6	54	88.5	0.06	(0.00-1.46)	0.068
	University	29	4.6	24	82.8	0.05	(0.00-3.57)	0.111
Occupation of HH head								

Farmer	361	56.8	354	98.1	1.00		
Government employed	75	11.8	69	92.0	0.24	(0.08-0.76)	0.029
Informal employment	160	25.2	156	97.5	0.76	(0.22-2.59)	0.530
Self-employed	11	1.7	8	72.7	0.06	(0.01-0.40)	0.018
Unemployed	29	4.6	26	89.7	0.17	(0.04-0.73)	0.030
Religion							
Catholic	330	51.9	319	96.7	1.00	-	
Protestants	151	23.7	145	96.0	0.79	(0.05-12.43)	0.799
Muslim	52	8.2	50	96.2	0.94	(0.03-29.95)	0.961
Adventist	44	6.9	42	95.5	0.92	(0.12-7.28)	0.910
Others	59	9.3	57	96.6	1.32	(0.15-11.26)	0.707
Ubudehe category (Social Economic Status)							
(Low Economic Status) I	104	16.4	102	98.1	1.00	-	
(Middle Economic Status) II	342	53.8	336	98.2	0.73	(0.03-15.69)	0.770
(High Economic Status) III	190	29.9	175	92.1	0.13	(0.01-2.14)	0.104
Score of head of HH on malaria prevention and transmission							
High	9	1.4	7	77.8	1.00	-	
Intermediate	395	62.1	379	95.9	5.05	(0.07-351.11)	0.311
Low	232	36.5	227	97.8	10.30	(0.25-419.16)	0.139
HH owns at least one mosquito net							
Yes	552	86.8	534	96.7	1.80	(0.38-8.57)	0.316
No	84	13.2	79	94.0	1.00		
Mosquito net condition							
Not torn	270	42.5	257	95.2	1.00	-	
Torn	307	48.3	300	97.7	2.14	(0.69-6.61)	0.121
NA	59	9.3	56	94.9	1.06	(0.27-4.24)	0.894
Source of information about the IRS							
Community Health Workers	189	29.7	186	98.4	1.00		
Healthcare providers	24	3.8	23	95.8	0.54	(0.01-25.93)	0.644
Local authority	391	61.5	384	98.2	0.97	(0.13-7.40)	0.961
Media (Radio, TV)	3	0.5	1	33.3	0.01	(0.00-0.21)	0.017
Neighbors	13	2.0	12	92.3	0.25	(0.00-16.21)	0.366
Others	16	2.5	7	43.8	0.02	(0.00-0.20)	0.013

*Adjusted for multistage selection weights

Multivariate analysis of the factors associated with IRS uptake among households in Ngoma district.

Multivariate analysis was performed to identify the factors associated with IRS uptake among households (*Table 2*). The results showed that participants from households headed by self-employed and unemployed persons were significantly more likely to consume IRS than were participants from households headed by farmers. Specifically, participants from households headed by self-employed persons had an AOR of 0.07 (0.01-0.55) and a p value of 0.026, while those with unemployed heads of household had an AOR of 0.18 (0.03-0.99) and a p value of 0.050 compared to heads of household who were farmers. In addition, people receiving information about IRS implementation activities from media (radio, TV) and from other informal sources were less likely to use an IRS with AORs of 0.01 (0.00-0.17) and 0.02 (0.00-0.15), respectively, than people receiving information about IRS implementation from community health workers.

Table 2. Multivariate analysis of the factors associated with IRS uptake among households in 2019–2020 in Ngoma district, Rwanda

Characteristic		Uptake	Weighted	IRS uptake status among 636 households		
	N	n	Row (%)	AOR	(95% CI)	P value
Occupation of HH head						
Farmer	361	354	98.1	1.00		
Government employed	75	69	92.0	0.27	(0.07-1.09)	0.059
Informal employment	160	156	97.5	0.75	(0.15-3.73)	0.611
Self-employed	11	8	72.7	0.07	(0.01-0.55)	0.026
Unemployed	29	26	89.7	0.18	(0.03-0.99)	0.050
Source of information about the IRS						
Community Health Workers	189	186	98.4	1.00		
Healthcare providers	24	23	95.8	0.39	(0.01-22.96)	0.513
Local authority	391	384	98.2	0.88	(0.13-6.01)	0.848
Media (Radio, TV)	3	1	33.3	0.01	(0.00-0.17)	0.012
Neighbors	13	12	92.3	0.35	(0.00-71.02)	0.571
Others	16	7	43.8	0.02	(0.00-0.15)	0.009

*Adjusted for selection weights

Distribution of respondents' characteristics and households with reported malaria cases within 6 months after IRS between 2018 and 2020 in Ngoma District

Table 3 shows the respondents' characteristics and households with reported malaria cases within 6 months after the IRS between 2018 and 2020 in Ngoma District. The survey enrolled 636 households with a median age of 39 years and an age range from 18 to 99 years. Most participants were females (n=365, 57.4%), were married (n=353, 53.9%), had a primary education (n=457, 71.9%), and were farmers (n=361, 56.8%). The most common religion was Catholic (n=330, 51.9%), and most participants were enrolled in the second category, *Ubudehe* (n=342, 53.8%). The study also showed that most households (n=553, 87.0%) were willing to participate in the next IRS intervention round, which is an important aspect of malaria prevention. It also indicated that 552 (87.0%) of the households visited had at least one mosquito net, which is a critical malaria control measure. This study further assessed the knowledge of heads of household on malaria prevention and transmission. Overall, 395 (68.2%) participants obtained an intermediate score, which means that they have some knowledge but may still need additional education on malaria prevention and transmission. The findings also suggested generally that during the household survey, 105 (14.6%) of the households reported having had at least one case of malaria among their household members within the past six months from the time of this survey. Among the subgroups, the prevalence was greater among households headed by males (21.3%) than among those headed by females (9.4%). By age, the prevalence was similar in the 18-30 and 31-60 age groups (13.4% and 16.6%, respectively) but lower in the over 60 age group (11.7%). There was a greater percentage of households headed by married individuals (16.7%) than by households headed by unmarried individuals (12.4%). There tended to be a greater percentage of households headed by people in higher education groups than unemployed households, which had the lowest prevalence (4.9%). Willingness to take up the next IRS round was associated with a lower prevalence (11.5%) than unwillingness (34.4%).

Table 3. Characteristics of the respondents and households with reported malaria cases within 6 months after IRS between 2019 and 2020 in the Ngoma District, Rwanda

Characteristic		Frequency	Households with Malaria cases within 6 months of IRS	Weighted Malaria Period Prevalence at H/H level	95% CI
		N=636	n=105	14.6%	(9.2-22.5)
Age groups					
	18-30 years	218	35	13.4%	(7.1-23.8)
	31-60 years	312	56	16.6%	(11.6-23.4)
	>60 years	106	14	11.7%	(4.6-26.7)
Sex					
	Male	271	63	21.3%	(13.3-32.3)
	Female	365	42	9.4%	(4.0-20.3)
Marital status					
	Married	353	65	16.7%	(9.6-27.5)
	Not married	283	40	12.4%	(7.8-19.2)
Education level					
	Never attended school	89	10	10.9%	(3.9-26.9)
	Primary	457	74	14.5%	(7.6-25.6)
	Secondary	61	13	16.8%	(6.4-37.4)
	University	29	8	21.7%	
Occupation of HH head					
	Farmer	361	63	16.1%	(10.8-23.2)
	Government employed	75	17	18.2%	(7.5-38.1)
	Informal employment	160	20	11.8%	(5.1-24.9)
	Self-employed	11	3	19.9%	
	Unemployed	29	2	4.9%	

Religion				
Catholic	330	66	18.2%	(11.1-28.4)
Protestants	151	18	10.8%	(6.4-17.4)
Muslim	52	5	9.2%	
Adventist	44	4	7.6%	(1.7-27.6)
Others	59	12	19.4%	(8.3-39.3)
Ubudehe category (Social Economic Status)				
(Low Economic Status) I	104	10	7.6%	(1.9-25.8)
(Middle Economic Status) II	342	65	17.3%	(9.9-28.5)
(High Economic Status) III	190	30	13.8%	(8.1-22.5)
Score of head of HH on malaria prevention and transmission				
High	9	1	5.1%	
Intermediate	395	52	12.2%	(7.8-18.5)
Low	232	52	19.6%	(10.5-33.6)
HH owns at least one mosquito net				
Yes	552	87	14.0%	(8.5-22.1)
No	84	18	18.9%	(9.7-33.4)
Condition of the mosquito net				
Torn	297	63	19.1%	(12.7-27.6)
Not torn	255	29	9.3%	(4.5-18.1)
NA	84	13	17.3%	(5.5-42.7)
Willing to take up the next round				
Yes	553	74	11.5%	(6.3-20.2)
No	83	31	34.4%	(22.1-49.3)
Source of information about the IRS				
Community Health Workers	189	32	14.0%	(6.6-27.3)
Healthcare providers	24	8	32.5%	
Local authority	391	58	13.8%	(7.9-22.8)
Media (Radio, TV)	3	1	33.3%	
Neighbors	13	5	31.1%	(6.9-73.5)
Others	16	1	6.5%	(0.6-42.8)

Trends of new malaria cases in the Ngoma District from January 2015 to December 2022

These data were collected from January 2015 to December 2022 to illustrate the trend of new cases of malaria in Ngoma District. The study revealed that from 2015 to 2018, new cases of malaria were seasonal. However, throughout 2019 and 2022, there was a gradual decline in the number of new cases that were maintained at very low levels over that period.

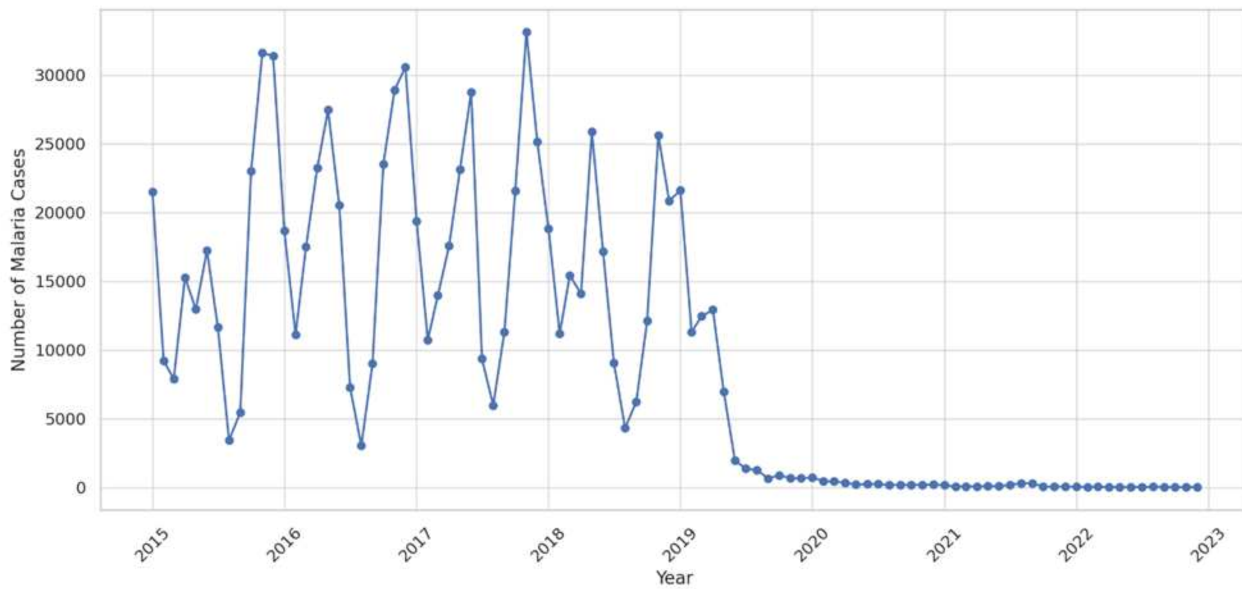

Figure 2. Trends of monthly new malaria cases in Ngoma district, Rwanda (January 2015–December 2022)

Interrupted Time Series (ITS) Analysis: Effect of Indoor Residual Spraying Interventions on Malaria Morbidity

Seasonal Decomposition

The application of seasonal decomposition to the malaria case time series data provided a foundational understanding of the patterns and trends in malaria transmission in the Ngoma District. The trend component helped in understanding the long-term progression or direction of malaria cases over the observed period, independent of seasonal variations. This trend could indicate whether malaria cases were generally increasing, decreasing, or remaining stable over time. The seasonal component was essential for identifying and quantifying regular patterns occurring at specific times of the year. Malaria transmission is known to be influenced by seasonal factors such as rainfall, temperature, and humidity. By isolating the seasonal component, we could better understand how these seasonal factors might affect malaria transmission. The residual component represented irregular or unpredictable fluctuations in malaria cases that could not be attributed to trends or seasonal patterns. This component could include random or one-off events that affect malaria transmission, such as outbreaks or effective public health interventions.

Through this decomposition, we gained a multifaceted view of malaria case data, enabling a more nuanced analysis of the factors influencing malaria morbidity.

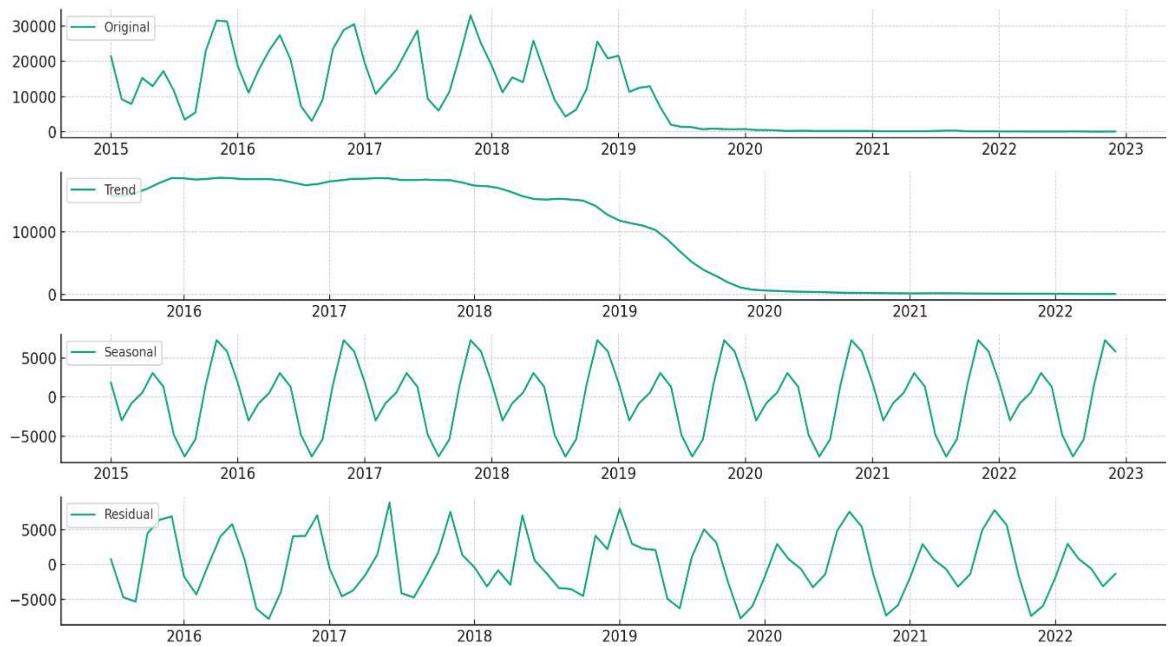

Figure 3: Seasonal decomposition of the new malaria cases in Ngoma District (January 2015 to December 2022)

Adjustment for Seasonality

In our analysis of new malaria cases, seasonality adjustment was pivotal, isolating nonseasonal effects and allowing a focused assessment of interventions and other nonseasonal factors on malaria morbidity. This approach minimized the confounding impact of inherent seasonal trends in malaria data, enabling a more accurate estimation of intervention impacts. It also clarified overall trends and irregularities in the data, enhancing our understanding of new malaria case dynamics. Importantly, by controlling for seasonality, the study's model reliability improved significantly. The model's adjusted R-squared value of 0.729 indicates that it explains approximately 72.9% of the variability in the seasonally adjusted new malaria cases, underscoring the effectiveness of our analytical approach.

ITS Analysis using the Segmented Regression Model

The segmented regression analysis of the seasonally adjusted malaria cases in the Ngoma District provided significant insights into the impact of the two interventions. The model's coefficients elucidated the following:

Baseline New Malaria Cases (Constant): The analysis estimated a baseline level of approximately 16,920 malaria cases, adjusted for seasonality. This figure represents the expected number of patients in the absence of the studied interventions.

First IRS Intervention (March 2019): A marked and statistically significant reduction in malaria cases was observed following the first intervention in March 2019. The model estimated a decrease of approximately 14,380 cases, a substantial decline with a p value less than 0.001, indicating a high level of statistical significance. This result indicates that the first intervention had a considerable and measurable impact on reducing malaria morbidity.

Second Intervention (August 2020): The effect of the second intervention, implemented in August 2020, resulted in a reduction of approximately 2,495 malaria cases. However, this change was not statistically significant (p value = 0.098), suggesting that the impact of the second intervention on reducing malaria cases, while apparent, was not as pronounced or certain as that of the first intervention.

Overall Model Significance: The F-statistic for the model was significant, underscoring the statistical validity of the model as a whole in evaluating the effects of these interventions.

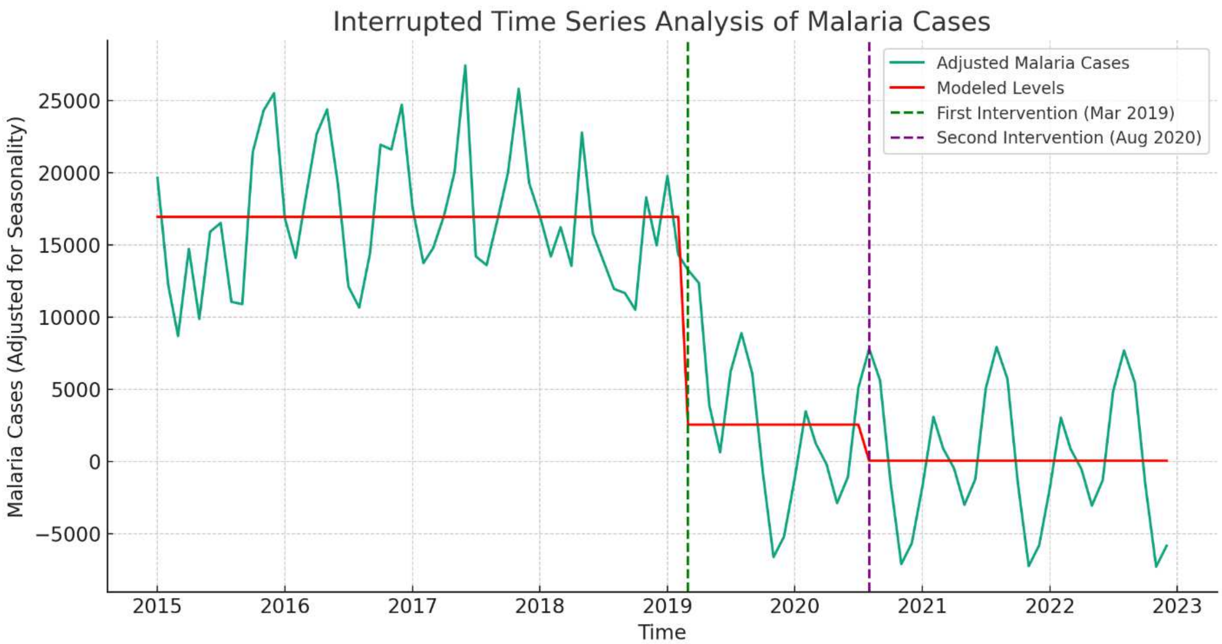

Figure 4: Interrupted time series output comparing the periods before and after the first and second IRS interventions in Ngoma District

DISCUSSION

This study aimed to evaluate the uptake of indoor residual spraying (IRS) for malaria control in Ngoma District and identify factors that affect the uptake of this intervention. The coverage of indoor residual spraying (IRS) among visited households in Ngoma District, Rwanda, was 96.4%, which is slightly lower than the coverage rate of 98.3% achieved during the IRS interventions supported by the PMI/VectorLink project in Rwanda[25]. However, the coverage rate achieved in this study is higher than that reported in other studies conducted in Uganda (89.3% in Lira district[26], 77.5% in Mulanda subcounty Tororo district[27]) and in Zimbabwe (87% in Chiredzi district[28]).

The finding of a slightly lower coverage of IRS in Ngoma District than what was anticipated is concerning but still high enough to have a sufficient impact on malarial control in the areas of study. Reports from other studies conducted in sub-Saharan Africa, including a study conducted in Zambia, revealed that the actual IRS coverage was usually lower than the estimated target coverage rate[29]. Our observation was also consistent with a study conducted in Uganda that found that although IRS was effective in reducing malaria transmission, coverage was not always sufficient to achieve maximum impact[30]. These findings suggest that efforts are needed to increase the coverage of IRS interventions to achieve maximum impact on malaria control.

On the other hand, the higher coverage rates reported in Ngoma District compared to other studies in sub-Saharan Africa may be attributed to the prioritization of malaria control efforts in Rwanda, as well as the strong partnership between the government of Rwanda and external partners to combat malaria. The high coverage rate of the IRS may also be attributed to the community-based approach used in the implementation of IRS interventions in Rwanda, which involves the active participation of community health workers in sensitizing households and mobilizing them for IRS activities[31].

The study revealed that there was a significant decrease in the incidence of malaria after the first IRS exercise, which continued to decrease at a slower rate over time. This finding is consistent with other studies that have shown the effectiveness of IRS in reducing malaria transmission. For instance, a study conducted in Ethiopia reported a significant reduction in malaria incidence after the implementation of IRS, with a 62% reduction in malaria incidence after the second round of spraying[32]. Similarly, a study conducted in Zambia reported a 90% reduction in malaria incidence after two rounds of IRS[10]. These findings suggest that IRS can be an effective tool for reducing malaria transmission in high-burden areas. However, the effectiveness of an IRS can be influenced by several factors, including the insecticide resistance of mosquitoes, the coverage and quality of the spraying campaign, and the behavior and compliance of the population. Therefore, it is essential to monitor the impact of the IRS regularly and to implement other malaria control measures to complement the IRS in areas with a high malaria burden.

The second IRS intervention, conducted in August 2020 in Ngoma District, was successful in sustaining the effect of the first intervention in March 2019, resulting in a continuous decrease in malaria incidence rates over time. This finding is consistent with other studies that have demonstrated the effectiveness of IRS in reducing malaria transmission and morbidity rates. A study conducted in Mozambique revealed that IRS reduced the incidence of malaria by 67% within three months after the intervention and sustained the effect for up to six months[33]. Similarly, a study conducted in Ethiopia reported a 62% reduction in malaria incidence following IRS intervention[32]. In Uganda, a study showed that IRS reduced malaria incidence by 45% [23].

These findings suggest that the IRS is an effective tool for controlling malaria transmission and reducing morbidity rates. However, it is worth noting that the IRS controls only indoor-biting mosquitoes and may not stop outdoor-biting mosquitoes. Therefore, other malaria control measures, such as the use of insecticide-treated bed nets, larvicide, and environmental management, may be necessary to complement IRS in controlling malaria transmission in areas with a high malaria burden.

The study results indicated that participants from households headed by self-employed persons and those with unemployed heads of household were significantly more likely to have IRS nonuptake than were participants from households headed by farmers. The findings of this study are consistent with those of previous studies in different countries reporting that socioeconomic factors are among the significant predictors of IRS uptake. For example, a study conducted in Uganda revealed that households headed by self-employed individuals were less likely to use an IRS than were those headed by farmers and salaried employees [27]. Similarly, a study conducted in Ethiopia reported that households with low incomes were less likely to use an IRS than were those with higher incomes [32]. The findings of this study suggest that interventions aimed at increasing IRS uptake should target households headed by self-employed individuals and those with unemployed heads of household in the Ngoma district. Such interventions could involve targeted health education and awareness campaigns, as well as financial incentives or subsidies, to increase the cost of IRSs for households in these categories.

The study limitations include the lack of a control group to better assess the effect of an IRS in comparison with a non-IRS district. It was assumed that other malaria control interventions were distributed evenly among all households in Ngoma District. In addition, it was assumed that the study data used were representative of the malaria situation, as all registered malaria cases at the community level and health facilities were considered. Despite these limitations, the study findings provide valuable information regarding the effect of IRS on malaria morbidity, which could be used to facilitate the development of a reliable and sustainable IRS program in other high-malaria-risk districts.

CONCLUSION AND RECOMMENDATIONS

This study emphasizes the significant role of Indoor Residual Spraying (IRS) in malaria control, showing that it has effectively reduced the incidence of malaria in Ngoma District from 2018 to 2021. Importantly, the research highlights that several factors, such as socioeconomic status, the source of information about the IRS, and the occupation of the head of household, strongly influence IRS uptake. This study provides compelling evidence that the IRS is a highly effective intervention in this setting, as marked reductions in malaria incidence rates were observed after each IRS exercise. However, disparities were noted, with rural households and those in lower socioeconomic categories showing less IRS uptake. This underlines the necessity of targeted efforts to ensure that the benefits of such interventions are equally distributed within the community.

Given the substantial influence of the quality and source of information on IRS uptake, it is beneficial to enhance education on indoor residual spraying (IRS) and malaria prevention, leveraging trusted figures or networks within the community. Emphasizing the importance of IRS within a broader malaria control strategy, alongside the use of bed nets and additional preventive measures, can significantly contribute to malaria control efforts. Targeted interventions addressing the specific needs of vulnerable socioeconomic groups are also crucial. These findings provide valuable insights that can inform the design of future malaria prevention strategies in similar settings.

Disclaimer

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