Population impact of malaria control interventions in the health district of Kati, Mali

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Abstract

Background: WHO and its partners have adopted alternative control interventions since the failure to eradicate malaria worldwide in the 1960s and 1970s. The aim of these interventions has been to redesign the control interventions to make them more effective and more efficient. The purpose of this study is to assess the population impact of control interventions implemented at the community health area level.

Methods: The analysis used data from the health information system on malaria cases and interventions (distribution of long-lasting insecticide-treated nets (LLINs), seasonal malaria chemoprevention (SMC), access to rapid diagnostic tests (RDT), intermittent preventive treatment for pregnant women (IPT)) collected in the Kati health district from 2017 to 2020. And the contextual parameters (temperature, normal difference vegetation index (NDVI) and rainfall) were obtained by remote sensing. A generalizedadditive model was used to assess the impact of malaria control interventions on malaria cases as a function of meteorological factors.

Results: The incidence of malaria varies from year to year and from health area to health area, as do meteorological factors in the study area. The distribution of long-lasting insecticide-treated nets, chemoprevention of seasonal malaria in children and access to rapid diagnostic tests for malaria were found to have a significant impact on the incidence of malaria in the population. Seasonal malaria chemoprevention was effective in reducing the incidence of malaria, while distribution of long-lasting insecticide-treated nets and access to rapid diagnostic tests increased with the number of malaria cases, reflecting efforts to distribute and use bed nets and to diagnose malaria cases among the population in the study area.

Conclusion: The study showed the impact of SMC on reducing malaria cases in the population and the significant efforts in LLIN distribution and malaria case diagnosis. To further reduce the burden of malaria, sustained efforts and new interventions are needed, including improving access to rapid diagnosis and treatment in communities.

Background

Following the failure to eradicate malaria worldwide in the 1960s and 1970s, WHO and its partners adopted a new set of control interventions, which were updated on a regular basis. The aim of these interventions was to redesign the various control interventions to make them more effective and efficient. These new control interventions focused mainly on controlling morbidity and reducing or even stopping mortality, especially in malaria-endemic areas. To make the interventions more precise, the WHO recommended that they be adapted to the socio-economic and epidemiological factors of different regions of the world. These control interventions were mainly: access to diagnosis and prompt treatment of malaria cases, the use of bed nets and vector control, and preventive measures in high-risk groups [1].

This global control program has had a significant impact on the incidence and prevalence of malaria in the world over the past 20 years. These good results have been the result of good coordination and sustained efforts by WHO and its partners through various targets and actions, including the Roll Back Malaria program launched in 1999, the targets for reducing malaria morbidity and mortality by 2030 [2] and the strengthening and development of new control interventions. These actions, reinforced by initiatives such as the Global Fund to Fight AIDS, Tuberculosis and Malaria, the commitment of African leaders through the Abuja Declaration [3] and the US President's Initiative to Fight Malaria [4], have made it possible to reduce malaria mortality by 60% in the world and by 44% in Africa. Even more impressive, according to the WHO 2020 report, 21 countries in the world have successfully eliminated malaria [5].

Despite these good results, elimination has not always been achieved, and malaria-related morbidity and disease remain high in endemic areas. Indeed, malaria remains a public health problem and a serious socioeconomic threat in most parts of the world. Despite the efforts of WHO and its partners, the WHO African Region appears to be resistant to the impact of control interventions. For example, the number of malaria cases has continued to increase since 2015, with 90% of malaria cases in 2016, 92% in 2017, 93% in 2018, 94% in 2019 and 95% in 2020 [5–9]. And in 2020, 94% of deaths recorded worldwide will occur in the African region. Children under 5 years of age are more affected, with a mortality rate of 77% [5,9]. In the same year, Mali recorded 843,961 severe cases with 1708 deaths [10]. Furthermore, the funding needed to control and eliminate the disease worldwide has increased significantly over the years, reaching US$1.3 billion in 2017, US$2.3 billion in 2018 and US$3 billion in 2019 [5]. In Mali, the main funding for malaria control comes from the Global Fund and the US President's Malaria Initiative, representing 36% and 43% of malaria control investment respectively [11].

In general, according to the 2007–2011 Strategic Plan for Malaria Control, malaria control interventions in Mali are essentially based on prevention and management of the disease. Prevention tools include the use of long-lasting insecticide-treated nets (LLINs) distributed to the general population, intermittent preventive treatment (IPT) for pregnant women, seasonal malaria chemoprevention (SMC) for children under five years of age, and indoor residual spraying (IRS). The management of malaria-related disease focuses on the systematic confirmation of all suspected cases of malaria by rapid diagnostic tests (RDTs) and early treatment of confirmed cases with artemisinin-based combination therapy (ACT), the control of epidemics and malaria-related emergencies, and the monitoring and evaluation of cases. In addition to these main axes, communication, social mobilization and operational research on new control interventions, drug and vaccine trials are also included [12].

These interventions continue to produce encouraging results, thanks to the commitment of national and international health and political authorities. In most cases, these results vary from year to year and from malaria-endemic area to malaria-endemic area around the world.

In Africa, the number of households using insecticide-treated nets (ITNs) increased significantly between 2000 to 2021. In 2020, 65% of households in sub-Saharan Africa had at least one ITN [9]. In Mali, this rate is 75% in 2018 and 91% in 2021, according to the 2018 Demographic and Health Survey Report [13] and the Malaria Indicators Survey in Mali [14]. Chemoprevention, which aims to prevent and reduce malaria disease and its consequences in the most vulnerable groups by using a combination of antimalarial drugs. In 2019, 49% of pregnant women in Africa received at least two doses of IPT during their pregnancy and 34% received at least three doses. This 3 dose rate increased slightly from the 2018 rate of 31% [5]; but decreased slightly to 32% in 2020. A similar trend was observed in Mali, where the proportion of pregnant women receiving the three doses of IPT increased between 2017 and 2018, i.e. 40% and 45% respectively and it decreased, from 45% in 2018 and 35% in 2021 [13,14]. Seasonal malaria chemoprevention is clearly making progress in the Sahelian region of Africa and has a significant impact on the incidence of malaria in children, and especially on the lethality rate. Several studies conducted in this region have demonstrated its efficacy [15–18]. On the other hand, poor compliance related to adverse drug reactions, particularly vomiting, abdominal pain, diarrhea, headache, fever and itching [19], may have a negative impact on the effectiveness of this control intervention [20]. In 2019, 22 million African children have treated with the SMC and 34 million in 2020 [5,9]. In Mali, 4 million children were targeted to receive SMC in 2018, and 4.2 million children were treated, representing a coverage rate of 106% [13].

Access to care is a very important factor in the management and prevention of malaria. Not only does it allow diagnosis and early treatment, but it also provides feedback on epidemiological information. However, access to healthcare remains poor in many parts of Africa, particularly in rural areas. This lack of access is mainly due to the absence of local health structures, poor access to health structures due to poor road networks (especially during the rainy season, a period of high malaria transmission, when heavy rains worsen the situation), and the cost of diagnosis and treatment. In 2019, 81% of children under 5 with fever in Africa had sought care, and of these, only 42% had received artemisinin-based combination therapy (ACT). By 2020, however, these percentages are projected to decline, with 76% of febrile children seeking care and only 29% receiving ACT [5]. In Mali, according to the Malaria Indicators Survey Report, 60% of febrile children under 5 had sought care and only 19% of these had received ACTs as antimalarial treatment [14].

The High Burden High Impact (HBHI) principle is to focus on local data and information collected in the field [5]. Mali is one of the 10 sub-Saharan African countries that meet the HBHI criteria. It is in this context that we have initiated this work at the level of community health areas, with the aim of assessing the impact of the control measures implemented on the population.

Methods

Study site:

The study was conducted at the peripheral level according to the Malian health pyramid, in the 35 health areas of the 23 communes of the Kati health district. The Kati health district is located in a Sudano-Sahelian zone where malaria transmission is seasonal and moderate [21]. Annual rainfall averages 1000 mm and occurs between June and September with an average minimum temperature of 20^0C and maximum of 35^0C. It is an area that is crossed by seasonal streams with few permanent streams. The economic activity is mainly based on the market gardening sector.

Data collection and source:

We analyzed data from the health information system on malaria, and data from remote sensing on meteorological and environmental variables. The study period was at the weekly temporal scale and at the spatial scale of health areas, from January 2017 to December 2020. The following data were extracted from the National Health Information System database (DHIS2: District Health Information System, version 2): number of confirmed malaria cases, number of LLINs distributed during net distribution to children under five years of age and pregnant women, number of children under five years of age treated during the SMC campaign, number of pregnant women treated with IPT, and total number of RDTs used for malaria case confirmation. The number of people who received LLINs during the campaign was provided by the NMCP activity reports. Meteorological parameters (temperature and rainfall) and Normalized Differentiation Vegetation Index (NDVI) data were obtained from the ERA-5 database of the European Center for Medium-Range Weather Forecasts (ECMRWF) [22]. Monthly data from DHIS2 were aggregated to annual malaria data.

Statistical analysis:

A descriptive analysis of the annual malaria incidence rate, control intervention data (LLIN, CPS, IPT and RDT coverage rates) and meteorological parameters was conducted.

To investigate the association between malaria cases and control interventions, adjusting for meteorological factors, we used the generalized additive model (GAM). This model, with a logarithmic transformation of the population in the offset, allowed us to estimate the standardized incidence ratio. A quasi-Poisson distribution was used to account for overdispersion. Spatial autocorrelation was accounted for by a Gaussian process, using the geographical coordinates of the center of gravity of each health area. Spline functions were used to explore the potentially non-linear relationships of factors with malaria. To account for the temporal autocorrelation of malaria incidence, a first-order autoregressive correlation was introduced into the model.

Software:

The various statistical analyzes were performed using R software version 4.0.5.4 (R Development Core Team, R Foundation for Statistical Computing, Vienna, Austria). The packages used were {mgcv} and {sf}. Maps were produced using QGIS, version 3.20.0 (Open-Source Geospatial Foundation Project, Beaverton, OR, USA). Microsoft Office Paint application was used for image processing.

Results

Descriptive analysis:

The incidence rate of malaria had decreased from 2017 to 2020 with a maximum of 527 cases per 1,000 person-years in 2018. There is no great variability in mean temperature, vegetation (NDVI) and annual rainfall during the study period (Fig. S1; Table 1). All the control interventions had a peak implementation rate of over 100% in the years 2020–2021. he average LLIN distribution rate and the average IPT coverage rate increased over the study period and reached a rate of more than 100% in 2020–2021. However, the average RDT testing rate among suspected cases gradually decreased from the beginning to the end of the study period. At the beginning of the study, and one year after its introduction into the general population (in 2016), the average coverage rate of SMC in the study area increased to 100%. After the first year, this rate gradually decreased to reach a rate of less than 100% in 2020 at the end of the study (Table 1).

Table 1
Evolution of the control interventions, the meteorological factors, and the incidence rate of malaria from 2017 to 2021

	2017–2018				**2018–2019**				**2019–2020**				**2020–2021**	
Variables	**Min**	**Median**	**Mean**	**Max**	**Min**	**Median**	**Mean**	**Max**	**Min**	**Median**	**Mean**	**Max**	**Min**	**Media**
LLIN	9.51	26.25	27.32	56.96	4.66	26.54	26.66	46.15	13.94	29.28	30.97	60.65	2.39	36.83
SMC	59.72	81.40	87.52	159.90	90.76	107.22	114.98	196.58	92.88	103.89	113.26	208.39	70.55	96.36
IPT	8.45	34.03	39.08	80.70	6.93	44.25	43.07	105.12	8.06	43.52	44.38	115.88	12.54	42.22
RDT	4.6	120.8	123.5	235.9	0.46	135.26	123.57	191.49	5.12	116.81	109.87	180.86	2.02	115.7
INCIDENCE RATE	3.32	67.76	103.21	429.05	1.44	75.81	103.64	527.01	11.06	72.26	103.09	439.19	6.88	60.39
TEMPERATURE (^{0}C)	27	28	28	29	27	28	28	29	28	28	28	29	28	29
RAIN FALL (mm)	745	886	869	959	852	1021	1013	1138	854	997	992	1123	940	1162
NDVI	0.46	0.60	0.60	0.67	0.43	0.60	0.59	0.65	0.44	0.61	0.60	0.66	0.42	0.62

LLIN = Long-Lasting Insecticidal Net, **SMC** = Seasonal Malaria Chemoprevention, **IPT** = Intermittent Preventive Treatment, **RDT** = Rapid Diagnostic Test, **NDVI** = Difference Vegetation Index

Multivariate analysis:

The generalized additive model (GAM) was used to assess the impact of control interventions on the malaria incidence. It found a significant negative linear relationship with the SMC coverage rate, indicating a significant reduction effect on malaria incidence (p = 0.046 Fig. 3a). A significant non-linear relationship was found with the LLIN coverage rate (p = 0.002) and the number of RDTs used for malaria case confirmation (p = 0.019). Overall, there is a slight decrease in the incidence rate with increasing LLIN coverage rate. However, the incidence rate tends to increase with the number of RDTs performed (Fig. 3b; Fig. 3c). The explained deviance was 84%.

Discussion

The aim of this study was to assess the impact of malaria control interventions on the general population at the level of community health areas in the Kati health district. The descriptive analysis showed that there was variation in the incidence rate of malaria from one health area to the other in the study area (Fig. 2a). Meteorological (rainfall, temperature) and environmental (NDVI) factors did not change significantly over the study period (Table 1; Fig. S1).

We found a significant negative linear relationship between malaria incidence rate and SMC coverage, explaining its effect in reducing malaria cases in the population, even though SMC is targeted at children under 5 years of age Our result corroborates the findings of several studies demonstrating the positive impact of this intervention tool against malaria in endemic areas. In 2018, Druetz et al, found a protective effect of SMC in a routine national malaria control program in Mali [23]. Furthermore, in a study of routine malaria case data, Sacko et al. observed a decrease in malaria incidence following SMC campaigns in five health districts in Mali with different epidemiological settings of malaria transmission [24]. In Senegal, Ndiaye et al had shown its effectiveness in preventing malaria episodes and reducing parasitemia [25]. In a study conducted in West and Central Africa, Milligan et al. demonstrated the efficacy of SMC in preventing malaria mortality and morbidity [26]. As the age group of SMC is school-age children (i.e. under 5 years old), they are considered to be the main contributors to the parasite reservoir and contribute to the perpetuating malaria transmission [27,28]. Treating these children not only protects them but also protects the surrounding population by reducing the number of circulating parasites. However, extending the age limit of children eligible for SMC from 5 to 10 years may not only protect more children, but also further reduce the size of the parasite reservoir [28,29]. In the literature, several authors have demonstrated the impact of SMC on reducing parasitemia [30–33]. In a study evaluating SMC as part of a routine program in Burkina, Druetz et al demonstrated a 10% reduction in parasitemia during the peak of the transmission season and a reduction in malaria transmission [34]. n Ghana, Tagbor et al. demonstrated the potential for SMC to have a significant public health impact in a region with a long duration of malaria transmission [35]. In 2017, in a pilot study in Niger, Salissou et al found that SMC significantly reduced the parasite load carriage, the number of episodes and incidence of malaria [36]. A non-linear relationship was found between the distribution of LLINs and the incidence rate of malaria, as well as between the coverage of RDTs and incidence rate of malaria. However, we did not find a positive impact of these tools in preventing malaria cases. The slight reduction in the incidence rate with increasing LLIN coverage seems to represent a threshold effect, around 70% coverage. In Uganda, Jagannathan et al found that despite high use of LLINs, the incidence of malaria still remains high [37]. The similar result was found by Ochomo et al in a study carried out in Kenya [38].

As expected, the incidence rate increases with the production of RDTs, indicating the effectiveness of the strategy of rapid access to diagnosis. SMC, distribution of LLINs and rapid diagnosis of cases by RDTs are very important pillars in the fight against malaria because of their easy implementation and use in the general population. Their effective use can significantly reduce the incidence of malaria in an endemic area. Walker et al demonstrated that LLINs can reduce malaria transmission in the African population at risk [39]. In central Ethiopia, Taffese et al observed a decrease in the incidence of malaria after an LLIN distribution campaign [40].

In this study, we did not find a significant impact of IPT on the incidence of malaria in the population in the study area. This result may be explained by IPT use in pregnant women, a restricted population that contributes little to the parasite circulation.

One of the limitations of our study was limited access to data from remote areas, at the village level. These data are most often collected by community health workers in peripheral areas of health areas. Community health workers (CHWs) play a role in prevention by providing a detailed explanation of the usefulness of mosquito nets and reinforcing their use. They also play an important role in curative care in these remote areas in the diagnosis and rapid treatment and especially the detection of severe malaria for correct and rapid care.

Conclusion

This study demonstrated that seasonal malaria chemoprevention (SMC), given to children under 5 years of age, has a reducing effect on malaria cases in the population. However, we have observed that the use of insecticide-treated mosquito nets (LLINs) and the rapid diagnostic tests (RDTs) increases with malaria cases, reflecting the efforts made in the distribution and use of mosquito nets as well as the diagnosis of malaria cases in the population of the study area. Thus, strengthening access to diagnostic testing in remote areas, particularly through community health workers (CHWs), under supervision, would contribute to strengthening the curative management of sick persons. But also, prevention, both by reducing the parasite reservoir and by reinforcing messages about the use of bed nets. In addition, it would make it possible to reinforce the detection of severe malaria for referencing. New control strategies must be based on strengthening interventions to fight malaria in remote areas.

Abbreviations

WHO: Word health organization; LLIN: Long-lasting insecticide net; RDT: Rapid diagnostic test; ACT: Artemisinin-based combination therapy; IPT: Intermittent preventive treatment; SMC: Seasonal malaria chemoprevention; ITN: Insecticide-treated net; DHIS2: District health Information System, version 2; NMCP: National malaria control program; ECMRWF: European center for medium-range weather forecasts; GAM: Generalized additive model; CHW: Community health workers.

Declarations

Author contributions:A.K., J.G., M.S.S. and I.SA. designed the study, established the analysis plan, and wrote the first version of the manuscript; A.K., M.C., performed the statistical analysis under the supervision of J.G. and I.SA.; C.S.B., P.D., M.D., B.K. and I.SI. contributed to data collection and description; M.S.S., J.L. contributed to the interpretation of the results and to the critical revision of the manuscript.

All authors have read and approved the final version of the manuscript.

Availability of the data: The data analyzed in this study can be obtained from the last author on reasonable request.

Ethics approval and consent to participate:permission to use the data analyzed in this study was requested and obtained from the National Malaria Control Program: #00000269/MSDS-SG/PNLP.

Conflicts of interest: The authors declare no conflict of interest.

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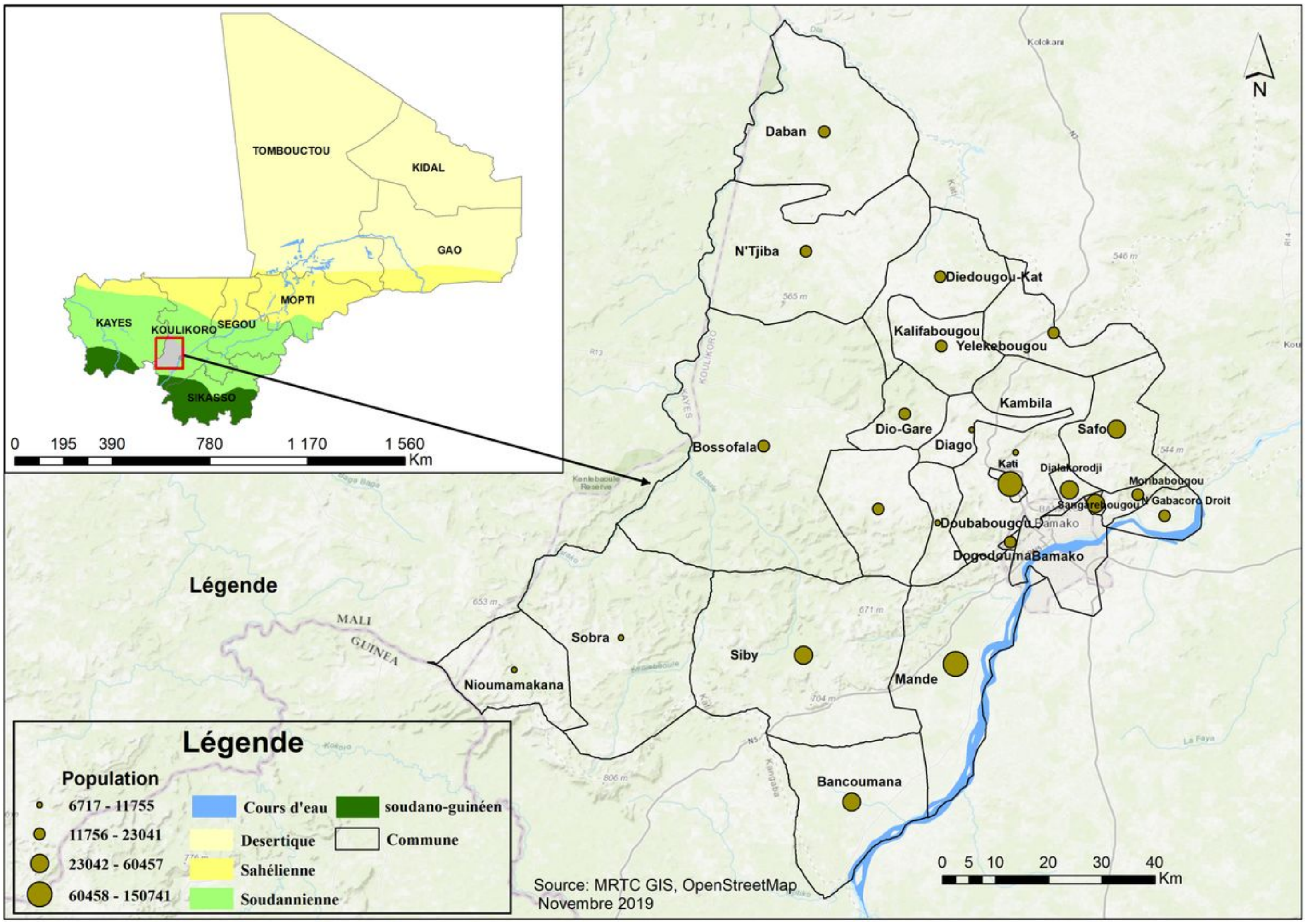
Figures



Source: MRTC GIS, OpenStreetMap
Novembre 2019

Figure 1

Map of Mali showing the study site (red frame): Kati health district with its 23 communes (green circle; the size of each circle is proportional to the population of each commune).(**Source:**MRTC GIS/RS, **Authors**: Mathias Dolo, Abdoulaye Katile, **Edition**: November 2019)

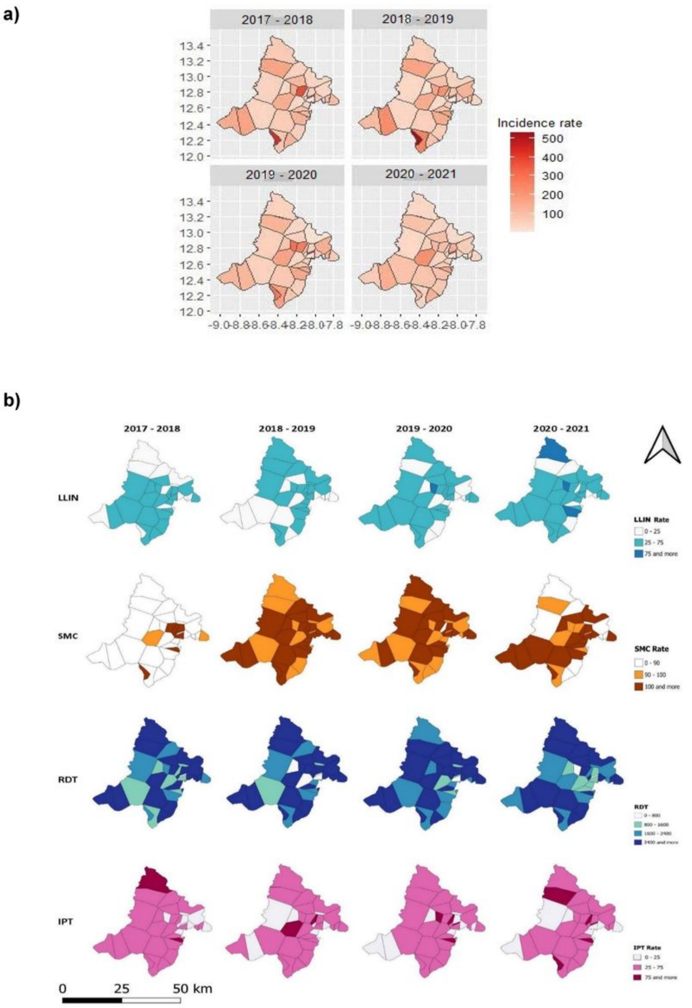


Figure 2

(a) the map of malaria incidence (b) and the map of intervention strategies [the distribution rate of LLIN (Long-Lasting Insecticidal Net), the rate of children receiving SMC (Seasonal Malaria Chemoprevention), the number of RDT (Rapid Diagnostic Test) used, the rate of pregnant women receiving IPT (Intermittent Preventive Treatment)] per health area.

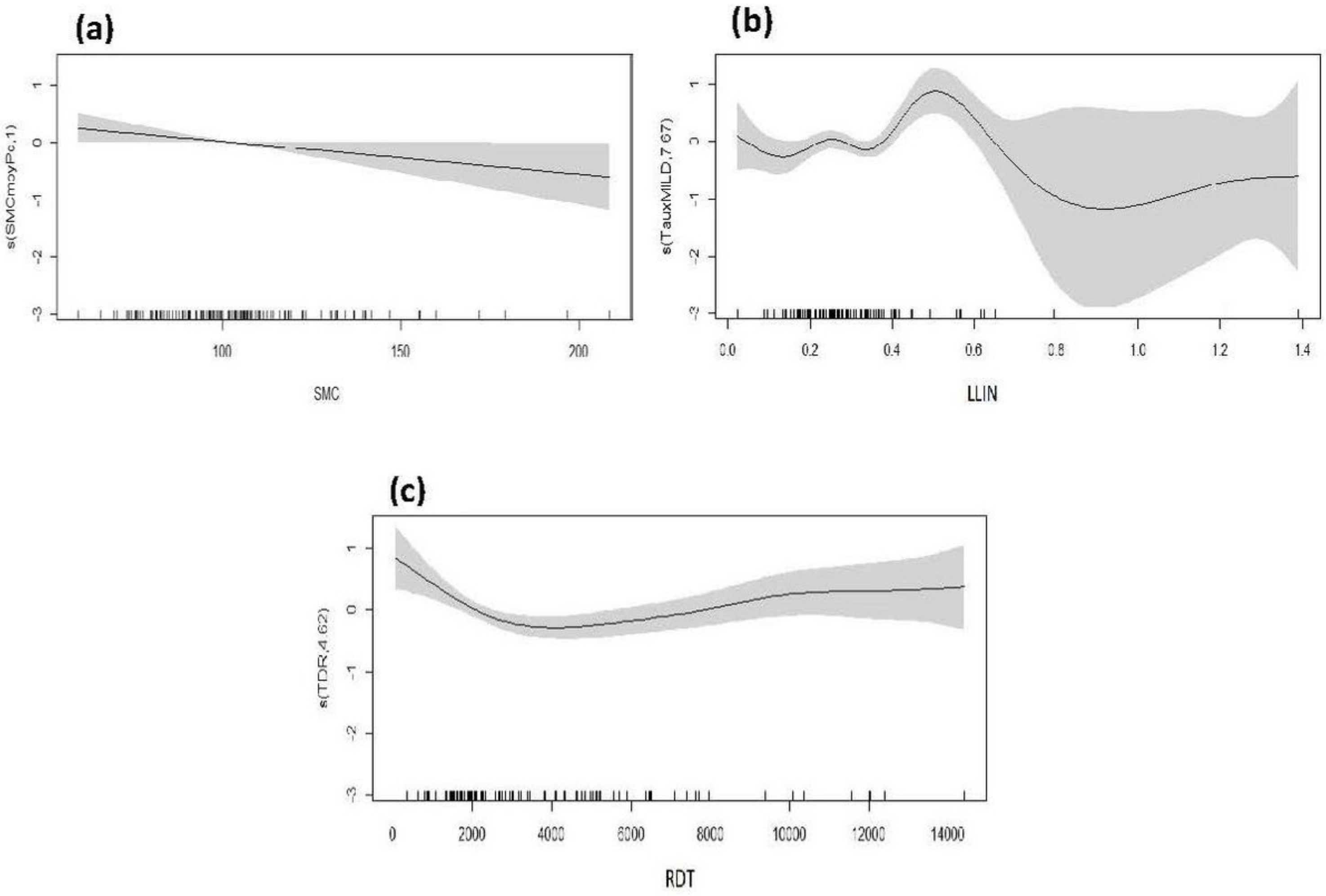


Figure 3

Relationship between malaria incidence (black curve with 95% confidence interval, grey area) and malaria control interventions: Seasonal malaria chemoprevention (SMC) **(a)**, insecticide treated mosquito nets (MILD) **(b)** and rapid diagnostic test (RDT) **(c)**.

Supplementary Files

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- Fig.S1.jpg