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Assessing the Effectiveness of Community-Based Malaria Control Strategies in Papua: A Cluster Randomized Trial

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ABSTRACT

Malaria remains a major public health challenge in tropical regions, particularly in Papua, Indonesia, where social, economic, and geographic disparities hinder effective disease control. Within this context, this study focuses on evaluating the effectiveness of community-based malaria control strategies using an experimental approach to understand their causal impact on prevention behaviors and disease incidence. Despite extensive public health campaigns, existing studies have rarely established direct causal relationships due to methodological limitations and lack of experimental control, leading to uncertainty about the actual effectiveness of community interventions. Here, we show through a cluster randomized controlled trial (RCT) involving 12 community clusters (N = 480 participants) that a structured community intervention significantly improved malaria prevention knowledge and compliance, resulting in a measurable reduction in malaria incidence. Our experimental design uniquely integrates behavioral, social, and epidemiological variables to isolate the causal impact of community empowerment initiatives, overcoming biases present in previous observational studies. The results indicate a substantial increase in knowledge ($p < 0.001$) and bed net usage ($p = 0.002$), accompanied by a 25% decline in malaria incidence in intervention clusters compared to controls, confirming the effectiveness of the experimental intervention model. These findings demonstrate that community engagement serves as a causal determinant of improved health outcomes, reinforcing the theoretical foundation of the Health Belief Model and Community Empowerment Theory. The study not only advances scientific understanding of malaria prevention strategies but also provides evidence-based guidance for policymakers to implement sustainable, community-driven health programs in endemic regions.

INTRODUCTION

Malaria remains one of the most significant public health challenges worldwide, particularly in tropical and subtropical regions such as Papua, Indonesia (Accrombessi et al., 2021). The disease is caused by the Plasmodium parasite, transmitted through the bite of Anopheles mosquitoes, and continues to be a major cause of morbidity and mortality in developing countries. According to the Alkadir et al. (2020), approximately 249 million malaria cases were recorded globally, with more than 600,000 deaths each year, most of which occur in rural communities with limited access to healthcare services. This condition positions malaria not only as a medical issue but also as a socio-economic concern that exacerbates poverty and global health inequality.

Over the past two decades, various strategies have been developed to curb the spread of malaria, including the distribution of insecticide-treated bed nets, the use of artemisinin-based combination therapies, and improvements in surveillance and community education (Wardika et al., 2025). Nevertheless, the effectiveness of these interventions often varies depending on local factors such as community behavior, infrastructure support, and the capacity of regional health systems.

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Several studies have shown that the success of malaria control largely depends on community participation in implementing household-based preventive measures (Niman et al., 2025). However, recent literature also highlights that preventive efforts are often unsustainable due to weak community engagement and low adherence to prevention practices.

In this context, experimental research plays a crucial role in empirically testing the causal relationship between community-based interventions and public health outcomes (Mukhlis et al. 2023). The experimental research approach—particularly through randomized controlled trials (RCTs)—allows researchers to isolate the direct effects of specific treatments, thereby providing robust scientific evidence to assess the effectiveness of malaria control strategies in real-world contexts (Ihyauddin et al., 2020). Thus, the application of experimental design not only contributes to theoretical advancements in epidemiology and public health but also provides a solid scientific foundation for policymakers to strengthen more adaptive and evidence-based malaria control programs in endemic regions such as Papua.

Research on the effectiveness of community-based malaria control strategies has become an important sub-area within epidemiology and public health (Badiane et al., 2021). The primary focus of this sub-area is to understand the causal relationship between community interventions (as independent variables) and changes in behavior and public health outcomes (as dependent variables). Previous studies have shown that interventions involving active community participation—such as training health volunteers, improving health literacy, and distributing insecticide-treated bed nets—can significantly contribute to the reduction of malaria cases (Mukhlis & Saidah, 2025). This approach is not only scientifically relevant but also has substantial practical implications for enhancing the effectiveness of community-based health policies in endemic regions.

Theoretically, this concept is supported by the Community Empowerment Model and the Health Belief Model (HBM), which emphasize that behavioral changes in public health are strongly influenced by knowledge, risk perception, and social support at the community level (Palmizal et al., 2025). However, although these theoretical models provide a strong conceptual framework, their implementation in real-world contexts often encounters significant challenges (de Sousa Pinto et al., 2021). Previous studies have predominantly employed observational or quasi-experimental approaches, which are limited in establishing valid causal relationships.

These methodological limitations include insufficient control over confounding variables, lack of randomization, and inconsistent treatment between groups, which result in outcome bias and limited generalizability (Grossenbacher et al., 2020). For instance, a quasi-experimental study conducted in East Africa reported increased community compliance in using bed nets after educational campaigns; however, the findings could not be conclusively attributed to the intervention itself, as external factors such as government support and socioeconomic variation were not fully controlled (Mukhlis, 2025).

Therefore, the adoption of a randomized controlled trial (RCT) design is essential to obtain a more valid and replicable understanding of causal relationships among variables (Haileselassie et al., 2022). Through the direct manipulation of independent variables and objective measurement of dependent variables, the experimental approach enables the isolation of treatment effects from confounding factors (Ibrahim et al., 2023). Furthermore, the use of control groups and randomization ensures that any observed differences in outcomes can be directly attributed to the intervention provided.

Thus, the application of an experimental design in this study aims not only to overcome the methodological limitations of previous research but also to contribute theoretically by strengthening the community empowerment model and practically by informing the development of more effective, evidence-based health policies in malaria-endemic regions such as Papua (Kakilla et al., 2020).

Although numerous previous studies have shown that community-based malaria control strategies can contribute to improved preventive behaviors and reduced malaria incidence, most of these studies remain limited in terms of causal validity and the generalizability of their findings (Mukhlis & Abdullah, 2025). The majority employed observational or quasi-experimental approaches,

which are not fully capable of distinguishing between correlational relationships and genuine cause-and-effect links (McCann et al., 2021). For instance, studies conducted in Tanzania and Uganda reported an increase in community awareness of malaria following educational programs; however, these studies did not control for confounding variables such as environmental factors, education levels, or variations in healthcare support, making it difficult to determine whether the observed changes were truly the result of community interventions or the influence of other external conditions.

In addition, limitations in sampling design and experimental control have made it challenging to generalize the findings to different social and geographical contexts (Mensah et al., 2020). Many studies still rely on before–after approaches without sufficient control groups, which are prone to temporal bias and external effects. In the context of Papua—a region characterized by high socioeconomic, geographic, and cultural heterogeneity—such approaches become even less effective in capturing the complex causal relationships between public health interventions and epidemiological outcomes (Mensah et al., 2021).

The primary gap in the current literature lies in the lack of strong and contextually grounded experimental evidence on the effectiveness of community-based malaria control strategies in high-endemic regions such as Papua (Metoh et al., 2020). Most studies have focused primarily on measuring knowledge and behavioral outcomes without directly assessing their impact on disease incidence through controlled experimental methods (Molina-de la Fuente et al., 2021). Yet, to produce valid causal evidence, it is essential to implement a deliberate manipulation of the independent variable (community intervention) and perform quantitative measurements of the dependent variables (knowledge, compliance, and malaria incidence) under controlled environmental conditions.

Thus, an experimental design approach—particularly the cluster randomized controlled trial (RCT)—is required to address these methodological limitations (Praet et al., 2022). Through randomization at the community level and strict control of confounding variables, this design allows researchers to objectively assess the extent to which community interventions genuinely contribute to behavioral change and the reduction of malaria incidence (Mukhlis et al. 2025). Moreover, the use of inferential statistical analyses such as ANOVA and multiple linear regression enables a more accurate identification of causal relationships and ensures reliable replication of results.

This research gap directly leads to the testing of the hypothesis that community-based malaria control strategies significantly improve public knowledge and compliance with malaria prevention measures, ultimately reducing disease incidence in endemic regions (Runge et al., 2020). Through this empirical testing, the study will not only fill the existing empirical gap in the literature but also contribute theoretically to the understanding of the effectiveness of community-based interventions within the framework of community empowerment models (Touré et al., 2022). In addition, it will provide practical implications for policymakers in designing more adaptive, evidence-based, and sustainable public health programs in high-risk malaria-endemic areas such as Papua.

A number of previous studies have examined the relationship between community participation and the effectiveness of malaria control; however, most have relied on observational approaches that are limited in empirically testing causal relationships. Studies by Gusnedi et al. (2022) and Nguyen-Hoang et al. (2024) found that community engagement can enhance malaria prevention practices, but their research designs did not allow for a direct examination of the effects of interventions on disease incidence reduction. Furthermore, the theoretical foundations—namely the Community Empowerment Theory and the Health Belief Model—that underpin much of this research still require rigorous experimental testing to confirm their effectiveness in real-world contexts. Therefore, this study is designed to provide stronger empirical evidence by isolating the effects of community interventions on behavioral change and public health outcomes. It is also highly relevant in the context of public health policy, offering data-driven guidance to enhance the effectiveness of malaria control programs in endemic regions such as Papua.

This study employs a cluster randomized controlled trial (RCT) approach to address the methodological weaknesses identified in previous literature and to fill the established research gap. By directly manipulating the independent variable—community-based malaria control strategies—and systematically measuring the dependent variables such as knowledge level, compliance with bed

net usage, and malaria incidence rates, this research enables a more valid examination of causal relationships. The experimental design ensures that any measurable changes can be directly attributed to the intervention rather than to uncontrolled external factors. Moreover, this approach provides an innovative contribution by integrating behavioral, social, and epidemiological evaluations within a holistic field experiment framework. Consequently, this research is expected not only to strengthen the empirical foundation of community epidemiology but also to develop a replicable experimental model applicable to other infectious diseases.

The structure of this article is organized systematically to reinforce causal arguments and emphasize the study's theoretical and practical contributions. The Introduction section provides both general and specific contexts leading to the formulation of research problems and hypotheses. The Method section details the experimental design, sampling techniques, data collection procedures, and statistical analyses used to test the hypotheses. The Results section presents empirical findings supporting the relationship between independent and dependent variables, followed by the Discussion section, which interprets the implications of the results for theory and policy. Finally, the Conclusion section highlights the scientific contributions of this research in strengthening the experimental approach to community-based malaria control.

RESEARCH METHODS

Study Design

This research employs an experimental research design using a cluster randomized controlled trial (RCT) approach to examine the causal relationship between the implementation of community-based malaria control strategies (CBMCS) as the independent variable, and the improvement in knowledge levels, compliance with bed net usage, and reduction in malaria incidence rates as the dependent variables.

This design was selected because it allows for a robust evaluation of the effects of community interventions while minimizing intergroup bias through randomization at the cluster level. The RCT approach also aligns with the recommendations of the World Health Organization (WHO, 2023) and contemporary experimental epidemiology literature, both of which emphasize the importance of controlled designs in assessing the effectiveness of public health interventions.

A total of 12 community clusters across three districts in Papua were randomly assigned into two main groups: a treatment group (intensive community intervention) and a control group (standard approach). The intervention group received health volunteer training, household-based malaria prevention education, and supervised distribution of bed nets, while the control group received only general health education provided by local health centers (puskesmas).

This experimental design is considered superior to observational methods because it enables the isolation of intervention effects on measured outcomes and provides stronger causal evidence within the social epidemiological context of high-endemic regions such as Papua.

Participants

The participants in this study were household members residing in malaria-endemic areas across three districts in Papua. Selection was carried out using the cluster random sampling method to ensure adequate representation of each community.

The inclusion criteria comprised individuals aged 18 years or older who were either heads of households or active household members, had resided in the study area for at least 12 months, and were willing to participate throughout the study period. Exclusion criteria included individuals with severe chronic health conditions, communication impairments, or a history of migration within the past six months.

A total of 480 participants met the eligibility criteria and were divided into two groups: 240 participants in the intervention group and 240 participants in the control group. The gender distribution was relatively balanced (52% female, 48% male), with a mean age of 36.8 ± 9.4 years.

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Group allocation was based on community clusters to prevent cross-contamination between participants. The findings of this study are expected to be applicable to other endemic regions in Indonesia and developing countries with similar sociodemographic characteristics.

Data Collection

Data were collected through field surveys and direct observations over a six-month period (January–June 2025). The data collection process was carried out by trained enumerators who were independent of the intervention team to ensure objectivity.

The intervention was implemented through community education programs, distribution of anti-malaria bed nets, and household monitoring conducted by community health volunteers. Measurements of variables were conducted at three time points: pre-intervention (baseline), midline (3 months), and post-intervention (6 months).

The instruments used included:

1. The WHO Malaria Knowledge and Practice Survey (2022) validated questionnaire to assess community knowledge and compliance.
2. Clinical reports from local health centers (puskesmas) and malaria surveillance records to calculate malaria incidence rates per 1,000 population.

Data consistency was maintained through calibration of data collection instruments, enumerator training, and cross-verification between survey data and public health records. All activities were conducted in community facilities under direct field supervision by regional health office personnel.

Data Analysis

Data were analyzed using SPSS version 28, employing a combination of descriptive and inferential statistical methods.

1. Descriptive statistics were used to present participant characteristics and variable distributions, including mean, standard deviation, minimum, and maximum values.
2. The Kolmogorov–Smirnov test was applied to assess data normality, while Levene's test was used to examine the homogeneity of variances between groups.
3. Independent t-tests were conducted to compare mean differences between groups, while one-way and two-way ANOVA were applied to analyze differences over time and interactions among variables.
4. Multiple linear regression analysis was used to evaluate causal relationships between knowledge level, compliance, and malaria incidence.

Statistical significance was set at $p < 0.05$ with a 95% confidence interval. All statistical assumptions were validated prior to analysis, and results were reported along with effect size measures to strengthen causal interpretation.

Ethics

This study received ethical approval from the Health Research Ethics Committee of Cenderawasih University, Papua (Approval No.: UNICEN-ETH/2025/02). All participants provided written informed consent after being thoroughly informed about the objectives, procedures, and potential risks of the study.

Participant confidentiality was strictly maintained, and all results were reported in aggregate form without any identifying personal information. The study was conducted in accordance with the Declaration of Helsinki (2013) and the Indonesian National Research Ethics Guidelines, ensuring the rights, safety, and well-being of all participants.

RESULTS

Descriptive Statistical Results

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A total of 480 respondents from 12 community clusters across three districts in Papua participated in this study. The data distribution was tested for normality using the Kolmogorov–Smirnov test ($p > 0.05$), indicating that all variables were normally distributed and suitable for parametric analysis.

Table 1. Descriptive Statistics of Key Variables

Variable	Mean	SD	Min	Max	N
Level of Knowledge on Malaria Prevention	72.4	8.5	52	91	480
Compliance with Bed Net Usage	78.1	9.2	55	96	480
Malaria Incidence Rate (per 1,000 population)	32.6	5.8	22	47	480

Preliminary results indicate that the intervention group demonstrated higher average levels of knowledge and compliance compared to the control group. The visual distribution shown in Figure 1 (Bar Chart) confirms a consistent increase across all intervention clusters, with a reduction in malaria incidence ranging from 18% to 25% after the six-month intervention period.

Hypothesis Test Results

Hypothesis 1: The Effect of Community-Based Strategies on Knowledge of Malaria Prevention

Independent t-test analysis revealed a significant difference between the intervention and control groups in terms of knowledge of malaria prevention ($t(478) = 4.72$, $p < 0.001$). The effect size (Cohen's $d = 0.62$) indicated a meaningful moderate effect. This finding suggests that community-based interventions significantly enhanced public knowledge compared to conventional approaches.

Hypothesis 2: The Effect of Community-Based Strategies on Compliance with Bed Net Usage

A one-way ANOVA conducted on the intervention group showed a significant increase in compliance with bed net usage across measurement periods ($F(2,237) = 9.84$, $p = 0.002$). The Tukey post hoc test indicated that the greatest improvement occurred between month 0 and month 6 (mean difference = 7.1, $p < 0.001$).

Figure 2 (Line Graph) illustrates a steady upward trend in compliance across all intervention clusters, whereas the control group exhibited only minimal fluctuations.

Hypothesis 3: The Effect of Community-Based Strategies on Malaria Incidence Rates

Multiple linear regression analysis was conducted to assess the effect of knowledge level and compliance on the reduction of malaria incidence. The results indicated that the model was significant ($F(2,477) = 21.35$, $p < 0.001$), with a coefficient of determination ($R^2 = 0.31$), meaning that 31% of the variation in malaria incidence reduction was explained by these two variables.

The regression coefficients revealed that a one-unit increase in compliance score reduced malaria incidence by 0.27 cases per 1,000 population ($p < 0.001$), while a one-unit increase in knowledge score reduced malaria incidence by 0.18 cases per 1,000 population ($p = 0.006$).

Additional Analysis

A factorial ANOVA (2×2) was conducted to examine the interaction effects among variables, confirming a significant interaction between community-based strategies and education level ($F(1,476) = 5.19$, $p = 0.023$). This finding indicates that the effectiveness of the program was higher among participants with at least a secondary level of education.

Subgroup analysis revealed that areas with active support from local health volunteers experienced an average malaria incidence reduction of 28.4%, compared to 15.7% in areas without such support.

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Figure 3 (Scatter Plot) illustrates a strong negative correlation between compliance and malaria incidence ($r = –0.56$, $p < 0.001$), reinforcing the hypothesized causal relationship.

Overall, the findings of this experiment demonstrate that community-based malaria control strategies significantly improved knowledge, increased compliance with bed net usage, and reduced malaria incidence in the study areas. All main hypotheses (H_1) were accepted, while the null hypotheses (H_0) were rejected at a significance level of < 0.05.

The intervention effects were consistent across clusters, with moderate to high effect sizes, supporting the external validity of the study. The non-significant results observed in certain subgroups were likely due to variations in community participation and differences in healthcare support across regions.

DISCUSSION

Summary of Key Findings

The findings of this study demonstrate that community-based malaria control strategies significantly increased public knowledge and compliance with bed net usage, which in turn substantially reduced malaria incidence rates in the intervention areas compared to the control group (Oxlade et al., 2021). These results support the main hypothesis proposed in the study, namely that community-based interventions have a strong causal effect on preventive behavioral change and public health outcomes, as evidenced by experimental analysis with rigorous control of confounding variables.

Contribution of Findings to the Research Question

These findings directly address the research question presented in the introduction—whether community-based malaria control strategies have a significant effect on improving preventive behavior and reducing malaria cases in endemic areas (Paintain et al., 2020). Through the cluster randomized controlled trial (RCT) design, this study successfully isolated the treatment effects from external factors such as geographic, social, and economic differences among communities (Mukhlis, Janwari, et al., 2023). The results indicate that the increase in public knowledge and compliance was not merely correlational but was causally driven by community education and empowerment interventions.

The experimental design employed in this study enabled the validation of causal relationships with a high degree of reliability. Cluster randomization prevented selection bias, while repeated measurements (pre-, mid-, and post-intervention) provided a dynamic depiction of behavioral and disease incidence changes (Arlinda et al., 2025). This approach demonstrated that malaria control based on community participation can serve as an effective and sustainable strategy, particularly in areas with limited access to healthcare services (Mukhlis, 2025a). Thus, this study confirms that strengthening community capacity is a primary causal component in significantly reducing the malaria burden.

Relation to Previous Literature and Theoretical Frameworks

These findings reinforce previous research emphasizing the importance of community engagement in malaria control, but with stronger causal evidence due to the experimental approach employed (Cissoko et al., 2020). Unlike earlier observational studies that merely identified associations between community awareness and malaria case reduction, this study provides empirical proof that the improvement in public knowledge and compliance is a direct result of structured educational and community supervision interventions.

From a theoretical perspective, these findings extend the application of the Health Belief Model (HBM) by demonstrating that individual risk perception and belief in the benefits of prevention can be significantly enhanced through community interventions focused on empowerment and direct education (Gwitira et al., 2020). The results also support the Community Empowerment Model, which highlights the importance of active community participation in the success of public health programs (Mukhlis, Arifin, Ridwan, Zulbaidah, et al., 2025). Practically, this study provides a

scientific foundation for policymakers to integrate experimental approaches into the evaluation of community-based health policies, particularly in resource-limited regions such as Papua. Thus, this research not only strengthens the empirical literature on the effectiveness of community-based interventions but also contributes conceptually and policy-wise to the formulation of infectious disease control strategies at both national and global levels.

Explanation of the Findings' Implications

The findings of this study hold significant scientific and practical implications in the fields of community epidemiology and public health policy. Scientifically, the results confirm that community-based interventions have a substantial causal effect on improving preventive behaviors and reducing malaria incidence (Lukole et al., 2022). This strengthens the theoretical argument of the Health Belief Model (HBM), which posits that risk perception and self-efficacy can be modified through processes of social empowerment and targeted education (Mukhlis, Maryam, et al., 2023). Through this experimental validation, the study provides strong empirical evidence that behavioral and social factors are not merely supporting variables but are causal determinants that can be deliberately manipulated to achieve measurable health improvements.

Practically, the findings support the reinforcement of community-based public health policies that position the community as the primary actor in disease prevention. This approach can be integrated into national programs such as the Healthy Living Community Movement (Gerakan Masyarakat Hidup Sehat—Germas) and Healthy Indonesia through a Family Approach (Program Indonesia Sehat dengan Pendekatan Keluarga—PIS-PK), with locally relevant evidence-based modifications (Rudasingwa & Cho, 2020). Furthermore, the intervention strategies tested in this study could serve as a model for controlling other infectious diseases such as dengue fever or filariasis, with appropriate adaptations to local social and environmental contexts. The experimental results also demonstrate potential applicability in low socioeconomic populations, where participatory approaches have proven to be more effective than top-down directives (Mukhlis et al., 2024). Thus, this study contributes to the formulation of evidence-based health policies and reinforces the practical relevance of the Community Empowerment Theory in real-world health implementation.

Study Limitations

Although the results of this study demonstrate significant and consistent causal relationships among the variables, several limitations should be considered when interpreting and generalizing the findings (Paratmanitya et al., 2021). First, the sample size was limited to 12 community clusters across three districts in Papua; therefore, the results may not fully represent broader populations with differing geographic and cultural characteristics. Second, although the experimental design controlled for most confounding variables, certain external factors—such as variations in the intensity of health education, climatic conditions, and differences in the quality of healthcare facilities—may still have influenced the outcomes of the intervention.

Additionally, this study only observed the effects of the intervention over a six-month period, so the long-term impact on behavioral changes and disease incidence reduction cannot be fully confirmed. Psychological and social factors such as participant fatigue, shifts in motivation, and differences in community leadership may also have contributed to unmeasured variations in outcomes. Therefore, while these findings provide strong evidence for the effectiveness of community-based strategies within an experimental context, generalization to other populations should be approached with caution and accompanied by replication studies in different geographic and socioeconomic settings. At the same time, these limitations open opportunities for future research to further expand and deepen the understanding of social dynamics in community-based disease control.

Prospective Statement for Future Research

Future research can build upon these findings by investigating the long-term durability of community intervention effects, for example, through longitudinal randomized trials that monitor behavioral changes and disease incidence over periods exceeding one year. Moreover, further studies are needed to explore the interaction between social variables—such as community trust in health

institutions, education levels, and government policy support—and the effectiveness of community-based interventions. Such an approach may help explain variations in community responses that cannot be fully captured by the current experimental model.

Subsequent research could also employ multilevel or adaptive experimental designs, allowing for dynamic analyses of individual, group, and environmental factors simultaneously, thereby enriching the understanding of causal mechanisms. In practical terms, future studies may test the integration of digital technology–based interventions—such as mobile health monitoring applications or SMS-based educational messaging—with community empowerment strategies to enhance both the effectiveness and efficiency of public health programs. By combining rigorous experimental approaches with socially contextualized innovations, future research can make significant contributions to the development of more adaptive, evidence-based, and sustainable models for disease control.

CONCLUSION

This study examined the effectiveness of community-based malaria control strategies in Papua through a cluster randomized controlled trial approach to test the causal relationship between community interventions and changes in behavior as well as public health outcomes. The findings revealed that community interventions significantly increased public knowledge and compliance with bed net usage, leading to a substantial reduction in malaria incidence within the intervention areas. These results not only address the research question but also reinforce the application of the Health Belief Model and Community Empowerment Theory in the context of social epidemiology, providing stronger empirical evidence through an experimental design.

Beyond its theoretical contribution, the study also offers practical implications for health policymakers in designing more effective and sustainable community-based disease prevention programs in endemic regions. Methodologically, this research overcomes the limitations of previous studies by demonstrating that an experimental approach can yield valid causal evidence in the evaluation of public health interventions. For future research, it is recommended that experimental designs be extended to different geographic and social contexts to assess the stability and generalizability of these intervention effects across broader populations.

CONFLICT OF INTEREST

The authors declare no conflict of interest related to the design, implementation, analysis, or publication of this research. The funding sponsor had no role in the study design, data collection, data interpretation, or the preparation of the manuscript.

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