Research Article

Malaria Prevention in Africa and Beyond: A Comparative Data Analysis of Strategies and Outcomes

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ABSTRACT

Malaria remains a major global health challenge, with Sub-Saharan Africa (SSA) bearing the highest burden. Insecticide-treated nets (ITNs) have been widely distributed as an effective intervention to prevent malaria transmission. However, the effectiveness of ITNs varies across regions. This study aims to evaluate the relationship between ITN distribution and malaria incidents and deaths, comparing trends in SSA and the Rest of the World (ROW) over the past two decades. Using comparative data analysis, malaria incidents and deaths from 2004 to 2023 were collected and categorized into two groups (SSA and ROW) based on classifications from The Alliance for Malaria Prevention. Pearson correlation models were used to assess the relationship between ITN distribution and incidents of malaria and malaria related deaths. Lag models were used to evaluate the delayed impact of ITN distribution. Contrary to findings suggesting that ITNs reduce malaria cases by over 50%, SSA revealed a significant increase in malaria cases despite increased ITN distribution ($r = 0.5996$, $p < 0.01$). In contrast, ROW showed a strong negative correlation ($r = -0.7358$, $p < 0.01$), indicating that ITNs were effective in reducing malaria cases in non-SSA regions. However, ITN distribution was significantly correlated with a reduction in deaths in both SSA ($r = -0.8254$, $p < 0.01$) and ROW ($r = -0.7314$, $p < 0.01$) demonstrating a strong negative correlation. Lag models confirmed that the impact of ITNs remained for up to 5 years. While ITN distribution effectively reduces malaria deaths, its impact on malaria incidence remains inconsistent in SSA.

Keywords: Insecticide-Treated Nets; Malaria Prevention; Sub-Saharan Africa; Global Health; Vector Control

INTRODUCTION

Scientific advancements dominate daily headlines, showcasing breakthroughs in anti-aging therapies, cutting-edge cancer treatments, and revolutionary cures for diseases once considered untreatable. Every day, modern science pushes the boundaries of what was once thought impossible, offering hope for longer, healthier lives.

Yet, on the other side of the world, millions continue to suffer and die from a disease that is both preventable and treatable - malaria. The number of malaria cases continues to rise each year. While technological innovation races forward, numerous communities still live in fear of an illness that should no longer pose a deadly threat. Children lose their futures and families

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lose their loved ones, all because of a disease that modern medicine already knows how to fight.

The question is no longer how to prevent malaria but rather why proven and effective interventions, such as insecticide-treated bed nets (ITNs), antimalarial drugs, and other vector control strategies, fail to deliver their full potential in some of the world's most affected regions.

The primary vectors of malaria are Anopheles mosquitoes, a common species found in subtropical regions worldwide. When a female Anopheles mosquito is infected with Plasmodium parasites, it becomes a vital vector for spreading malaria. As the mosquito bites a human to take a blood meal, it injects Plasmodium sporozoites into the bloodstream. These parasites travel to the liver, where they multiply, and begin to infect red blood cells causing respiratory distress, organ failure, metabolic complications and severe anemia. When another mosquito bites the infected person, it ingests the parasite, becoming a new carrier and another cycle of transmission (1).

One method currently studied as one of the cheapest and most effective ways to stop the disease is the use of insecticide-treated mosquito nets (ITNs). Each net is manufactured at around $3 and is studied to have capabilities of reducing up to 55% of malaria episodes (2). Since Anopheles mosquitoes are most active at night, a simple net placed over the bed can prevent mosquito bites in many cases. More specifically, ITN is a mesh with holes smaller than mosquitoes treated with Pyrethroids, an insecticide and often Piperonyl Butoxide (PBO). ITNs treated with PBO are used in areas where mosquitos developed a resistance toward Pyrethroids, by enhancing the effects of Pyrethroids through an interference with enzyme that mosquitoes use to detoxify insecticide (3).

These nets are hung over a bed, and as people sleep inside the net, carbon dioxide exhaled by the individuals escapes through the mesh, attracting mosquitoes. As mosquitoes approach and touch the net's surface, the insecticide coating poisons their nervous system, ultimately stopping their hearts, making ITNs a highly effective mosquito-killing tool (1).

This easy-to-use, cost-effective preventative tool is now widely distributed on a global scale by various nonprofit organizations and philanthropical agencies. However, despite large-scale distribution efforts, malaria cases continue to rise, raising critical questions about implementation and real-world effectiveness.

METHODS AND MATERIALS

Data of malaria cases and deaths

Utilizing UNICEF data repository, World Health Organization (WHO)'s World Malaria Report 2024, World Bank's Open Data for Development Indicator, European Centre for Disease Prevention and Control's Malaria Report and United Nations (UN)'s health statistics, number of malaria cases and deaths between 2004 and 2023 were gathered and divided into two geographical groups. When using malaria cases given by cases per 1000 people, World Bank's Open Data and its Population was used to calculate malaria cases and death per the whole country's population.

Classification of countries

Countries were classified into two regions: Sub-Saharan Africa (SSA) and Rest of the World (ROW) based on categorization from The Alliance for Malaria Prevention. This classification was used to group the world wide ITN distribution by the Alliance for Malaria Prevention. The SSA group included countries predominantly located in Africa south of the Sahara, where malaria is most prevalent. The ROW group included all other countries outside of this region.

The SSA category included the following countries: Angola, Benin, Botswana, Burkina Faso, Burundi, Central African Republic (CAR), Cameroon, Cabo Verde, Chad, Comoros, Congo, Côte d'Ivoire, Djibouti, Democratic Republic of the Congo (DRC), Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, São Tomé and Príncipe (STP), Sudan, South Sudan, Eswatini, Tanzania, Togo, Uganda, Zambia, Zimbabwe (4). The ROW category included the following countries: Afghanistan, Anguilla, Antigua and Barbuda, Australia, Azerbaijan, Bahamas, Bangladesh, Barbados, Belgium, Belize, Bhutan, Bolivia, Brazil, Cambodia, Canada, China, Colombia, Costa Rica, Cuba, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Fiji, Finland, France, Germany, Greece, Grenada, Guatemala, French Guiana, Guyana, Haiti, Honduras, Hungary, India, Indonesia, Iran, Iraq, Italy, Jamaica, Jordan, Korea (Republic of), Korea (Democratic People's Republic of), Lao People's Democratic Republic, Lebanon, Kyrgyzstan, Malaysia, Marshall Islands, Mauritius, Mayotte, Mexico, Micronesia (Federated States

of), Morocco, Myanmar, Nepal, Netherlands, New Caledonia, New Zealand, Nicaragua, Norway, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, St. Lucia, Samoa, Saudi Arabia, Singapore, Solomon Islands, Spain, Sri Lanka, Suriname, Sweden, Switzerland, Syria, Tajikistan, Thailand, Timor-Leste, Turkey, United Arab Emirates, United States of America, Uzbekistan, United Kingdom of Great Britain and Northern Ireland, Vanuatu, Venezuela, Vietnam, Yemen (4).

Using comparative data analysis of the number of ITN distributed in different countries grouped as those in SSA and those in the ROW, the study examines the connection between the number of ITN and cases of Malaria reported each year since 2004.

Statistics

All statistical analyses were conducted in R 3.2.3 using RStudio. To assess the relationship between ITN distribution and malaria cases or deaths, Pearson correlation models were used in order to measure the strength and direction of a linear association between ITN distribution and malaria cases and then the deaths (5). 5-year lag models are used to account for potential delayed effects of ITN distribution on malaria outcomes. In these models, ITN distribution data were systematically shifted back by 1 to 5 years, allowing us to examine whether ITNs take time to reach full effectiveness.

RESULTS

ITN Distribution and Malaria Cases in SSA and ROW

Upon a Pearson linear correlation model examination, the correlation between the distribution of ITNs and malaria cases are moderately positive ($r = 0.5996$) in SSA region ($P < 0.01$) in contrast to a strong negative correlation ($r = -0.7358$) between the two in ROW region ($P < 0.01$) (Table 1).

The relationship between ITN distribution and malaria cases in SSA and ROW is shown in Figure 1. SSA data points are represented in blue, while ROW data points are shown in red. The regression lines indicate the direction of association, with the SSA regression line (pink) showing a moderately positive correlation ($r = 0.5996$) while the ROW regression line (green) demonstrates a strong negative correlation ($r = -0.7358$) between ITN distribution and malaria cases ($P < 0.01$). These results suggest that the effect of ITNs

Table 1. The Pearson's r scores table

Region	Lag	Pearson's r	p-value	Confidence Interval
SSA	0	0.5996	0.0052	(0.214, 0.824)
	1	0.6833	0.0013	(0.332, 0.868)
	2	0.6733	0.0022	(0.301, 0.867)
	3	0.7459	0.0006	(0.414, 0.903)
	4	0.7071	0.0022	(0.326, 0.891)
	5	0.6585	0.0076	(0.221, 0.875)
ROW	0	-0.7358	0.000217	(-0.889, -0.435)
	1	-0.7775	0.000089	(-0.91, -0.5)
	2	-0.8475	0.000009	(-0.942, -0.63)
	3	-0.8468	0.000018	(-0.943, -0.617)
	4	-0.8516	0.000028	(-0.947, -0.616)
	5	-0.7554	0.0011	(-0.914, -0.397)

The table shows a positive r score across all SSA region where as the ROW region shows a negative r score across all lag models. All r scores are statistically significant ($P < 0.01$).

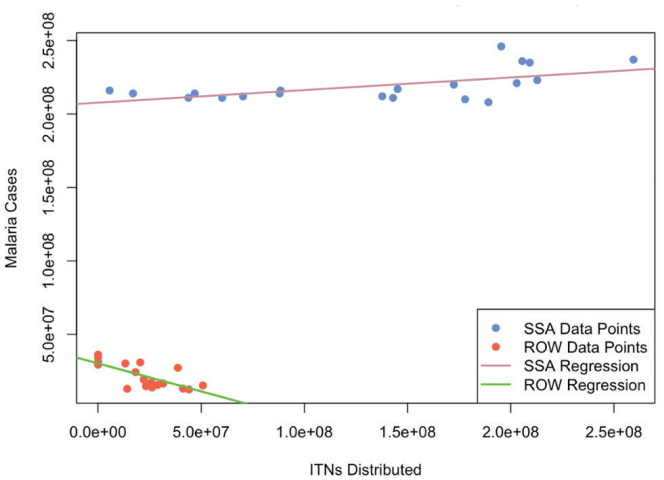

Figure 1. Pearson correlation between ITN distribution and malaria cases by region (contemporaneous, lag 0). Scatter points show observed values; solid lines are linear fits. In SSA, ITN distribution is moderately and positively correlated with malaria cases ($r = 0.5996$, 95% CI 0.214–0.824, $P = 0.0052$). In the ROW, the correlation is strongly negative ($r = -0.7358$, 95% CI −0.889 to −0.435, $P = 0.000217$). See Table 1 for confidence intervals and additional lag models.

on malaria reduction vary by region, with a significant decline in malaria cases observed in ROW and a moderate increase in malaria cases observed in SSA.

When delayed impact was placed using a 1-to-5-year lag model on Pearson correlation test, correlation between ITN distribution and Malaria cases remains strongly positive ($r > 0.5996$) and peaks at Lag 3 ($r = 0.7459$) ($P < 0.01$) in SSA region. Equivalent lag model in Pearson correlation between ITN distribution and Malaria cases in ROW maintains a strong negative correlation ($r < 0.7358$), peaking at Lag 4 ($r = -0.8516$) ($P < 0.01$) (Table 1).

The graph examines the effect of ITN distribution on number of malaria cases in SSA and ROW was delayed by a year five times to examine its potentially delayed effect on the number of reported cases (Figure 2). SSA exhibits a positive correlation between the number of ITN distributed and the number of malaria cases while ROW on the other hand exhibits a negative correlation between the two.

ITN Distribution and Malaria Deaths in SSA and ROW

Linear Pearson correlation was conducted between the number of ITN distributed and the count of malaria death in SSA to reveal a strong negative correlation ($r = -0.8254$) ($P < 0.01$). Same correlation in ROW also showed a strong negative correlation ($r = -0.7314$) ($P < 0.01$).

In Figure 3, the contemporaneous (lag 0) relationship between ITN distribution and malaria deaths is presented. Both SSA and ROW showed strong negative correlations, indicating that higher ITN coverage was consistently associated with fewer malaria-related deaths. Specifically, SSA exhibited a correlation coefficient of –0.8254 ($P < 0.01$), while ROW showed a correlation of –0.7314 ($P < 0.01$). These findings suggest that, despite regional differences in malaria incidence trends, ITN distribution has a robust protective effect on malaria mortality across both SSA and ROW.

When the same model was delayed by a year for 5 years, both SSA region ($r < -0.5446$) ($P < 0.01$) and ROW region ($r < -0.7292$) ($P < 0.01$) shows a moderate to strong negative correlation between the number of ITN distributed and counts of death caused by malaria in respective regions (Figure 3). The negative correlation peaked at Lag 0 ($r < -0.8254$) in SSA region and Lag 2 ($r < -0.8635$) in ROW region (Table 2).

As shown in Figure 4, ITN distribution was strongly and negatively correlated with malaria deaths

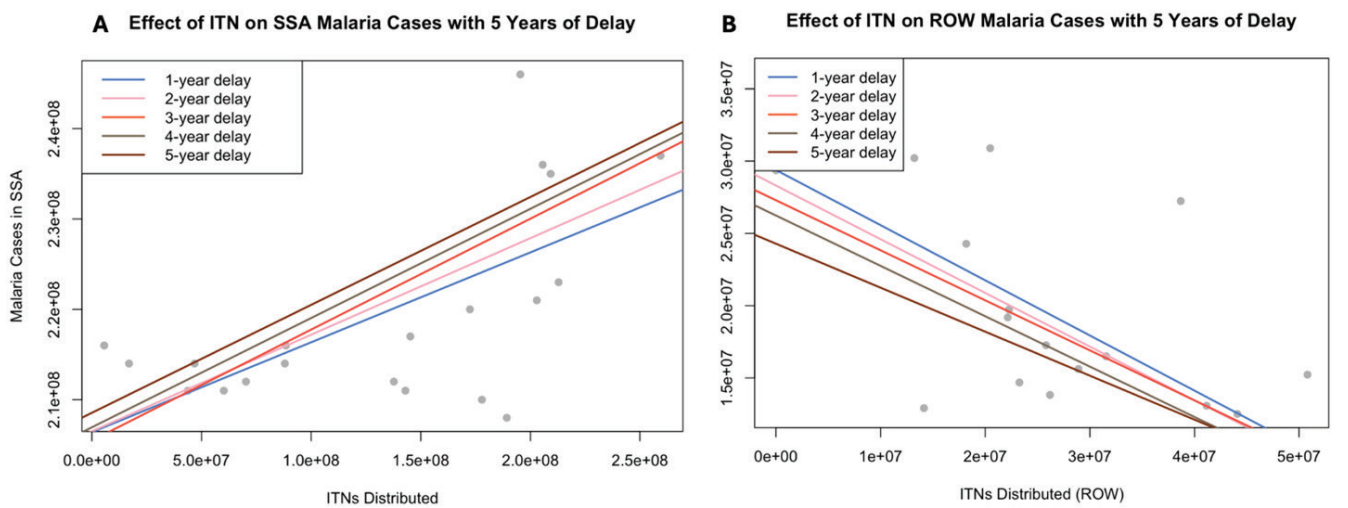

Figure 2. Pearson correlation between ITN distribution and malaria cases across lag models (1–5 years). (A) Effect of ITN on SSA Malaria cases with 5 years of delayed lag. ITN distribution is positively correlated with malaria cases, and the magnitude of correlation increases with longer lag periods (1–5 years). (B) Effect of ITN on ROW Malaria cases with 5 years of delayed lag. ITN distribution is negatively correlated with malaria cases across all lag models, with stronger negative slopes observed at longer delays. Gray points represent observed data, and colored lines correspond to regression fits for each lag scenario.

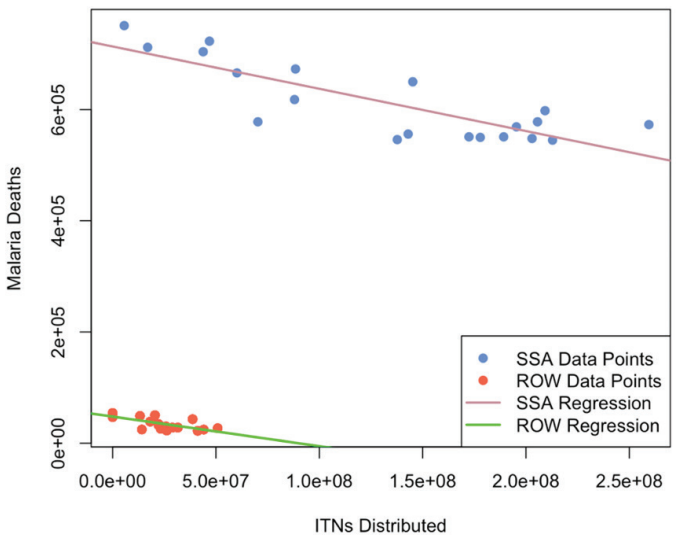

Figure 3. Pearson correlation between ITN distribution and malaria deaths by region (contemporaneous, lag 0). Scatter points represent observed values, with solid lines showing linear fits. In Sub-Saharan Africa (SSA), ITN distribution was strongly and negatively correlated with malaria deaths (r = –0.8254, 95% CI –0.929 to –0.603, P < 0.01). In the rest of the world (ROW), a similar strong negative correlation was observed (r = –0.7314, 95% CI –0.886 to –0.507, P < 0.01). See Table 2 for additional lag models and confidence intervals.

Table 2. Pearson's correlation coefficients between ITN distribution and malaria deaths across lag models (0–5 years) in SSA and the ROW

Region	Lag	Pearson's r	p-value	Confidence Interval
SSA	0	-0.8254	0.0000007445	(-0.929, -0.603)
	1	-0.7692	0.000118	(-0.907, 0.484)
	2	-0.7855	0.000112	(-0.916, -0.503)
	3	-0.7042	0.001602	(-0.885, -0.338)
	4	-0.6674	0.004737	(-0.874, -0.256)
	5	-0.5446	0.035802	(-0.826, -0.045)
ROW	0	-0.7314	0.0002483	(-0.886, -0.507)
	1	-0.7812	0.0000786	(-0.912, -0.507)
	2	-0.8635	0.00000391	(-0.948, -0.665)
	3	-0.8202	0.0000554	(-0.933, -0.56)
	4	-0.8232	0.0000894	(-0.937, -0.553)
	5	-0.7292	0.00204	(-0.904, -0.346)

All r scores are statistically significant (p < 0.01).

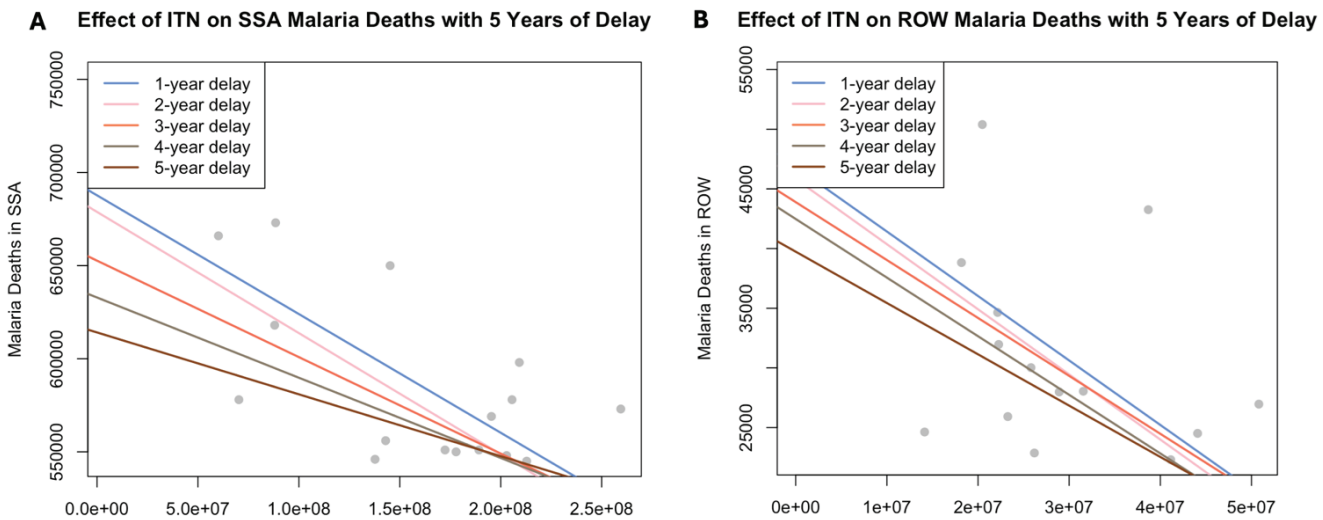

Figure 4. The ITN distribution and malaria death counts are negatively correlated in both SSA and ROW regions (P < 0.01). (A) Effect of ITN on SSA Malaria deaths with 5 years of delayed lag model. (B) Effects of ITN on ROW Malaria deaths with 5 years of delayed lag model.

in both Sub-Saharan Africa (SSA) and the rest of the world (ROW). In panel A, greater ITN distribution in SSA was consistently associated with substantial reductions in malaria deaths, with the slope of decline becoming steeper when longer lag periods (3–5 years) were considered. Similarly, in panel B, the ROW region exhibited a comparable pattern, where higher ITN coverage corresponded to fewer malaria deaths across all lag models. These findings confirm that, despite temporal delays, scaling up ITN distribution significantly decreases malaria mortality in both SSA and ROW ($P < 0.01$).

Both SSA ($r = -0.8254$) and ROW ($r = -0.7314$) showed a strong negative correlation suggesting that increase of ITN distribution significantly decrease malaria deaths in both SSA and ROW ($P < 0.05$). Comparing their correlation score, the number of ITN distribution is more strongly associated with a reduction in deaths in SSA compared to ROW.

DISCUSSIONS

Unexpectedly, while insecticide-treated nets (ITNs) have been widely documented to reduce malaria incidence by over 50%, their distribution in Sub-Saharan Africa (SSA) has been accompanied by a significant increase in malaria cases. In contrast, Rest of the World (ROW) regions exhibited a steady decline in malaria incidents with increased ITN distribution.

This inverse correlation in SSA suggests the presence of confounding factors that may be counteracting the expected benefits of ITNs. Enhanced health surveillance systems may lead to more effective and comprehensive reporting, potentially reflecting a rise in malaria incidents due to improved detection mechanisms rather than an actual increase in incidence (7). Rapid population growth in SSA could result in a higher number of malaria infections, even if the per capita rate remains constant, thereby challenging malaria infection control efforts. Additionally, climate change and man-made environmental alterations may create favorable breeding conditions for Anopheles mosquitoes, potentially increasing transmission rates. It has also been reported that economic hardships and food insecurity have driven some communities to repurpose ITNs for activities such as fishing and crafting, reducing their availability for malaria prevention (8).

Despite this unexpected trend, ITN distribution was strongly associated with reduced malaria-related deaths in both SSA and ROW. Statistically significant negative correlations between ITN distribution and malaria mortality rates suggest that while ITNs may not be fully effective in preventing malaria cases in SSA, they play a critical role in reducing the severity and fatality of infections. This may indicate that ITNs, although unable to completely prevent mosquito exposure, still contribute to lowering the likelihood of severe malaria episodes and complications.

Our lag model analysis revealed that the impact of ITN distribution persists over time, with a delayed reduction in malaria cases and deaths for up to five years in both SSA and ROW. This finding suggests that ITNs may take time to reach full effectiveness, emphasizing the need for long-term monitoring and intervention strategies rather than immediate outcome assessments.

CONCLUSIONS

Contrary to common beliefs, Malaria remains endemic in many countries and more than 3.4 billion people (approximately half of the world's population) are still at risk. While ITNs remain a key intervention in the fight against malaria, their effectiveness varies significantly by region. In SSA, confounding variables may be limiting their full potential, requiring complementary malaria control measures. Addressing these challenges through comprehensive, data-driven, and context-specific strategies is crucial for achieving sustained malaria reduction and prevention.

This study has several limitations. First, Pearson correlation tests establish associations between variables but do not imply causality; therefore, the findings should be interpreted as associative rather than definitive. More robust evidence could be obtained from longitudinal or randomized controlled studies. Second, the study relies on secondary data from international organizations (WHO, UNICEF, World Bank), which may vary in accuracy and consistency across regions. Third, while we report correlation coefficients and p-values, future work should include confidence intervals to strengthen the interpretation of effect sizes. In addition, because Pearson correlation assumes independence of yearly observations, potential autocorrelation in time-series data may bias the results; future analyses using time-series specific approaches (e.g., ARIMA, generalized least squares) would provide a more rigorous assessment. Finally, unmeasured confounding factors such as insecticide resistance, environmental changes, and human behavioral practices

may have influenced malaria trends, limiting the ability to attribute changes solely to ITN distribution.

CONFLICT OF INTERESTS

The author declares that there are no conflicts of interest related to this work.

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