

Enhancing Malaria Control in Nigeria: A Data-Driven Approach to Prioritizing Insecticide-Treated Net Assessment

Abimbola H. Afolayan[1(✉)], Gideon E. Igbo[2], and Oluwafemi A. Sarumi[3]

[1] Information Systems Department, Federal University of Technology, Akure, Nigeria
ahafolayan@futa.edu.ng
[2] Computer Science Department, Federal University of Technology, Akure, Nigeria
[3] Institute of Computer Science, Heinrich-Heine University Düsseldorf, Düsseldorf, Germany

Abstract. Malaria remains a major public health challenge in sub-Saharan Africa, with Nigeria accounting for 31.9% of global malaria deaths in 2020. Despite efforts to control malaria through World Health Organization (WHO)-recommended interventions such as insecticide-treated nets (ITNs) and indoor residual spraying, the disease persists. Effective malaria control requires informed decision-making at multiple levels, with community health workers (CHWs) playing a crucial role in implementing and assessing interventions at the grassroots level. This study applies the Analytic Hierarchy Process (AHP) to evaluate ITNs effectiveness from the perspective of CHWs. Eight key criteria were analyzed: affordability, availability, accessibility, acceptability, suitability, previous experience, beliefs, and malaria knowledge. Data was collected through structured questionnaires and analyzed using AHP. The results showed malaria knowledge as the top priority (24.8%), followed by previous experience with malaria (22.9%). These findings provide valuable insights for policymakers to enhance ITNs distribution and malaria prevention efforts. By incorporating CHWs' perspectives, resource allocation can be optimized, leading to more effective malaria control strategies.

Keywords: Malaria Epidemic · Insecticide Treated Nets · Decision Criteria · Analytic Hierarchy Process

1 Introduction

Malaria remains a critical public health challenge, particularly in sub-Saharan Africa, where it is a leading cause of morbidity and mortality. The disease, caused by Plasmodium parasites and transmitted through the bites of infected female Anopheles mosquitoes, disproportionately affects tropical and subtropical regions [1]. Among the five Plasmodium species known to cause malaria in humans, Plasmodium falciparum is the most virulent and is responsible for the majority of malaria-related deaths, particularly in Africa [2]. Despite decades

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of global and regional efforts to control malaria, the disease persists as a major burden, with Nigeria being the most affected country.

According to the World Health Organization [3], Nigeria accounted for 31.9% of global malaria deaths in 2021, translating to approximately 200,000 fatalities. The overall malaria incidence has increased, with cases rising from 227 million in 2019 to 241 million in 2020. Similarly, the number of deaths surged from 558,000 in 2019 to 627,000 in 2020, underscoring the urgency for more effective intervention strategies. Various control measures, such as long-lasting ITNs, indoor residual spraying, larval source management, and intermittent preventive treatment for pregnant women, have been implemented, but challenges persist in achieving sustained reductions in malaria prevalence and mortality [3].

Vector control remains the cornerstone of malaria prevention, with ITNs being one of the most effective strategies [4]. ITNs provide a physical barrier against mosquito bites while also delivering insecticidal effects, significantly reducing transmission rates when properly used. Since the WHO launched mass ITNs distribution campaigns in 2007, aiming for universal coverage (one net per two individuals), there has been a notable increase in ITNs usage in sub-Saharan Africa [5]. However, ensuring continued ITNs effectiveness requires sustained efforts, including replacing worn-out nets and addressing challenges related to accessibility, affordability, and acceptability. Studies indicate that many distributed ITNs deteriorate before their intended lifespan, reducing their efficacy in malaria control [6].

Effective malaria control depends on well-coordinated decision-making at multiple levels of governance, from national policymakers to local authorities and healthcare providers [7]. In Nigeria, the National Malaria Control Program formulates policies in collaboration with international organizations, while the State Malaria Elimination Programs adapt these strategies at the state level. At the grassroots level, CHWs serve as the link between public health initiatives and local populations, ensuring the effective distribution of ITNs and educating communities on malaria prevention. Despite their critical role, CHWs' perspectives on ITNs distribution and effectiveness are often overlooked in policy and resource allocation decisions. Engaging CHWs in decision-making can enhance the adoption and sustainability of ITNs interventions by addressing locally relevant barriers and community concerns.

Given the complexity of malaria control, Multi-Criteria Decision Analysis (MCDA) methodologies provide a systematic approach to evaluating and prioritizing intervention strategies. The AHP [8] is one of the most widely used MCDA techniques for structuring complex decision problems. AHP allows the integration of qualitative and quantitative factors through pairwise comparisons, ensuring a more objective and consistent prioritization process [9]. This method has been applied in various malaria-related studies, including identifying high-risk zones, evaluating intervention effectiveness, and optimizing resource allocation [10–12].

Although previous research has employed AHP to rank malaria control strategies, few studies have focused specifically on assessing ITNs from the

perspective of CHWs. Given their frontline experience and direct engagement with at-risk populations, CHWs offer valuable insights into the real-world factors influencing ITNs effectiveness, including community preferences, behavioral patterns, and logistical challenges. Incorporating their perspectives into decision-making can lead to more effective and context-specific malaria control policies. This study aims to evaluate decision criteria for assessing ITNs using the AHP methodology, with a particular focus on the perspectives of CHWs. By systematically ranking key factors such as affordability, accessibility, acceptability, durability, and prior experience, this research provides a structured framework to guide policymakers in optimizing ITNs distribution and utilization. The findings will contribute to evidence-based decision-making, improve the efficiency of malaria intervention programs, and ultimately enhance malaria prevention and control efforts in Nigeria.

2 Materials and Methods

The research utilized both primary and secondary data sources. Primary data were collected through structured questionnaires distributed to 40 CHWs in Akure, the capital of Ondo State, located in southwestern Nigeria, with an estimated population of 803,062 based on recent projections from the World Population reviews. Akure serves as an ideal location for investigating the roles of CHWs in accessing the intervention of ITNs for malaria control, given its diverse population, active governmental health programs through community healthcare providers.

The CHWs were selected through purposive sampling. The questionnaire comprised two sections: one focused on demographic information and the other designed to capture respondents' insights. The demographic composition of respondents indicated a predominance of females (65%) over males (35%). Participants were categorized by age as follows: 62.5% were between 26 and 40 years old, 25% were between 41 and 55 years old, and the remaining 12.5% were between 56 and 70 years old. In terms of professional qualifications, 12.5% held the position of Junior Community Health Extension Workers, 37% were Community Health Extension Workers, and 5% were Senior Community Health Extension Workers. Additionally, 2.5% held Certificates in Community Health, 20% had Diplomas in Community Health, and 22.5% possessed Bachelor's degrees in Community or Public Health. The secondary data were obtained from literature and other relevant sources on malaria interventions.

In analyzing the effects of ITNs, we considered eight crucial decision criteria as shown in Table 1 based on previous studies [12,13], and guidelines from the Nigeria Federal Ministry of Health. The CHWs rated the importance of each criterion, comparing their efficacy in assessing ITNs. The questionnaire sought to transform responses into nine-point AHP scale numbers. These values were then used to calculate each decision criterion's relative weights and rank them using the AHP. The AHP technique's primary feature is pair-wise comparisons, enabling the evaluation of alternatives for different criteria and the estimation

of criteria weights [14]. The AHP method organizes complex decision-making problems into hierarchies, defines criteria, evaluates their interactions, and synthesizes data to derive weights representing preferences [15]. The AHP approach adopted in this study comprises five steps, as illustrated in Fig. 1.

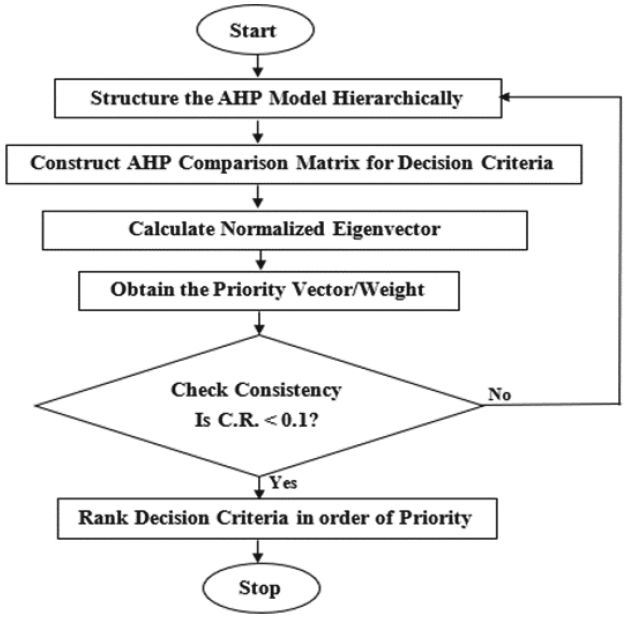


Fig. 1. Flowchart of AHP Process.

The hierarchical structure as shown in Fig. 2 consists of three levels. The first level (target level) describes the goal of the whole hierarchical structure, which is the ranking of decision criteria for assessing ITNs for malaria control. The second level contains the decision criteria to be evaluated and ranked. The third level contains the WHO-recommended malaria intervention strategy for ITNs.

This research considered eight decision criteria. Table 1 lists and briefly describes each of the decision criteria.

The CHWs were asked to rank the significance of decision criteria for evaluating ITNs for malaria control. The ratings were based on the 9-point Saaty AHP scale: (1) = Equally Important, (3) = Weakly Important, (5) = Fairly Important, (7) = Strongly Important, and (9) = Absolutely Important. The judgments from the respondents were entered using the Saaty AHP scale for pairwise comparisons. Based on the Saaty AHP scale, the expert's preferences were obtained, and Equation (1) was used to construct the AHP pairwise comparison matrix of the decision criteria. A matrix A is created to elicit pairwise comparisons performed at a given time. Matrix A in Eq. (1) shows the experts' judgment

Table 1. Evaluated decision criteria.

S/No	Criteria	Description
1	Affordability	Affordability of ITNs
2	Availability	Availability of ITNs to the population
3	Accessibility	Accessibility of ITNs
4	Acceptability	Acceptability of ITNs by the population
5	Suitability	Suitability of the use of ITNs
6	Previous Experience	Previous experience of the population with the use of insecticide-treated nets
7	Beliefs	Beliefs of the population
8	Malaria Knowledge	Malaria knowledge of the population

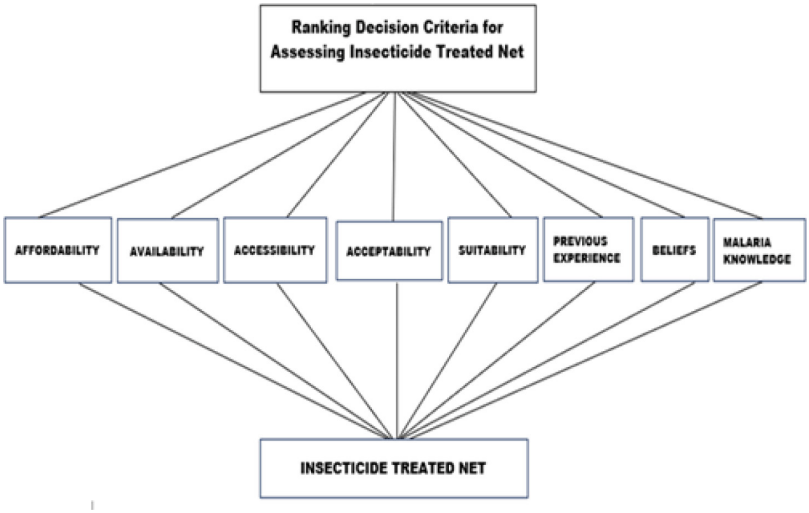


Fig. 2. Analytic Hierarchy Process Structure.

preference for the i^{th} criterion over the j^{th} criterion. The pairwise comparison for all respondents is shown in Fig. 3.

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & a_{23} & \cdots & a_{2n} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \frac{1}{a_{3n}} & \cdots & 1 \end{bmatrix} \tag{1}$$

where A is the pairwise comparison matrix, and a_{ij} represents the relative importance of criterion i compared to criterion j.

Matrix		Affordability	Availability	Accessibility	Acceptability	Suitability	Previous Experience	Beliefs	Malaria Knowledge
		1	2	3	4	5	6	7	8
Affordability	1	1	1	1	7/8	3/7	1/3	1 1/2	1/4
Availability	2	1	1	1 1/2	1	1/2	2/5	1 2/3	1/3
Accessibility	3	1	2/3	1	1	3/8	1/4	1 1/2	2/7
Acceptability	4	1 1/7	1	1	1	1/2	2/7	1 2/3	2/7
Suitability	5	2 1/3	2 1/9	2 3/4	2	1	2/3	2 2/3	3/4
Previous Experience	6	3 2/7	2 1/2	3 4/5	3 1/3	1 4/9	1	3 5/6	4/5
Beliefs	7	2/3	3/5	2/3	3/5	3/8	1/4	1	2/7
Malaria Knowledge	8	3 4/5	3	3 1/3	3 5/8	1 1/3	1 1/4	3 3/5	1
Column Sum		14.28	11.85	14.99	13.51	5.948	4.46	17.37	3.99

Fig. 3. Pairwise comparison for all respondents.

To determine the normalized eigenvector, the element in each cell is divided by its corresponding column total, as shown in Eq. (2).

$$b_i = \frac{a_{ij}}{D} \tag{2}$$

where b_i is the normalized eigenvector and D is the column total of the decision criteria.

The Priority weight W_i is calculated by dividing the sum of all elements in each row of the normalized eigenvector by the number of elements in the row, as shown in Eq. (3).

$$W_i = \frac{\sum_{j=1}^{8} b_i}{n} \tag{3}$$

where W_i is the priority weight and b_i is the normalized eigenvector.

The priority vector/weights W_1,W_2,W_3,W_4,W_5,W_6,W_7,W_8 are then shown in a single matrix in Eq. (4).

$$\mathbf{W} = \begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ W_4 \\ W_5 \\ W_6 \\ W_7 \\ W_8 \end{bmatrix} \tag{4}$$

Also, we verified the consistency of the expert judgments while doing the AHP analysis. We observed some inconsistency in the pairwise comparison because the numerical values were obtained from people's arbitrary preferences. Thus, we calculated the consistency ratio using the Saaty model [15] as shown in Eq. (5)

$$C.R = \frac{C.I}{R.I} \tag{5}$$

where $C.R$ is the consistency Ratio, $C.I$ is the consistency Index and $R.I$ is the Random Index

Based on the Saaty model, reasonable judgments are those with a consistency ratio of less than 0.1, and those with a consistency ratio of more than 0.1 are either corrected or dismissed. RI refers to random pairwise comparisons with judgments that have been input arbitrarily, which is affected by the size of matrix n. The consistency index can be defined as a deviation or degree of consistency as shown in Eq. (6)

$$C.I = \frac{\lambda_{\max} - n}{n - 1} \tag{6}$$

where n is the decision matrix's row count and $\lambda_{\max}$ is the comparison matrix's eigenvalue

To determine the comparison matrix's largest eigenvalue $\lambda_{\max}$ is calculated using Eq. (7).

$$\lambda_{\max} = \frac{S_i}{n} \tag{7}$$

where S_i is the sum total of all s_i as shown in Eq. (8).

$$S_i = \sum_{j=1}^{n} s_i \tag{8}$$

where s_i is the product of the priority weight and the column total of individual criteria as shown in Eq. (9).

$$s_i = \sum_{i=1}^{n} W_i * D \tag{9}$$

where W_i is the priority weight and D is the column total of the individual criteria.

Therefore, the decision criteria were ranked in order of priority after ascertaining that the consistency ratio was lower than 0.1.

3 Results

The priority determination for each criterion is derived from a questionnaire survey, with the first section gathering demographic information and the second section posing questions for respondent input. CHWs assess the importance of eight decision criteria for evaluating ITNs in malaria control, utilizing a 9-point Saaty AHP scale. The study evaluates eight decision criteria: affordability, availability, accessibility, acceptability, suitability, previous experience, beliefs, and malaria knowledge. The ranking of decision criteria employs the AHP package developed by [16], resulting in the synthesis of priorities and the subsequent identification of the most crucial decision criterion for ITNs assessment in malaria control, as presented in Table 2.

Table 2. Ranking of Priority Weights for All Respondents.

Criterion	Criteria	Weights	Rank
C_8	Malaria Knowledge	0.2475	1
C_6	Previous Experience	0.2294	2
C_5	Suitability	0.1665	3
C_2	Availability	0.0849	4
C_4	Acceptability	0.0768	5
C_1	Affordability	0.0716	6
C_3	Accessibility	0.0688	7
C_7	Beliefs	0.0545	8

Figure 4 indicates that malaria knowledge is the most crucial factor influencing the decision-making process for using ITNs in malaria prevention, given its highest priority weight of approximately 24.7%. Subsequently, Previous Experience holds significant importance with a priority weight of 22.9%, while Suitability, Availability, Acceptability, Affordability, and Accessibility follow in descending order of priority weights. Beliefs rank the lowest, with a priority weight of 5.5%. In practical terms, this implies that when decisions are made concerning adopting ITNs for malaria prevention, a focus on enhancing malaria knowledge is paramount.

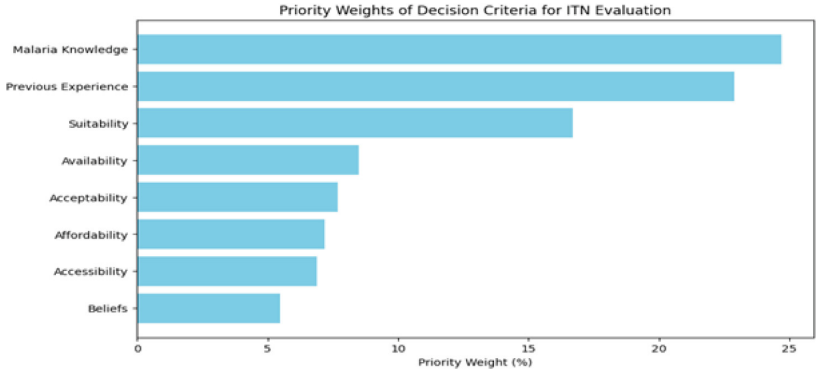


Fig. 4. Visualization of the ITNs decision criteria ranking highlights malaria knowledge as the most influential factor in the decision-making process.

3.1 Discussion

Despite numerous initiatives to curb malaria transmission in Nigeria, the prevalence of malaria cases has persistently risen. In the fight against malaria in Nigeria, [12,13] have recommended prioritizing ITNs. The selection of appropriate criteria for evaluating ITNs in malaria control is a critical decision for healthcare policymakers, particularly those in secondary and tertiary healthcare.

This research builds upon the work of [13] by incorporating a broader perspective from community health workers, strengthening the understanding of key factors in malaria prevention. Notably, malaria knowledge emerged as the most critical criterion, with a priority weight of 24.8%, underscoring its pivotal role in combating the disease. This finding aligns with studies [17] and [18], which highlight the ongoing challenge of low malaria awareness among vulnerable groups, including rural communities, mothers, pregnant women, and caregivers of young children. Furthermore, this study reinforces the findings of [19], which emphasize the effectiveness of health education interventions in promoting the use of ITNs among pregnant women. By demonstrating the crucial role of increased knowledge in ITNs ownership, usage, and awareness, our results highlight the urgent need for targeted educational initiatives to enhance malaria prevention efforts.

Moreover, this study identifies prior experience with ITNs as the second most influential factor in determining their usage, carrying a significant priority weight of 22.9%. This emphasizes the crucial role of familiarity and past exposure in promoting long-term adoption and effective utilization. Additionally, the study highlights a persistent issue: despite owning ITNs, many individuals continue to use them sub-optimally. This trend is consistent with findings from previous research [5,20–24], indicating ongoing challenges in achieving proper ITNs utilization. These insights underscore the pressing need for targeted awareness campaigns, behavioural interventions, and policy measures to bridge the gap

between ITNs ownership and sustained use, ultimately enhancing malaria prevention efforts.

In this study, suitability ranked as the third most influential factor, with a priority rating of 16.7%. This underscores its crucial impact on user adherence, as discomfort and perceived warmth continue to deter consistent ITNs use, an issue echoed in previous research [25]. By drawing attention to this barrier, our study emphasizes the urgent need for innovative ITNs designs that improve breathability and comfort without compromising effectiveness. These findings advocate for targeted interventions, including educational initiatives to help users adapt to ITNs and policy-driven efforts to promote user-friendly net designs. Addressing these challenges is essential for closing the gap between ITNs ownership and regular use, ultimately enhancing malaria prevention efforts in vulnerable communities.

According to the Nigeria Malaria Indicator Survey 2015 [26], 69% of households in Nigeria owned at least one ITNs. However, despite this widespread ownership, actual utilization remained significantly low, with only 37% of households consistently using mosquito nets. In our study, availability emerged as the fourth most influential factor affecting ITNs usage, with a priority weight of 8.5%, highlighting ongoing disparities in access and distribution. This finding underscores the urgent need for targeted interventions to enhance awareness, improve accessibility, and promote behavioural adoption of ITNs, particularly among vulnerable populations at high risk of malaria.

In this study, acceptability ranks as the fifth most influential factor in ITNs utilization, with a priority weight of 7.7%. This finding aligns with previous research [5], which highlights the widespread misuse of ITNs for unintended purposes, such as bed covers, blankets, fishing nets, or window treatments. This misuse reduces their effectiveness in malaria prevention and reflects gaps in awareness and adherence. Addressing cultural and practical misconceptions through targeted educational campaigns is essential to improving ITNs acceptability. By understanding these behavioural patterns, policymakers and health workers can implement more effective interventions to enhance ITNs usage and strengthen malaria prevention efforts.

Affordability and accessibility ranked as the sixth and seventh most influential factors in ITNs utilization, emphasizing Nigeria's reliance on international donors like The Global Fund for malaria interventions [2]. Despite increased ITNs distribution, challenges persist in ensuring proper usage [27]. A major concern is the resale of freely distributed ITNs, driven by financial hardship and lack of awareness, which hinders accessibility for vulnerable groups [28]. Additionally, logistical barriers, including poor distribution networks, further limit access [29]. To address these issues, stronger monitoring, improved distribution strategies, and community engagement efforts are essential [2,30]. Strengthening these areas will help bridge the gap between ITNs ownership and effective utilization.

Beliefs ranked as the least influential factor in ITNs utilization (5.5%), as CHWs prioritize more pressing barriers like malaria knowledge, accessibility, affordability, and comfort [2,31]. Despite this low ranking, misconceptions about

ITNs rooted in distrust of Western interventions and a perceived low malaria risk still hinder their proper use [28,30]. However, CHWs view these beliefs as manageable through sustained education and community engagement. Strengthening culturally tailored health campaigns and involving trusted local leaders can help dispel myths and improve ITNs adoption [2].

4 Conclusion

Malaria stands as a critical global public health challenge, especially prevalent in Africa, with Nigeria reporting the highest incidence. Introducing ITNs is a pivotal malaria control strategy endorsed by the WHO. Involving CHWs in prioritizing decision criteria for assessing ITNs for malaria control in Nigeria helps provide valuable insights into the key criteria for assessing ITNs in malaria control at the community level. By leveraging this information, state and central-level policymakers can make informed decisions, optimize resource allocation, improve program effectiveness, and ultimately contribute to more successful malaria control efforts in Nigeria. The AHP assessed and prioritised eight decision criteria: affordability, availability, accessibility, acceptability, suitability, previous experience, beliefs, and malaria knowledge. The analysis reveals a high ranking of malaria knowledge by CHWs, underscoring its significance in decisions concerning ITNs for malaria control. This research aids healthcare providers in comprehending the importance of each decision criterion, facilitating improved decision-making. It is important to note that this study focuses solely on ranking decision criteria for ITNs. This study was conducted in Akure, Ondo State, Nigeria. In future research, we aim to expand the scope of data collection to include additional states and regions across the country, broaden the evaluation criteria and sub-criteria, and incorporate a wider range of malaria intervention strategies recommended by the WHO across multiple case studies.

Disclosure of Interests. The authors declare that there is no competing interest.

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