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Co-creation and application of a framework for the de-prioritization of urban communities during insecticide-treated bed net mass campaigns for malaria prevention and control in Kwara State, Nigeria

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Abstract

Background Malaria continues to be a major cause of illness and death worldwide, particularly affecting children under the age of five and those living in high-burden countries like Nigeria. Long-lasting insecticidal nets (LLINs) are one of the effective interventions for malaria control and prevention. In response to funding constraints in the Global Fund Grant Cycle 7, Nigeria's National Malaria Elimination Programme (NMEP) aimed to develop an approach that maximizes the impact of limited malaria interventions by focusing on areas with the greatest need. We developed an urban LLINs distribution framework and a novel strategy, which was piloted in Ilorin, the capital of Kwara State.

Methods A participatory action research approach, combined with abductive inquiry, was employed to co-design a framework for guiding bed net distribution. The final framework consisted of three phases: planning, data review and co-decision-making, and implementation. During the framework's operationalization, malaria risk scores were computed at the ward level using four key variables, including malaria case data and environmental factors, and subsequently mapped. A multistakeholder dialogue facilitated the selection of the final malaria risk maps. Additionally, data from an ongoing study were analyzed to determine whether local definitions of formal, informal, and slum settlements could inform community-level stratification of malaria risk in cities.

Results Akanbi 4, a ward located in Ilorin South and Are 2, a ward in Ilorin East consistently had lower risk scores, a finding corroborated during the multistakeholder dialogue. A map combining malaria test positivity rates among children under five and the proportion of poor settlements was identified as the most accurate depiction of ward-level malaria risk. Malaria prevalence varied significantly across the categories of formal, informal, and slum

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settlements, resulting in specific definitions developed for Ilorin. Thirteen communities classified as formal settlements in Are 2 were de-prioritized during the bed net distribution campaign.

Conclusions The framework shows promise in facilitating evidence-based decision-making under resource constraints. The findings highlight the importance of stakeholder engagement in evaluating data outputs, particularly in settings with limited and uncertain data. Enhancing surveillance systems is crucial for a more comprehensive approach to intervention tailoring, in alignment with WHO's recommendations.

Keywords De-prioritization, Reprioritization, Bed nets, LLINs, Malaria

Background

Malaria remains a leading cause of disease and death globally among children under the age of five, with an estimated 263 million cases and 597,000 deaths recorded in 2023 alone [1]. Malaria control strategies include prevention methods such as long-lasting insecticidal nets (LLINs), indoor residual spraying, chemoprevention, and vaccines, as well as the prompt treatment of properly diagnosed cases with artemisinin-combination therapy [2]. Although these tools and strategies have been widely adopted, progress has recently stalled, with high-burden countries experiencing a rise in cases since 2017 [3]. In addition to disruptions in malaria services due to COVID-19 [4–6], these countries face significant challenges [6, 7]. These challenges include limited resources that restrict access to essential prevention tools [7, 8]. Such constraints underscore the need for effective strategies to prioritize available resources for those at highest risk.

The World Health Organization's Global Malaria Programme recommends a subnational tailoring process for intervention distribution, which may be applicable to addressing questions of intervention allocation in low-resource settings [6, 9]. This process involves establishing a national team for data gathering and strategy development, stratifying malaria risk and its determinants, and using mathematical modeling to predict the impact of different intervention strategies [6, 9, 10]. These steps ensure strong stakeholder participation and alignment with national malaria strategic planning.

In Nigeria, where the malaria burden is among the highest globally [1], the implementation of such tailored strategies is critical, particularly in addressing the unique challenges faced in high-risk areas. However, during preparations for the 2023 mass campaign, the National Malaria Elimination Programme (NMEP) faced time constraints that limited their ability to engage in this process. Moreover, there was no accepted guidance on how to approach net distribution in resource-constrained settings.

Presently, LLINs are central to Nigeria's malaria vector control efforts [11], traditionally distributed in 3-year cycles to align with their estimated biological efficacy [12, 13]. This strategy aims for universal coverage, defined as one bed net for every two individuals at risk within a household [12, 13].

Nonetheless, changes in Nigeria's net distribution strategy 2023–2025 Global Fund funding cycle were warranted due to funding gaps that led to serious impediments. A substantial 40% shortfall in partner funding, compared to a 7% gap in the previous cycle, resulted in an insufficient number of LLINs that could be procured for distribution during mass campaigns in urban areas [14]. This funding constraint necessitated the development of an alternative approach to distributing the available nets, considering the varying disease risk across urban settings.

In this paper, we aimed to develop a framework for creating an LLIN distribution strategy in urban areas, with a focus on allocating LLINs to those at the highest risk. Our goal was to co-design this framework in collaboration with Nigeria's national and state malaria control programs and key implementing partners to guide the selection and implementation of an LLIN distribution approach amidst shortages. We demonstrate its application in selecting a net distribution strategy in Ilorin, Kwara State, offering insights into our analytical and participatory methods, as well as the challenges we experienced, as a guide for potential users. Finally, we discuss the outcomes of the process and the key lessons learned.

Methods

Study design

The NMEP collaborated with the Urban Malaria Research Team at Loyola University Chicago (Previously at Northwestern University) to develop a rapidly implementable strategy for determining which communities would receive LLINs during the distribution campaign. Faculty and staff from the university were collaborating with the NMEP in the design and conduct of field epidemiologic and entomologic studies to understand the burden and determinants of malaria risk in two Nigerian cities [15]. It was hoped that insights gained from these studies would be useful in informing the bed net distribution approach.

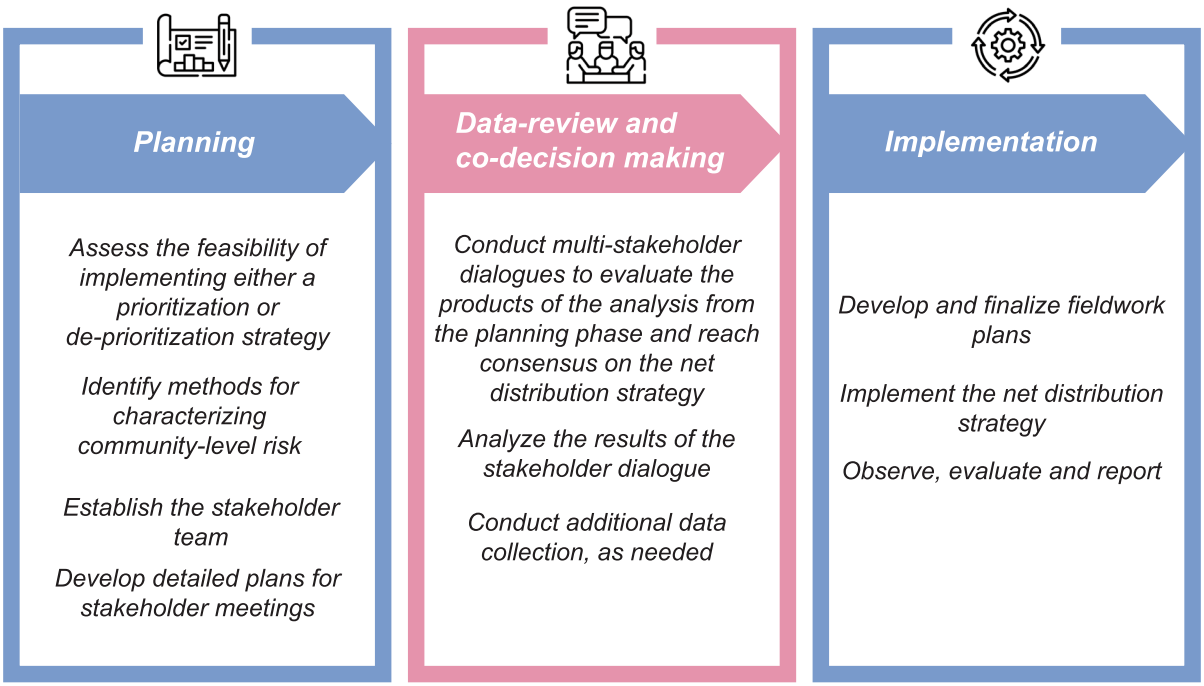

Fig. 1 Co-designed framework for informing LLINs distribution amidst limited supply

Framework development approach

The initial LLIN distribution framework was created following discussions between the research team with the NMEP and was refined after its application in Ilorin. We adopted a co-design approach rooted in abductive inquiry [16, 17] and participatory action research (PAR) principles [18, 19].

By employing an abductive research lens, we used a non-linear, iterative process, combining data gathering, analysis, and practical experiences to ensure the framework's applicability to realistic scenarios. Stakeholder engagement followed PAR principles which emphasize: (1) action-oriented research that generates new knowledge, (2) active collaboration and empowerment of participants throughout the research process, and (3) contextual understanding in data interpretation [18, 19]. Stakeholders were identified purposively by the NMEP and the Kwara State Ministry of Health. PAR's methodological pluralism enabled the co-design of each stage of the framework in close collaboration with stakeholders.

The framework was shaped using morphological analysis [16, 20, 21], which helped identify the key dimensions of the LLIN distribution process and categorize them systematically. Additionally, co-design and co-creation frameworks from healthcare innovation and public health interventions [22, 23] inspired the framework's structure.

The lead author documented the initial draft of the framework, which was iteratively refined based on notes and experiences from its application in Ilorin. Feedback from the authorship team further shaped the final version of the framework, shown in Fig. 1.

Framework pilot setting and context

This framework was developed to guide the targeted distribution of bed nets in Nigerian cities. The NMEP aimed to pilot the framework during microplanning for the Kwara State bed net distribution campaign. Ilorin, the state capital, was selected as the pilot location because it was the only urban area conducting a mass distribution campaign with a restricted number of nets available for distribution at the time of the study. Communities in three Local Government Areas (LGAs) in Ilorin, namely, Ilorin East, Ilorin West, and Ilorin South, were classified by the State Ministry of Health as part of the urban axis. These three LGAs are subdivided into 35 wards and have approximately 1.4 million residents, according to the 2023 Kwara State Micro Plan (unpublished data obtained by email from the NMEP). Figure 2 depicts the three LGAs and the boundaries of the corresponding wards. Additional file 1: Fig. S1 presents a visualization of the number of communities, wards, and population sizes by LGA, with Ilorin West having the largest population, followed by Ilorin South.

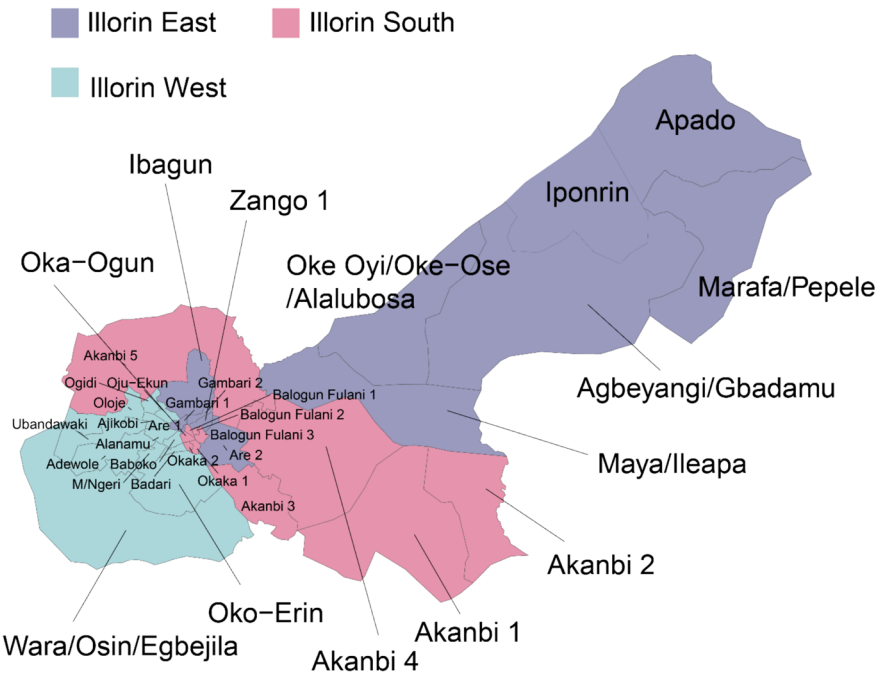

Fig. 2 Map of the Ilorin metropolitan area. Each of the 35 wards is colored by its corresponding LGAs

A map of population density, highlighting the most densely populated wards, such as Oko-Erin and Bada is shown in Additional file 1: Fig. S2.

Framework description and operationalization

The framework is organized into three stages: a planning phase, a data review and co-decision-making phase, and an implementation phase. Each stage includes a series of activities, summarized in Fig. 1. A detailed description of the different phases and associated activities engaged by the research team during the pilot is provided.

Phase 1: Planning

Activity 1—Assess the feasibility of implementing either a prioritization or de-prioritization strategy for LLINs distribution A data-gathering and analysis exercise was conducted by the NMEP and the Loyola team to assess malaria risk at the ward level in Ilorin and evaluate the feasibility of implementing either a prioritization or de-prioritization approach.

Prior to the exercise, the NMEP and the Loyola team defined and discussed both strategies. Prioritization involved identifying and ranking communities—small geographic areas within wards—based on their malaria risk and the expected impact of LLINs. This method aims to ensure that the highest-risk communities receive nets first, with any surplus distributed to lower-risk areas. In contrast, de-prioritization involves excluding low-malaria-risk communities from the distribution, while all other communities receive nets. Although prioritization is more precise because it targets LLINs to areas where they are most impactful, it is also more complex. It requires reliable data for comparing risk levels and careful implementation to account for uncertainties in population sizes and the number of nets needed. De-prioritization, on the other hand, is simpler but requires accurate identification of low-risk communities to prevent over-distribution, ensuring that nets are distributed fairly to all other communities.

The data gathering exercise involved an internet search to identify shapefiles for Ilorin's wards using a combination of terms that included "Ilorin", "Kwara", "wards", shapefiles, and "admin 3". Shapefiles are vector data formats used to store geographic data as points, lines, and polygons. In the case of Ilorin wards, we searched for ward shapefiles in a polygon format. Searches of Nigeria's national malaria repository and Loyola University Chicago's data repositories were conducted to find data reflecting aspects of ward-level malaria risk, including receptivity, anthropogenic landscapes, and active transmission. Search terms used for the repositories included words such as "malaria", "settlement", "housing", "building", "vegetation", and "waterbodies". These datasets were aggregated and summarized to the ward-level. Missing data on test positivity rates was estimated by taking the

average from adjacent wards. Following a similar method to Young and colleagues [24], 10 malaria risk scores were generated using various combinations of the normalized variables. The 10 combinations were generated due to our limited knowledge of ward-level malaria risk. We aimed to create various maps with different risk configurations to determine which one best aligned with stakeholder knowledge. Further details of the data aggregation, missing data estimation, and methods for the creation of risk scores are described in Additional file 1.

Activity 2—Identify methods for characterizing community-level risk Due to the absence of community-level malaria test positivity data from Ilorin, data generated from an ongoing malaria study [15] in Ibadan, Nigeria, were analyzed to assess whether variations in malaria burden exist across communities classified using locally defined categories of formal, informal, and slum settlements. As part of the study design each enumeration area, household, and individual was classified according to these definitions. A detailed description of this process is available elsewhere [15]. Descriptive analysis was conducted to examine variations in malaria test positivity rates, as determined by rapid diagnostic tests, across different settlement types.

Activity 3—Establish the stakeholder team The NMEP and Kwara State Malaria Elimination Programme selected members of the stakeholder team. The goal was to choose individuals experienced in malaria control or LLINs campaign distribution in Ilorin, capable of critically evaluating the analysis outputs. Identified individuals received invitation letters to participate in a 3-h stakeholder meeting. Invitees included eight members from administratively defined urban communities in Ilorin working within the Kwara State Malaria Elimination Program, four representatives of the NMEP, and eight representatives from implementing partners, including Catholic Relief Services, the Society for Family Health, and Management Sciences for Health. Observers from various international institutions including the Global Fund, the World Health Organization, and Tropical Health were also invited.

Activity 4—Develop detailed plans for stakeholder meetings The stakeholder meeting's aims were defined as follows: (1) delineating urbanized wards from rural wards, (2) identifying the most representative ward-level map of malaria risk, (3) building consensus on the approach to community-level de-prioritization, (4) selecting wards for de-prioritization activities, and (5) Developing a checklist for categorizing urban settlements in Ilorin into formal, informal, and slum categories through field observation of settlement characteristics. Plans for the stakeholder meeting converged around adopting a multi-stakeholder dialogue (MSD) structure. An MSD is an organized and engaged process designed to develop collective strategies and foster mutual understanding, with a major strength being the opportunity it provides for stakeholders to engage in co-decision-making [25]. The MSD was designed to include small-group data review sessions, group reporting sessions, and a large group discussion to achieve the meeting's aims. This was to ensure that all stakeholders had the opportunity to share their perspectives. Discussion guides for the MSD were developed to facilitate these sessions (Additional file 1, pages 10–15). It was agreed that the MSD would be jointly facilitated by the NMEP and Loyola University Chicago teams (C.O., I.D.O., and L.M.).

Phase 2: Data review and co-decision-making

Activity 1—Conducting the MSD An MSD was held via Zoom on September 12, 2023, and saw attendance from approximately 30 individuals from the invited organizations. In the initial sessions, participants were divided into three smaller groups, each guided by a moderator, to foster inclusive and active discussions. Among the moderators were I.D.O. and L.M., who also took on the role of note-takers. These sessions, lasting between 30 and 45 min, focused on evaluating data quality and analyzing settlement features to identify variables most accurately reflecting malaria risk and would assist in the delineation of urban extents and their corresponding settlements. Participants examined maps that illustrated four key variables related to malaria risk. Additionally, participants discussed and categorized various types of settlements—formal, informal, slums, and rural—highlighting specific communities and neighborhoods in Ilorin. At the end of each session, group representatives presented a summary of their discussions and findings to all attendees during an audio-recorded session, facilitating a shared understanding and collective insights.

In a follow-up session, which was also recorded, participants engaged in a detailed evaluation of 2 selected scoring maps from 10 developed options that depicted malaria risk based on variables identified in the previous session as being closely associated with malaria prevalence. During this review, all factors influencing the ward rankings on these maps were fully disclosed, promoting transparent and open discussions. This approach was particularly valuable for addressing any disagreements regarding the rankings and ensuring a comprehensive

evaluation. The participants quickly reached a consensus on one of the two maps, resulting in the remaining maps not being reviewed. Participants also agreed that only two wards, identified as the lowest risk areas would be de-prioritized.

The culmination of the MSD focused on crafting a comprehensive checklist to categorize communities into formal settlements, informal settlements, and slums. This task drew upon insights gathered throughout earlier sessions on criteria for classifying settlements as formal, informal, or slums. A preliminary checklist, formulated as part of ongoing research in Kano and Ibadan [15], served as the starting point for discussion. Participants critically assessed this draft to identify elements applicable to Ilorin's context and to refine it for greater relevance. The collaborative effort culminated in a consensus on the final ward rankings, the refined checklist, and strategies for community de-prioritization.

Activity 2—Analysing the results After the MSD, the audio recordings were transcribed using Microsoft Word's transcription tools. IDO and LM meticulously reviewed the initial transcripts alongside the original audio recordings to ensure their accuracy, making any necessary corrections. Following this, LM, with IDO's assistance, carried out a thematic analysis [26] of the refined transcripts and the notes taken during the breakout sessions.

Activity 3—Additional data collection to classify settlements To facilitate the classification of settlements within the two wards selected for de-prioritization using the outputs derived from Activity 1, a 1-day training session was conducted for 32 individuals recruited by the Kwara State Ministry of Health. This team comprised 20 research assistants, 8 community mobilizers, and 4 supervisors, who were briefed on the final de-prioritization process and trained in using the settlement classification checklist. A pilot of the process in two communities enhanced the team's ability to accurately classify settlements according to the agreed-upon approach from the MSD. Insights from the pilot were discussed in a debrief session, leading to further checklist revisions. The final version of this checklist (refer to Additional file 1), which includes factors like the settlement plan, housing quality, road networks, social amenities, environmental quality, and the availability of waste disposal services, was integrated into the KoboCollect application [27] for streamlined data collection.

Guided by the Kwara State Micro Plan, which contains all community names, teams—each consisting of one community mobilizer and two research assistants—visited and classified all communities in two wards selected for de-prioritization. These teams meticulously observed and documented community characteristics using the checklist, took photographs, and recorded geo-coordinates at the estimated centroids of each community. These coordinates were plotted in real time to verify the communities' locations within ward boundaries. The final classification of each community was collectively determined by all research assistants. This extensive classification exercise took place over 3 days, from September 18 to September 20, 2023. Subsequently, community centroids were mapped according to their settlement category, and these maps were shared with all stakeholders. A follow-up meeting with stakeholders took place on September 21, 2023. This meeting reviewed the classification results and decided on which communities would be excluded from the upcoming LLINs distribution campaign. The agreed-upon criteria for de-prioritization were (1) being located within a cluster of formal settlements, and (2) being situated a significant distance from any dams.

Phase 3: Implementation phase

Activity 1—Develop and finalize the fieldwork plan A detailed fieldwork plan was developed and finalized, outlining the logistics of LLINs distribution in Ilorin. The plan included a timeline for distribution, the allocation of resources, communication materials on how to respond to complaints regarding non-receipt of LLINs during the campaign, and the roles and responsibilities of stakeholders involved in the fieldwork. Staff of the Catholic Relief Service led the implementation of the LLINs campaign in collaboration with the Kwara State Ministry of Health.

Activity 2—Implementation of the net distribution strategy The 2023 Ilorin mass campaign was conducted from September 24 and November 15, 2023. It was an integrated effort that combined the distribution of LLINs and the administration of one cycle of Seasonal Malaria Chemoprevention (SMC). Over 2.9 million LLINs, that contained dual active ingredients (alphacypermethrin plus chlorfenapyr) manufactured by BASF and a half million Sulfadoxine-Pyrimethamine with Amodiaquine (SPAQ) doses manufactured by S-Kant were procured for the campaign. The campaign featured a single-phase door-to-door integrated strategy for distributing LLINs and administering SPAQ. Although the campaign staff had the community names and geographic coordinates of their centroids, there was not sufficient time to demarcate the community boundaries during the campaign. As

such, decisions on the community boundaries had to be made during the distribution process.

Activity 3—Independent observation, evaluation, and reporting Members of the NMEP served as independent observers, taking notes on the gaps and challenges encountered during the implementation of the de-prioritization activities. These field reports were shared with all stakeholders to guide future LLINs distribution planning.

Results

The results of the various activities, data analyses, and corresponding decisions arising from the application of the framework to the LLIN campaign processes in Ilorin are presented below. The subsections align with each phase of the framework.

Planning phase outcomes

Characterizing ward-level malaria risk to inform the choice between a prioritization or de-prioritization approach

The data-gathering exercise identified key datasets, including shapefiles from the GeoPoDe website [28] showing the 35 wards in Ilorin, malaria case data among children under 5 (U5 TPR) from health facilities in Ilorin sourced from the national malaria repository, and geospatial data on residential settlement types [29], monthly enhanced vegetation index (EVI) [30], and proximity to water bodies [30]. Each variable was analyzed and aggregated at the ward-level and in their naïve and normalized forms. Table 1 presents the variable definition, range, and source. Figure 3 shows ward-level distribution of each variable in both forms.

Wards with the highest proportion of poor settlement types and mean EVI were predominantly located in Ilorin East. Notable ward-level variations were observed in proximity to water bodies and U5 test positivity rates. Wards in Ilorin South and East exhibited the shortest distances from their centroids to water bodies, with values ranging from 0 to 1000 m. In Ajikobi (Ilorin West), Balogun Fulani 1(Ilorin South), Balogun Fulani 3 (Ilorin East), and Okaka 2 (Ilorin South), all children who presented at the reporting health facilities tested positive for malaria.

Figure 4 displays maps of the ward-level malaria risk scores generated for each of the 10 combinations of the variables described in Table 1. The two maps presented and discussed during the MSD are also highlighted. The number on the map represents the ward rank, where a rank of 1 indicates the lowest malaria risk, and a rank of 35 indicates the highest risk. Across all composite scores, wards with the highest malaria risk scores were predominantly located in Ilorin East while Akanbi 4 (Ilorin South) and Are 2 (Ilorin East) consistently had lower risk scores.

Following the data gathering and analysis, it became clear that there was insufficient information to adopt a prioritization approach to LLINs distribution. The lack of ward-level data on the expected impact of LLINs and community-level data on malaria risk prevented the NMEP from ranking wards and communities by their level of need for LLINs.

Characterizing community-level malaria risk

Figure 5 illustrates the results of the data analysis, exploring whether local settlement type definitions reflect differences in malaria burden. The findings reveal that individuals living in communities classified as slum settlements experienced a malaria prevalence over four times higher than those in formal settlements and nearly twice as high as those in informal settlements. These results suggested that settlement-type classifications based on local knowledge could serve as a useful proxy for characterizing community-level malaria risk.

Data review and co-decision-making outcomes

MSD findings

Major findings from the MSD can be categorized as follows: (1) perspectives on data quality for understanding ward-level malaria risk and the extent of urbanization, (2) perspectives on ward-level risk score maps and ranking, and selection of de-prioritized wards, and (3) perspectives on settlement features and next steps. Details on these findings are provided below.

Data quality for characterizing ward-level malaria risk and perspectives on the urban extent of Ilorin

Stakeholders were concerned about the relevance of the EVI to understanding malaria risk. Participants pointed out that EVI, while indicative of greenness, might not accurately represent environmental conditions crucial for determining malaria risk in cities. This is because wards that they believed were at high risk of malaria tended to have a low EVI.

Concerns about the U5 TPR centered around its limited scope, as only data from individuals seeking care at public health facilities were used while neglecting those who self-medicate or visit private facilities. Concerns were also voiced regarding the variability in data quality over time and inconsistent reporting rates from health facilities. Participants questioned the completeness and reliability of the data for making accurate judgments on the U5 TPR across different locations: *"...we also said that the quality of that data....because you will agree with*

me in 2014 up to 2017, I can't imagine what the data on DHIS are compared to what we have from 2019 to date and some other factors come into play whereby some data are not being reported due to one reason or the other…Do we have a complete data to give to pass a judgment on the TPR for different location[s]"—Representative of the Kwara State Malaria Elimination Program. Despite the issues raised, there was a consensus that the U5 test positivity rate still provided the best representation of malaria risk at the ward level.

Regarding the depictions of ward-level settlement housing and infrastructure quality, and distance to water bodies as shown in Fig. 3A, participants largely agreed. They observed that areas with better housing conditions, like Are 2 and Akanbi 4, likely experienced lower malaria prevalence. Nonetheless, they noted variations in housing quality within wards: *"…However, that doesn't mean that all the houses in Akanbi 4 are good quality. So, we have some that are okay, of the good quality and we have some that are not of the good quality…."*—Representative of the Kwara State Malaria Elimination Programme.

To define the urban extent in Ilorin, participants started by defining the features of rural areas. They mentioned that rural settlements had minimal social amenities or infrastructure, high natural vegetation, and low population density, typically with agriculture as the main occupation. Examples of wards identified as encompassing urban and rural settlements were provided. Figure 6 presents a summary of the stakeholder perspectives on ward-level malaria risk and urban/rural extent in the Ilorin metropolis.

Ward-level malaria risk maps and ranking, and selection of de-prioritized wards

Stakeholders concurred during the MSD that the map incorporating the under-five (U5) test positivity rate and settlement classification most accurately depicted malaria risk (Fig. 4A). It was also noted that wards such as Are 2 and Akanbi 4, which was expected to include households of higher socioeconomic status, received the lowest malaria risk rankings. As a result, these wards were chosen as priority areas for initiating de-prioritization efforts in the upcoming net distribution campaign. In addition, participants recognized that living conditions were heterogeneous within and between wards, further supporting the need for additional fieldwork to better characterize settlements.

Table 1 Description and source of the variables identified during the data gathering exercise

Variable	Definition/description	Range (units)	Source
Proportion of poor settlement types	Classification of neighborhood blocks based on density, orientation, and building size using high-resolution imagery collected from 2017 to 2018. Within the original dataset, blocks were categorized into five distinct groups: A, B, D, F, and M. We analyzed the dataset to estimate the proportion of blocks featuring substandard infrastructure and housing across each ward	0.32–1.00 (not applicable)	Gates Foundation Geographic Information Systems team (email communication) A detailed presentation is available here [29]
Enhanced vegetation index (EVI)	Quantifies vegetation greenness, serving as an indicator of the availability of suitable habitats for mosquito breeding. Data is derived from predicted surfaces for 2020, enabling us to estimate the annual mean EVI for each ward	0.09–0.37 (not applicable)	Malaria Atlas Project (MAP) [30]
Distance to water bodies	Straight line distance from the center point (centroid) of each ward to the nearest water bodies within Ilorin, measured in meters. This data was extracted from a raster created in 2017	0–5857 (meters)	MAP [30]
Test Positivity Rate among children under the age of 5 years (U5 TPR)	Estimated at the ward level from health facilities that reported conducting malaria tests using blood smear microscopy or rapid diagnostic tests among children under the age of 5 years. The analysis utilized routine surveillance data collected between 2014 and 2021	0.08–1.00 (not applicable)	National Malaria Elimination Programme (email communication)

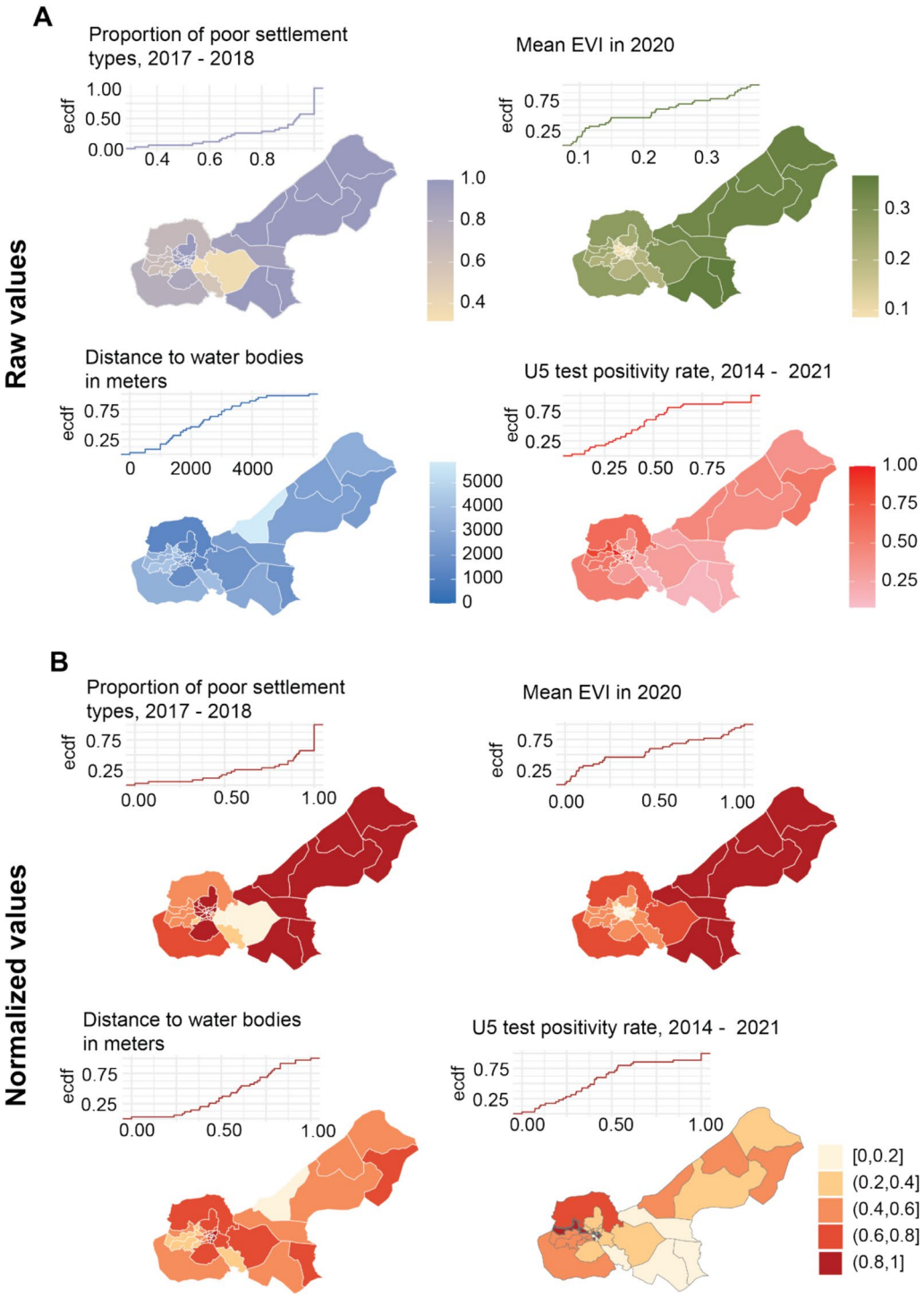

Fig. 3 Pre- and post-normalization maps and empirical cumulative distribution function (ECDF) of variables used in creating the malaria risk scores. **A**) Values and ECDF before normalization and **B**) Values and ECDF after the normalization process. The ECDF is the same for all variables except distance to water bodies where the scale was reversed. EVI is short for enhanced vegetation index

Settlement features and next steps

Participants in the MSD reported that the criteria for classifying settlements as formal, informal, or slums included factors such as housing layout and quality, access to basic amenities like hospitals, the presence of official addresses, and government services. Figure 7

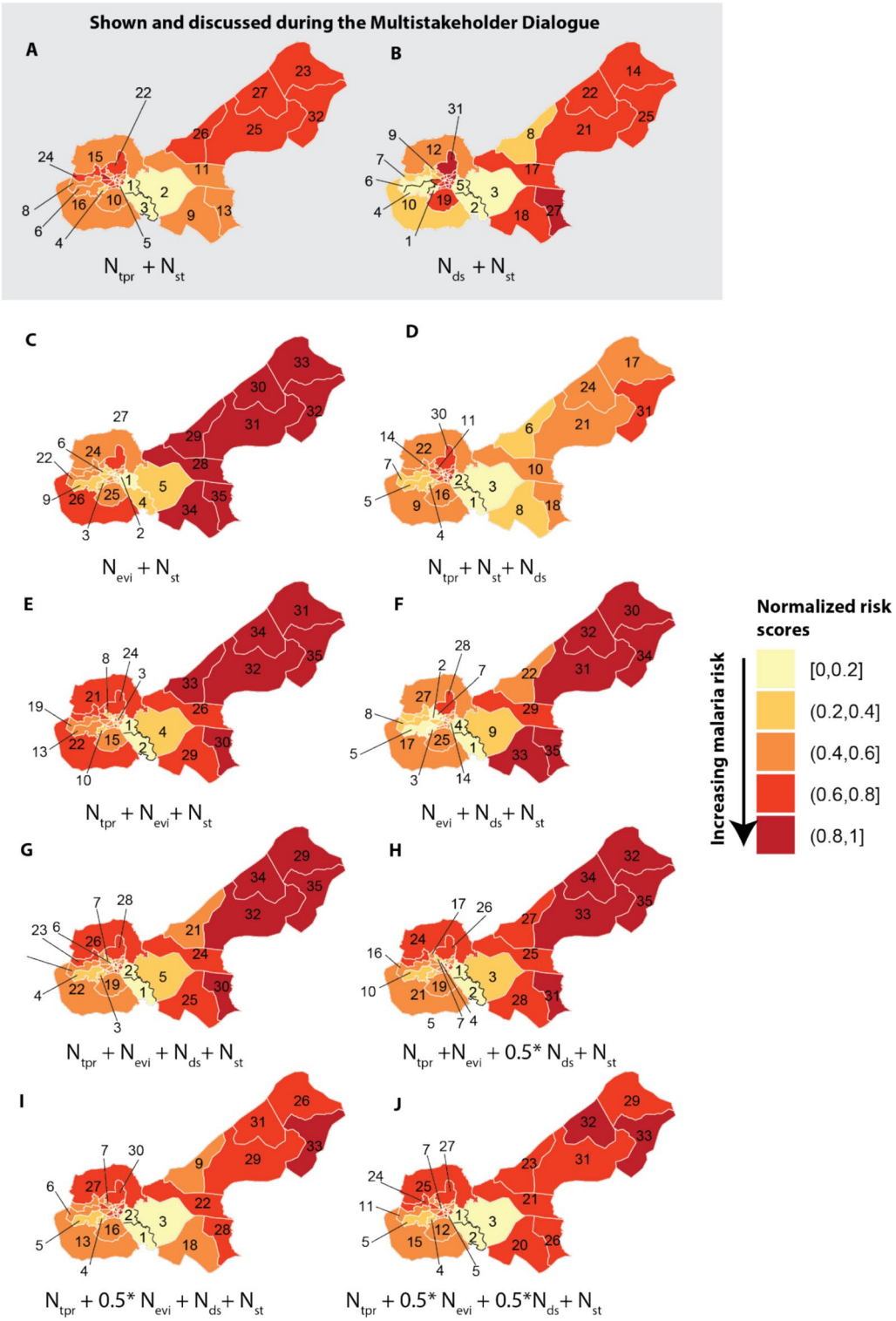

Fig. 4 Ward rankings by malaria risk score using combinations of variables. Note: Rankings range from 1 (lowest rank) to 35 (highest rank), depicting lowest to highest risk. Smaller wards are not labeled due to size constraints. Variables used in the ranking-N_{tpr} (normalized U5 test positivity rate), N_{st} (normalized proportion of poor settlement types), and N_{ds} (normalized distance to water bodies), N_{evi} (normalized enhanced vegetation index)

presents a word cloud illustrating key themes, with the size of each word reflecting the frequency of its mention by participants. Since the draft checklist for classifying settlements already incorporated elements to assess housing quality, layout, and the presence of addresses, these items remained unchanged. However, it is important to highlight that additional features suggested by MSD participants—like the presence of high-income earners and registration of buildings in official databases, for categorizing settlement types—were deemed unobservable and, thus, not included.

Following the discussion of the checklist, it was agreed that the Kwara State Ministry of Health would lead fieldwork to classify settlements in the de-prioritized wards—Are 2 and Akanbi 4 into the formal, informal, and slum categories using the checklist.

Settlement classification

Research Assistants from the Kwara State Ministry of Health visited and classified all 115 communities in Akanbi 4 and all 73 communities in Are 2 into categories of formal, informal, and slum settlements. Using the agreed-upon criteria for de-prioritization: (1) being located within a cluster of formal settlements, and (2) being situated a significant distance from any dams, 13 communities designated as formal settlements were de-prioritized in Are 2. In Akanbi 4, no community fulfilled these criteria. Figure 8A shows the de-prioritized settlements. The list of de-prioritized settlements in Are 2 was shared with implementing partners to incorporate into the plans for the net distribution campaign.

Implementation phase outcomes

Field observation findings during the LLIN/SMC integrated campaign in Ilorin

Members of the NMEP visited all 13 de-prioritized settlements and six in prioritized areas to monitor the implementation of de-prioritization activities. They observed that residents of communities perceived to have high or middle socioeconomic status were less likely to collect nets or grant teams access to their homes.

The absence of clear demarcation for de-prioritized communities, including street names, posed a significant challenge, as it hindered distribution teams from identifying where to begin and end net distribution. Additionally, some teams lacked maps covering their assigned communities, leading to missed households and instances of teams operating outside their designated areas. Another issue was the timing of visits, which often did not align with residents' availability, making it difficult to determine the number of individuals eligible to receive LLINs or SMCs who were present in the homes.

Discussion

The growing funding gap for malaria control and elimination [1, 31, 32] is likely to reduce the availability of LLINs. This means that endemic countries will need to transition from universal coverage to more targeted, efficient resource allocation. To our knowledge, this is the first time a framework has been developed and applied to address malaria intervention resource allocation in urban areas. There are no similar studies or studies with comparable data from Ilorin or other cities in Nigeria. Methods for the development of co-designed frameworks typically rely on abductive reasoning [16], participatory action research [22], morphological analysis [16], and recursive

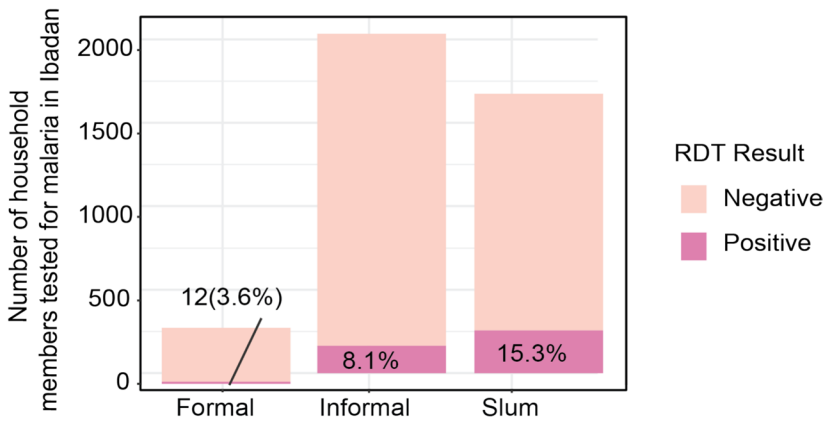

Fig. 5 Findings from an ongoing cross-sectional household survey in Ibadan. Malaria prevalence by Rapid Diagnostic Test (RDT) in communities designated as formal settlements, informal settlements, and slums

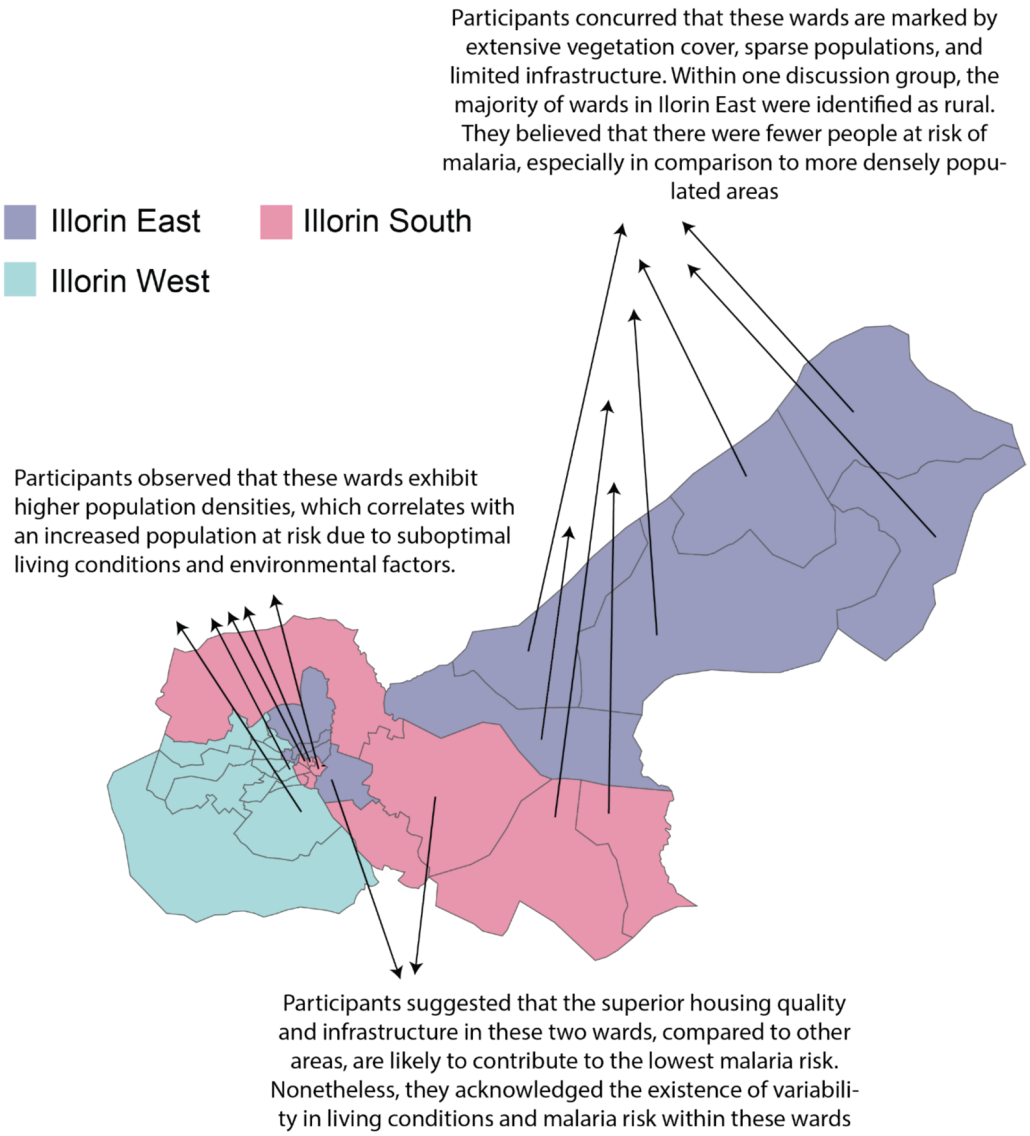

Fig. 6 Summary of stakeholder perspectives on factors correlated with ward-level malaria risk and urban/rural extent of Ilorin metropolis

learning [23], similar to the approach used in this work. However, unlike other studies, the amount of stakeholder input was constrained by time, and further refinement of the framework after its application to new cases may be necessary.

Presently, the NMEP is conducting an evaluation of the de-prioritization activities to determine trends in clinical malaria cases and deaths following de-prioritization. Early results from the process evaluation indicate that 98% of households in de-prioritized areas were built with modern building materials and had window screens [33]. Furthermore, population access to LLINs in deprioritized areas was 23% lower than the 60% coverage observed in areas that were included in the distribution campaign, and de-prioritization did not impact the receipt of SMC [33]. However, without baseline information, it is unclear if the difference in net access can be directly attributed to de-prioritization. It is possible that households in de-prioritized areas do not use nets due to minimal mosquito exposure, which may be a result of their higher-quality housing. Additional studies are needed to assess the impact of de-prioritization on net coverage.

This case study demonstrates that implementing targeted LLIN distribution strategies relies heavily on the availability and quality of data for characterizing malaria risk at different administrative levels, active stakeholder

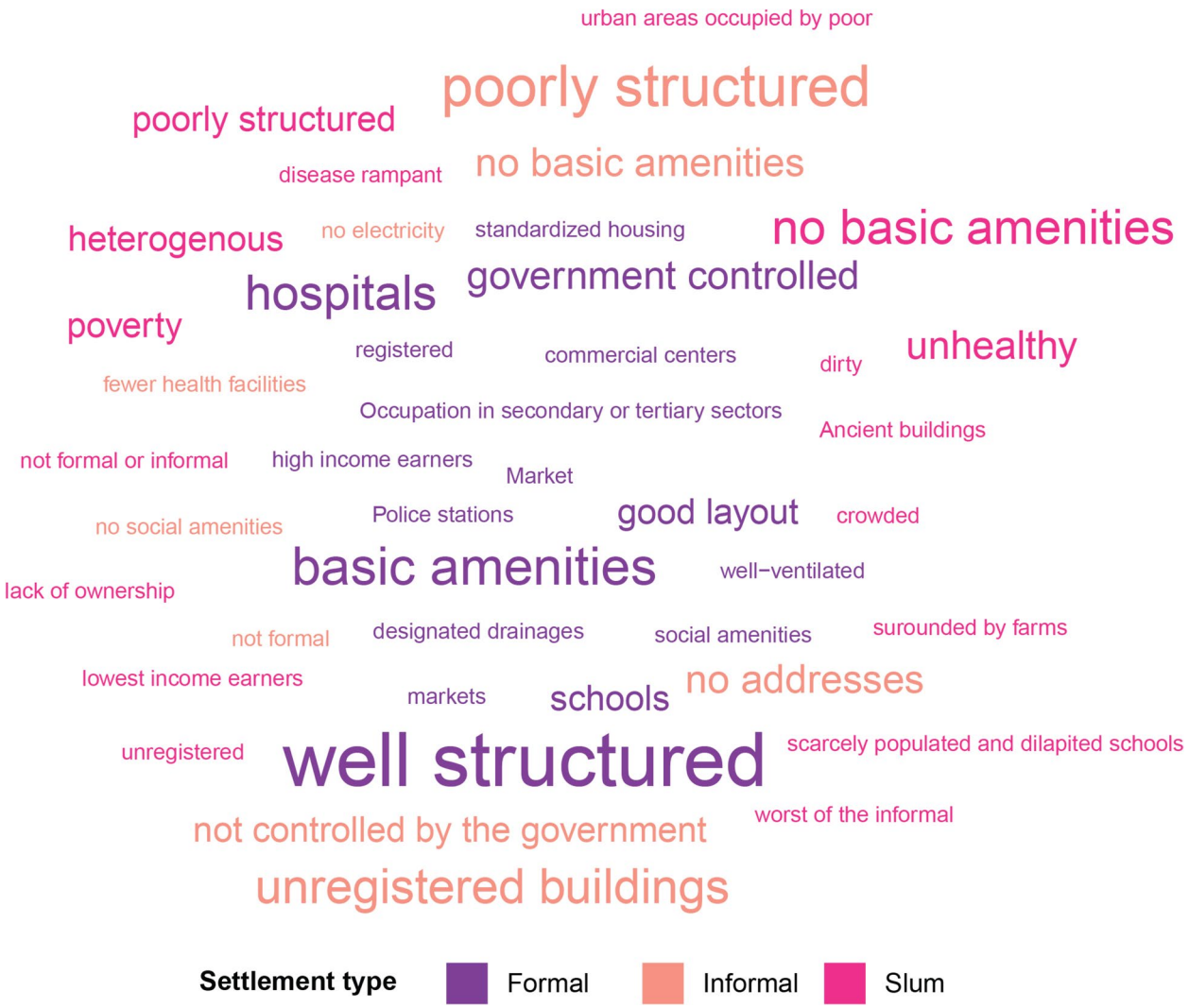

Fig. 7 Key themes identified from the MSD on the features of formal, informal settlements, and slums. Word size reflects the popularity of the theme among participants

engagement, and the capacity for data analysis and execution of action plans.

The WHO's Global Framework for responding to malaria in urban areas emphasizes the importance of a locally led response using high-quality data, including epidemiologic, entomologic, intervention, and mobility data at the smallest administrative units to identify and prioritize those at risk [34]. More recent guidance from the WHO suggests that communities can be excluded from receiving bed nets during net distribution campaigns based on current and historical data on malaria prevalence rate [35]. However, fine-scale malaria risk data at the smallest administrative levels are often unavailable for urban areas in malaria-endemic countries [36–38]. Collecting this data requires significant investment in improved routine and ad-hoc surveillance systems [37, 39]—a step that is both welcomed and encouraged. Transitioning from aggregate to case-based surveillance models would bridge data gaps by facilitating the collection of individual-level data for community prioritization [40, 41]. Yet, these adaptations are resource-intensive, requiring investments to expand case notification systems and to include private sector health facilities, where many urban residents seek care [34, 42–45]. Our framework offers a practical approach for characterizing urban malaria risk even in the face of data, resource, and time limitations, while surveillance systems are being strengthened.

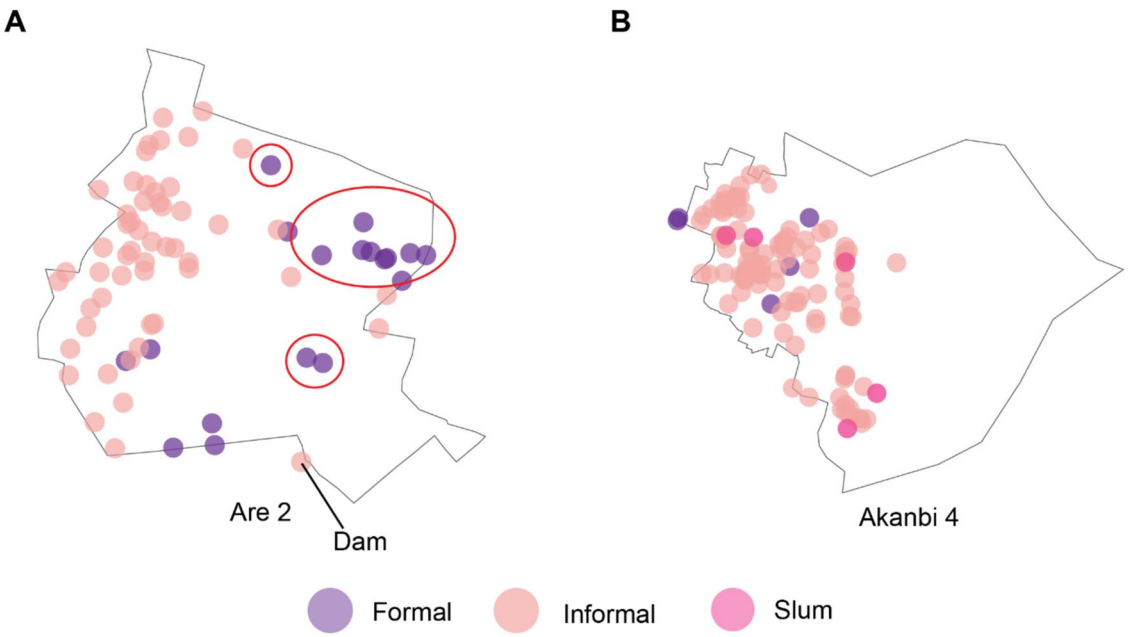

Fig. 8 Communities in Are 2 and Akanbi 4. De-prioritized areas circled in red. **A**) All 73 communities are categorized in Are 2 and **B**) All 115 communities are categorized in Akanbi 4 ward, respectively. Points represent community centroids. Purple-colored points circled in red color represent formal settlement communities that were de-prioritized during the 2023 mass campaign

Operationalizing the principles of PAR in this study, from planning through implementation and in the design of the framework, ensured that the outcomes were contextually relevant and well-received by the national and state malaria control programs, as well as their implementation partners. Presumably, there were notable equity and justice gains, as those most affected by the issue and with a stake in the outcome were able to contribute meaningfully to public health decisions and knowledge creation [46]. In our experience, researchers often face challenges in engaging non-technical stakeholders in data analysis and interpretation. We demonstrate that this can be achieved through the subjective evaluation of data quality, common in public health [47] and the business sector [48], combined with a visual assessment of malaria risk based on stakeholder experience. This process helped identify the most relevant variables for defining malaria risk in urban contexts and was crucial in advocating for additional fieldwork to better understand community-level malaria risk.

However, stakeholders may not always have perfect knowledge of a geographic area or the dynamics of malaria transmission, as they experience challenges in distinguishing between areas of high, medium, and low malaria risk. Nevertheless, this should be seen not as a limitation of the process, but as a lesson learned. Future iterations of this framework could include capacity-building activities before the data review and co-decision-making phase and consider crowd-sourcing information to address this challenge.

One key driver for developing this framework was the time constraints surrounding the decision-making process. Given the heavy workload that malaria program staff often experience, this is likely a common feature of their work. Developing internal systems that support rapid, participatory decision-making will enhance alignment with national malaria strategic planning, local knowledge, research evidence, and internal cohesion [49]. We sought to address this gap by developing a software tool that the NMEP can use for data visualization and malaria risk mapping, minimizing reliance on external expertise [50]. We are currently conducting trainings to facilitate the adoption of the tool during future planning for bed net distribution in urban areas.

The limitations of this work fall into three categories: those related to the study's conduct, the framework's structure, and its application. Time constraints imposed by the net distribution timeline prevented us from conducting a rigorous literature review and multiple stakeholder engagement sessions during the framework development process. These limitations should be addressed in future efforts to refine the framework. Additionally, the framework's structure and activities were shaped by the involvement of the Loyola University team, the availability of data and time, which means that when implemented solely by national and state malaria

programs with improved data availability and capacity as well as with more time, the order and type of activities may vary. For instance, the establishment of the stakeholder team could be the first activity prior to the data gathering and analysis activity, if it is expected that the stakeholder team will contribute to data gathering.

The framework's implementation posed practical challenges, such as delineating boundaries for de-prioritized communities and managing distribution logistics. Observations from Ilorin revealed that unclear community boundaries, despite microplanning, created confusion during bed net distribution. Innovations in microplanning processes and technologies that enable rapid community mapping with minimal technical expertise using high-resolution satellite imagery are needed. However, publicly available satellite imagery often lacks the resolution required for such mapping and may not be up to date. Additionally, malaria programs frequently lack the resources and capacity to acquire and process real-time, high-resolution imagery. Overcoming these two challenges would represent a significant advancement not only for malaria programs but also for other health initiatives.

Future applications of this framework must carefully consider the decision-making process for excluding areas from intervention campaigns. In settings with severe funding constraints, larger areas, including informal settlements and slums, may need to be de-prioritized. In these cases, it is unclear how such situations would be approached in the absence of high-quality data on malaria risk and monitoring to detect resurgence.

Finally, although impact evaluations and resurgence monitoring are recommended, how to approach this in resource-constrained settings—especially when programs may lack funding—is unclear. Addressing this gap should be a priority in future work.

Conclusions

Given the diverse nature of malaria risk and funding constraints in urban areas, national and state malaria control programs are increasingly exploring alternative strategies to better tailor interventions. The World Health Organization's Global Framework for the Response to Malaria in Urban Areas provides valuable guidance for developing comprehensive response plans, integrating multiple interventions, and strengthening surveillance systems. Our framework can serve as a foundation for these strategies, offering a practical approach for engaging stakeholders in collaborative decision-making and conducting thorough, rapid data analysis to guide intervention planning.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s44263-025-00126-0.

Additional file 1: Demographic information, description of methods for characterization of malaria risk, activity guide for multistakeholder dialogue, and observation checklist for categorizing communities into formal, informal and slum settlements. Figure S1: Population sizes and number of communities and wards by LGA in Ilorin. For plotting purposes, the number of communities was downscaled by 10 and population sizes by 10,000. Figure S2: Maps of population density and sizes in Ilorin wards. Data on population density was obtained from the website of the Center for International Earth Science Information Network at Columbia University. Figure S3: Median ward rankings across all 10 scoring formulas colored by LGA. Table S1: Description and source of variables related to malaria risk used in the LLIN de-prioritization analysis. Table S2: The scoring formulae used in each map of malaria risk.

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Disclaimer

Beatriz Galatas is a staff member of the World Health Organization. The author alone is responsible for the views expressed in this article and do not necessarily represent the decisions, policy or views of the World Health Organization.

Authors' contribution

IDO, LM, EB, CA, CO, and BG conceptualized the framework. LM and IDO conducted all statistical analysis. IDO, EB, AF, JA, AOO, and IA supported the development of the initial checklist for categorizing settlements. AF, JA, AOO, and IA collected data in Ibadan that provided the evidence base for the work in Ilorin. IDO, CA, and CO curated the data used in this work. CO, CA, IDO, and LM planned the MSD. EB and IDO coordinated and trained the field assessment data collectors. CO led the field observations. IDO, LM, and EB prepared, wrote, and developed the first draft manuscript. All authors read and approved the final manuscript.

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Data availability

Data summaries at the ward level, used in deriving the malaria risk scores have been deposited in a GitHub repository [51]. Request for the facility-level TPR data should be sent to Cyril Ademu, Team Lead, Surveillance, Monitoring and Evaluation of the National Malaria Elimination Programme via dmcyril@yahoo.com. All data below the ward-level, except for the community-level geographic coordinates, would be made available by the corresponding authors on request.

Declarations

Ethics approval and consent to participate

Initial ethics approval for analysis of data to characterize malaria risk by settlement type using field study, publicly available data, and test positivity rate data to inform resource allocation was obtained from Northwestern University (IRB ID: STU00217380-MOD0001) and Nigeria's National Health Research Ethics

Committee (Approval Number: NHREC/01/01/2007–10/10/05/2022). Due to the short time scale for this work, the team's transition from Northwestern University to Loyola University Chicago, and the inclusion of a multistakeholder dialogue as part of this work, ethics approval and a waiver of consent and authorization was obtained retrospectively from the Institutional Review Board at Loyola University Chicago Health Sciences Division (Approval Number: LU 218266) to cover the multistakeholder dialogue. The study conformed to the ethical principles of the Helsinki Declaration for the protection of participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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