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High net coverage, incomplete protection: factors associated with malaria resurgence in three elimination districts of Zimbabwe1. Rameck Makokove, Plan International Zimbabwe, Malaria Prevention Control and Elimination Programme

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Research Article

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Abstract

Background

In Zimbabwe, insecticide-treated nets (ITNs) are the core intervention in low-transmission districts pursuing sub-national malaria elimination. Masvingo, Chegutu and Gokwe South entered the elimination phase in 2017, yet malaria incidence rose despite ITN coverage exceeding 95%. The drivers of this resurgence under high net coverage remain uncharacterised. This study assessed the behavioural, socio-economic, entomological and environmental factors associated with malaria resurgence and ITN utilisation across the three districts.

Methods

A mixed-methods design was used, comprising a cross-sectional analytical survey complemented by a qualitative strand, an entomological survey and environmental remote sensing. A stratified multistage sample of 314 household heads was surveyed on knowledge, attitudes and practices, net utilisation and outdoor activities. Eleven environmental health technicians and 14 village health workers were interviewed as key informants. Host-seeking mosquitoes were sampled indoors and outdoors using CDC light traps, and climatic and vegetation trends (2016–2020) were analysed using NASA POWER and Landsat data. Associations of socio-demographic factors with ITN utilisation were assessed using a population-averaged logistic regression model, accounting for clustering of households within wards, while qualitative and climate data were analysed thematically and with the Mann–Kendall test, respectively.

Results

Knowledge of malaria was high, with 81.8% identifying mosquitoes as the mode of transmission, but only 11.8% knew the correct three-year net replacement interval. Although 83% owned ITNs, only 49% reported sleeping under a net the previous night; use was seasonal, with 54.1% using nets only during the rainy season, and 68% of those needing replacements failed to obtain them. Higher education independently predicted positive attitudes towards nets. Receiving malaria information (adjusted odds ratio [aOR] 1.75, 95% CI 1.18–2.59) and older age (aOR 1.63, 95% CI 1.12–2.38) were independently associated with net use, whereas women were less likely than men to have used a net (aOR 0.73, 95% CI 0.55–0.96). Outdoor livelihood, water-collection and socio-cultural activities coincided with peak vector-biting hours. *Anopheles gambiae sensu lato* and the *Anopheles funestus* group were active both indoors and outdoors, with *An. gambiae* showing bimodal biting. No statistically significant long-term trends in temperature, rainfall or humidity were detected. Village health workers were the main and most preferred source of malaria information.

Conclusion

Malaria resurgence in these elimination districts is multifactorial rather than the failure of a single intervention. High awareness (81.8%) and net ownership (83%) coexisted with seasonal and inconsistent use, barriers to replacement, and outdoor activity overlapping with vector biting. Sustaining elimination gains requires accessible net replacement, practical and segmented social and behaviour change communication, strengthened entomological surveillance, and contextually tailored interventions for residual outdoor transmission.

Background

Malaria remains a major public health problem despite sustained investment in prevention and control. In 2024, an estimated 282 million malaria cases and 610 000 deaths occurred globally across 80 endemic countries, with the World Health Organization (WHO) African Region accounting for 94% of cases and 95% of deaths; children under five years of age accounted for about 75% of malaria deaths in the Region [1]. Globally, progress has stalled: rather than declining towards the Global Technical Strategy targets, malaria case incidence rose from 59 to 64 cases per 1000 population at risk between 2015 and 2024, and malaria mortality has shown little improvement since 2015 [1]. Malaria financing has not kept pace with need, and recent reductions in international funding have disrupted core interventions, including net distribution, social and behaviour change (SBC) and surveillance, leaving many endemic countries facing competing health priorities under severe resource constraints [1, 2].

The Global Technical Strategy for Malaria 2016–2030 calls for universal access to core vector control interventions for all populations at risk [3]. Given widespread resource constraints, WHO discourages overlaying ITNs and indoor residual spraying (IRS) in the same area, except during malaria outbreaks and foci responses [4]. Over the 25 years since 2000, malaria control interventions have substantially reduced the disease burden in Africa. Updated modelling estimates indicate that approximately 1.6 billion malaria cases were averted between 2000 and 2024, with vector control accounting for 77.7% of cases averted [1]. ITNs remained the largest single contributor, averting an estimated 1.13 billion cases, while IRS averted a further 85 million cases [5]. These findings reinforce earlier evidence that ITNs were responsible for the majority of malaria cases prevented in sub-Saharan Africa between 2000 and 2015 [6]. Consistent with this, the large-scale distribution of conventional pyrethroid-only ITNs in Uganda was followed by a decline in malaria parasite prevalence among children aged 2–10 years from 25.4% at baseline to 14.8% six months after distribution (prevalence ratio = 0.60; 95% CI 0.54–0.68; $p < 0.0001$), with prevalence remaining significantly below baseline at 25 months [7].

In Zimbabwe, ITNs were introduced in 2000, initially for children under five years, pregnant women and people with immune-suppressing conditions, before moving to universal distribution in 2010 [8]. Nets are delivered through mass campaigns repeated every three years, complemented by continuous distribution to cater for attrition that occurs between mass campaigns. The country aims for universal coverage, that is, providing one net per sleeping space [4, 9]. Campaigns conducted between 2017 and

2021 achieved programmatic ITN coverage above 95%, exceeding the national target of 85% [10]. Between 2000 and 2020, national malaria incidence declined by 84%, from 136 to 22 per 1000 population [10].

Following this decline, Zimbabwe adopted a sub-national malaria elimination strategy, stratifying districts by annual parasite incidence (API). Districts with an API of 5 or more cases per 1000 population implement IRS as the core vector control intervention, whereas those below this threshold implement ITN distribution [9]. Consistent with WHO guidance, IRS and ITNs are not co-deployed in the country except during outbreaks and foci responses. Masvingo, Gokwe South and Chegutu are among the 28 districts in the elimination category.

These three districts transitioned to the elimination phase in 2017 after recording an API below 5 per 1000 population in 2016, and a continued decline towards elimination was anticipated. Instead, API rose between 2016 and 2020: from 1.5 to 2.9 per 1000 population in Masvingo, from 0.4 to 2.0 per 1000 in Gokwe South, and from 1.0 to 1.9 per 1000 in Chegutu. This represented a 1.9- to 5.0-fold increase over the 2016 baseline, although API in all three districts remained below the 5 per 1000 transition threshold. Before 2017, IRS was conducted annually in these districts, targeting wards with more than 5 cases per 1000 population. Following the districts' transition from the control to the elimination phase in 2017, ITN distribution became the core vector control intervention, with IRS deployed only in identified active foci and for outbreak response. This was consistent with WHO guidance, which does not recommend overlaying IRS with ITNs. Thus, the resurgence observed from 2017 to 2020 occurred under a policy in which ITNs were the core vector control intervention.

The factors associated with malaria resurgence in the three elimination districts, despite high ITN coverage, have not been characterised. The protective efficacy of ITNs demonstrated in randomised controlled trials, including reductions in all-cause child mortality and in uncomplicated malaria episodes [11], depends on nets being used consistently and correctly. In particular, whether the distributed nets are consistently and correctly used, and which behavioural, socio-economic, entomological and environmental factors constrain their protective effect, remain unclear. Resurgence under high net coverage is likely multifactorial, reflecting health-service, socio-cultural, socio-economic and vector-related determinants that shape ITN access and use and, in turn, exposure to infective mosquito bites. Identifying the factors associated with malaria resurgence in these settings is essential for sustaining elimination gains and for prioritising context-specific interventions to complement ITN distribution. This study therefore aimed to determine the factors contributing to malaria resurgence in three elimination districts with high ITN coverage, examining community knowledge, attitudes and practices regarding net use; socio-cultural and socio-economic determinants of utilisation; mosquito host-seeking behaviour; the social and behaviour change strategies implemented around net distribution; and the spatiotemporal influence of climatic variables on vector proliferation.

Methods

Study design and sites

This study employed a mixed-methods design, comprising a cross-sectional analytical survey, with an embedded qualitative strand and complementary entomological and environmental (remote-sensing) components, to investigate the factors associated with malaria resurgence in the three elimination districts of Zimbabwe that had sustained high ITN coverage between 2017 and 2021. Household interviews, key informant interviews and entomological collections were conducted in October 2021, while the environmental component drew on a five-year (2016–2020) time series of climatic and land-surface data.

The study was conducted in rural wards of Masvingo, Chegutu and Gokwe South districts (Fig. 1), which lie within the low-to-moderate, short-seasonal malaria transmission stratum of Zimbabwe [10] and have experienced a resurgence of malaria despite high ITN coverage.

Gokwe South lies in agro-ecological regions III and IV, where rainfall is erratic and unreliable; region IV constitutes 82% of Masvingo district's land area, while Chegutu lies in agro-ecological region IIb, characterised by mid-season dry spells and high temperatures. The three districts receive a mean annual rainfall of 600–1000 mm, with about 95% of precipitation falling between October and April, and experience temperatures ranging from 18°C to 33°C. Livelihoods across the three districts are dominated by crop and livestock production [10].

Study population and recruitment

The study population comprised household heads aged ≥ 18 years from households that had received ITNs and were resident in the selected wards, together with the environmental health technicians (EHTs) and village health workers (VHWs) serving those wards. For each selected household, the household head was invited to participate; where the household head was unavailable, the adult in charge aged ≥ 18 years was interviewed. All EHTs and VHWs operating in the selected wards and villages were recruited as key informants. Households contributing to the entomological component were drawn from those that had completed the household interview.

Sample size and sampling

The household sample size was estimated using the single-population-proportion (Cochran) formula [12], $n = Z^2p(1 - p)/d^2$, assuming an expected ITN utilisation of 75% consistent with the high net coverage previously reported in the study districts, a 95% confidence level ($Z = 1.96$) and a 5% margin of error (d), which yielded 288 households. After allowing for approximately 10% non-response, a minimum of 317 households was targeted, and 314 household heads were enrolled and retained for the final analysis.

A stratified multistage sampling strategy was used. First, the three districts were purposively selected because they had experienced malaria resurgence despite high ITN coverage. Within each district, wards

were stratified according to their 2020 malaria incidence relative to the 2016 baseline: wards with 2020 incidence at or below baseline were assigned to Stratum A, and those with incidence above baseline to Stratum B. Simple random sampling, using a random number table, was then applied at each stage of the multistage sampling process. In line with methodological guidance indicating that a sample comprising approximately 10% or more of an accessible population may be adequate for descriptive survey studies when the sample is appropriately selected [13], 10% of wards were randomly selected within each stratum, followed by 10% of villages within each selected ward and 10% of households within each selected village.

Table 1
Sample sizes at each sampling level

District Name	Total Number of Wards	Wards randomly selected into the study (10%)	Average number of villages in each ward	Villages randomly selected into the study (10%)	Total number of households in selected villages	Proportionate households sampled from selected villages
Masvingo	33	4	48	19	**3173**	**100**
Chegutu	29	3	50	15	**3435**	**108**
Gokwe South	36	4	45	18	**3456**	**109**
Total	98	11		52	**10,064**	**317**

For the entomological component, two households were selected per ward among those that participated in the household survey.

Data collection procedures

This study was conducted during the COVID-19 pandemic. Before fieldwork, research assistants were trained in research ethics, interviewing and observation techniques, and COVID-19 infection prevention and control measures. Quantitative data were captured electronically on smartphones and tablets using the Solstice application (mWater) and transmitted to a central server.

Household interviews. Household heads were interviewed using the standardised and validated World Health Organization structured questionnaire. The questionnaire was developed in English, translated into Shona, and back-translated into English by a professional translator. It was pretested in a non-participating ward with characteristics comparable to those of the study wards, and the findings were used to improve the clarity of the questionnaire items. The primary outcome, ITN utilisation, was operationally defined as self-reported sleeping under an ITN on the night preceding the survey. The questionnaire collected information on household socio-demographic characteristics and knowledge, attitudes and practices (KAP) related to malaria transmission, signs and symptoms, and prevention. It

also assessed outdoor livelihood and socio-cultural activities that occurred during peak mosquito-biting hours, including who participated and the time of day, and exposure to malaria social and behaviour change communication (SBC).

Key informant interviews. Eleven EHTs and 14 VHWs were interviewed using a semi-structured guide covering the primary sources of malaria information, the channels and frequency of its dissemination, the SBC strategies implemented, and the resources available to support these activities, thereby complementing and triangulating the themes raised by household respondents.

Entomological collection. Host-seeking adult mosquitoes were sampled indoors and outdoors using Centers for Disease Control and Prevention (CDC) miniature light traps, each positioned beside the feet of a person sleeping under an untreated bed net as a proxy for a human-baited catch. One indoor and one outdoor trap were operated per household from 18:00 to 06:00, and hourly indoor and outdoor catches were recorded on a standard CDC observation checklist. Two households per ward were each sampled on three consecutive nights, giving six trap-nights per trap position per ward. *Anopheline* specimens were identified morphologically to the *Anopheles gambiae* complex and *Anopheles funestus* group using the keys of Gillies and Coetzee [14]; culicine mosquitoes were counted and discarded. Specimens of the *An. gambiae* complex were preserved individually in Eppendorf tubes containing silica gel and transported to the De Beers Research Laboratory in Chiredzi. Molecular identification of sibling species by polymerase chain reaction (PCR) was not undertaken, as it was beyond the objectives of this study; archived specimens remain available for future analysis.

Environmental and remote-sensing data. Gridded daily precipitation, temperature and relative humidity for the study sites during 2016–2020 were obtained from the National Aeronautics and Space Administration Prediction of Worldwide Energy Resources (NASA POWER) database. Cloud-free (< 1%) Landsat 8 Operational Land Imager (OLI) scenes (30 m spatial resolution) covering the study districts during the peak-transmission months of October and April were retrieved from the United States Geological Survey EarthExplorer portal; the corresponding path/row tiles were 169/074 and 171/072 (Masvingo), 170/073 and 170/072 (Chegutu), and 171/072 and 171/073 (Gokwe South).

Data management and analysis

Quantitative data were exported from the central server to Microsoft Excel for cleaning and recoding, and analysed in Python (statsmodels version 0.15). Analyses included participants with complete data for the outcome and covariates of interest. Categorical variables were summarised using frequencies and percentages.

The primary outcome was ITN utilisation, defined as self-reported sleeping under at least one ITN on the night preceding the survey. Associations between participants' explanatory variables and utilisation were first screened using Pearson's chi-square test where expected cell counts were greater than five, with crude odds ratios (cOR) obtained from simple logistic regression. Variables associated with utilisation at

$p < 0.25$ on screening, together with a priori confounders (district, education, sex and age), were entered into a multivariable model. Perceived ease of understanding ITN messages (screening $p < 0.001$) was not entered because it was missing for 34 respondents, whose exclusion would have reduced the complete-case sample, and because it overlapped conceptually with receipt of malaria information and perceived adequacy of ITN information, both of which were retained.

Because households were clustered within wards, and the number of wards contributing to the analysis (11) was too small to support a stable random-effect variance in a mixed-effects framework, a population-averaged generalised estimating equation (GEE) model was fitted, yielding adjusted odds ratios (aOR) with cluster-robust 95% confidence intervals. Multicollinearity was assessed using the variance inflation factor (all values < 5), and the robustness of the findings was examined in sensitivity analyses using ward cluster-robust logistic regression and alternative predictor sets.

Respondents' current primary and preferred sources of information were summarised descriptively as the proportion of respondents reporting each source. Because respondents could report more than one source, percentages do not sum to 100%.

All statistical tests were two-sided, and $p < 0.05$ was considered statistically significant.

Qualitative data from the key informant interviews were analysed thematically around three predefined domains (SBC, livelihoods, and socio-cultural activities). Transcripts were read for familiarisation, coded, and organised into concepts and themes, which were then tabulated to derive domain-specific findings.

For the environmental analysis, the mean monthly precipitation, temperature and relative humidity for 2016–2020 were computed, and monotonic temporal trends were assessed using the two-sided Mann–Kendall test. Satellite imagery was radiometrically calibrated and atmospherically corrected using the Semi-Automatic Classification Plugin (SCP) in QGIS version 3.4 and then mosaicked by period to cover the entire study area. The Normalised Difference Vegetation Index (NDVI) was derived from the Landsat 8 OLI red and near-infrared bands. The minimum, mean and maximum NDVI were extracted per scene, and the mean NDVI was used to characterise inter-annual vegetation trends.

Ethical considerations

The Medical Research Council of Zimbabwe approved the study (MRCZ/A/2784), and permission to conduct it was obtained from the Ministry of Health and Child Care through the National Malaria Control Programme. Verbal informed consent was obtained from all participants before enrolment, and additional consent was obtained from household heads for placement of CDC light traps in their homes. Confidentiality was maintained through the use of unique study identifiers and secure storage of study records. Study data will be retained for at least five years and disposed of in accordance with the national data-protection framework.

Results

Socio-demographics

The response rate was 99.1%. A total of 314 respondents participated in the study: 196 (62.4%) were female and 118 (37.6%) were male. A total of 108 (34.4%) respondents were from Gokwe South, 107 (34.1%) were from Chegutu and 99 (31.5%) were from Masvingo District. The majority of the respondents (252; 80.3%) were married, and slightly over half (169; 53.8%) had secondary education. Approximately 8.3% of the households had a pregnant member. About half of the respondents (49.7%) were unemployed, 43.9% were formally or informally employed and 6.4% were retired or in other categories. Table 2 shows the distribution of respondents by sex across the three districts.

Table 2
Distribution of respondents by sex and district

District					
		Masvingo	**Chegutu**	**Gokwe South**	**Total**
		n = 99 (31.5%)	**n = 107 (34.1%)**	**n = 108 (34.4%)**	**N = 314 (100%)**
Sex	Male	24 (24.2%)	47 (43.9%)	47 (43.5%)	118 (37.6%)
	Female	75 (75.8%)	60 (56.1%)	61 (56.5%)	196 (62.4%)
Total		99 (100%)	107 (100%)	108 (100%)	314 (100%)

Knowledge, attitudes and practices (KAP)

Knowledge on malaria

Mode of transmission

Knowledge of malaria was high, with 81.8% identifying mosquitoes as transmitters of malaria. In the current study, misconceptions about what transmits malaria included drinking unsafe water (3.2%), eating unsafe food (1.6%), contaminated air (0.3%) and other insects and vectors (0.3%).

Signs and symptoms

The most frequently mentioned signs and symptoms of malaria were headache (64.5%), general body weakness (44.4%), fever/sweating (41.9%), nausea and vomiting (39.9%), high temperature (36.4%), loss of appetite (21.4%) and dizziness (18.2%).

Prevention

Most of the study participants were aware of malaria prevention measures, with 81.8% mentioning the use of ITNs. A small proportion (5.4%) said they did not know how people can protect themselves from malaria. Some (27.7%) mentioned issues encompassing environmental management, personal protection, health-seeking behaviour and prophylaxis.

Vulnerable groups

When asked about vulnerable groups that need protection from malaria, the respondents mentioned children under five, the elderly, pregnant women and the chronically ill, as shown in Table 3.

Table 3
Vulnerable groups needing protection from malaria

Category	Yes	No	Reasons for Need
Children under 5	288 (91.7%)	26 (8.3%)	• *Weak immune system* • *Chances of dying are high* • *May take longer to associate signs and symptoms with malaria*
The elderly	291 (92.7%)	23 (7.3%)	• *At-risk group* • *Weak immune system* • *Are as vulnerable as children*
Pregnant women	283 (90.1%)	31 (9.9%)	• *May have complications* • *High risk of stillbirths* • *Are limited in what medications they can take*
The chronically ill	276 (87.9%)	38 (12.1%)	• *Need to avoid complications of existing disease and malaria complications*

Treatment-seeking behaviour: Most respondents (69.5%) reported that they would seek treatment within a day of the onset of malaria symptoms, while 26.1% reported a delay of one to two days before seeking treatment. In addition, 85.4% stated that they would seek treatment at a health facility, while 14.3% mentioned visiting VHWs for rapid diagnostic tests. Only 0.3% stated that they would seek treatment from traditional/faith healers.

Frequency of ITN replacement

Knowledge of how often ITNs should be replaced was low, with only 37 (11.8%) respondents correctly selecting three years. The largest proportion of respondents (31.5%) thought ITNs should be replaced every six years, while 29.3% said ITNs should be replaced annually.

Attitudes on malaria

Most respondents (98.1%) agreed or strongly agreed that malaria is a serious health problem. About 80% of the respondents agreed or strongly agreed that ITNs can adequately protect one from malaria.

Regarding malaria prevention, 95.8% of the respondents agreed or strongly agreed that malaria can be prevented, and 97.1% agreed or strongly agreed that malaria can be treated and cured. The majority of the respondents agreed that ITNs are safe for pregnant women (62.7%) and children (62.1%). Despite the positive attitude towards the safety of ITNs for children and pregnant women, about 29% of the respondents were either undecided or disagreed.

The level of education was a statistically significant predictor of a positive attitude towards the use of ITNs. Respondents with higher education were more likely to endorse the statements that ITNs adequately protect against malaria, that ITNs are safe for children and for pregnant women, and that people should sleep under an ITN every night (all $p < 0.001$).

Practices

ITN ownership

Eighty-three per cent (83%) of the respondents owned ITNs, and the majority of them had last received ITNs in 2021. Of the respondents who owned ITNs, the majority (87%) received ITNs through mass campaigns, followed by community channels (8%) and Expanded Programme on Immunisation (EPI) channels (5%). Most of the respondents received more than five ITNs per household. However, 53% of the respondents indicated that they had not received adequate nets, that is, one ITN per sleeping space. The study revealed 952 indoor sleeping spaces and 42 outdoor sleeping spaces in the wards. The majority (68.9%) of indoor sleeping spaces were covered by nets during observations, whereas 42.9% of the outdoor sleeping spaces were covered. About 16.7% of the outdoor sleeping spaces were said to have been covered by nets the previous night. Of the sleeping spaces covered by nets the previous night, 28% were used by children under five, while pregnant women used 15%. Of the pregnant women reported to be present in the study area, 38.5% slept under ITNs the night before the survey. Approximately 50% of the under-fives in the studied households slept under ITNs the night before the survey.

Utilisation of ITNs

Household heads indicated that they utilised the nets distributed to them, which was confirmed by 92.9% of the VHWs who were interviewed. Asked when they used ITNs, the majority of the respondents (54.1%) said that they used nets only during the rainy season, while 29.4% used nets all year round and 12.4% said they used the nets only during the dry season. The remaining 4.1% indicated that they never used nets. When asked whether they faced any challenges in using nets, most of the respondents (67.2%) reported none, while 32.8% of the respondents said that they faced challenges. The challenges faced were mainly itchiness (69.9%), feeling hot under the net (18.4%), difficulties with hanging (16.5%) and concerns about shape or colour. Most households were better suited to cone-shaped nets than to the rectangular nets that were distributed. Of those who had needed to replace their ITNs, 7% said they managed to replace their ITNs within one week. Sixty-eight per cent (68%) of the respondents who needed to replace their nets were unable to do so. Of the respondents who failed to replace their nets,

45.1% did not have time, and 41.3% did not know where to collect the nets. The remaining 13.6% said they were hindered by the long distances from the health centre and the VHW.

Care of bed nets

Washing

When asked whether they washed their bed nets, 86% of the respondents said that they did; of these, 45.5% indicated that they washed their nets annually, followed by monthly (19.4%), quarterly (17.5%) and half-yearly (10.5%). When asked where they dried their nets, most of the respondents (72.6%) indicated that they dried them outdoors in the shade. Seventeen per cent (17%) of the respondents dried their nets outside in the sun.

Storage of ITNs

Thirty-four per cent (34%) of the respondents indicated that they kept ITNs over the bed at all times, while 29.6% kept the ITNs indoors and covered. A small proportion (7.6%) of the respondents kept their ITNs outdoors and uncovered. Four per cent of the respondents did not consent to observation. Among the households that were observed, 48.8% had ITNs hung over the bed, while 51.2% did not. All nets observed hanging over beds were indoors and not exposed to direct sunlight.

Checking of ITNs for damage

The majority of the respondents (54.4%) did not check their nets for damage, while 27.4% checked daily, 11.5% checked monthly and 6.7% checked their nets weekly.

Alternative use of ITNs

Most of the respondents (91.7%) indicated that they did not use ITNs for other purposes. However, 21.3% said they knew of some community members who used nets for other purposes. This was supported by a majority of the responses from the VHWs, who indicated that some community members used bed nets for other purposes. The most frequently mentioned alternative use of nets was fishing (50%), followed by fencing of fowl runs (41.7%). The covering of plants and roof shading each accounted for 4.2%.

According to the VHWs, the reasons for using nets for other purposes were economic, such as catching fish to generate income, covering fowl runs for poultry projects and covering gardens. The other reason given by the VHWs for using nets for other purposes was ignorance.

Socio-cultural and socio-economic factors

Socio-economic factors

Sleeping habits: Most respondents (77%) went to bed between 20:00 and 22:00, while 19% went to bed between 18:00 and 20:00 in all districts. The entomological collections showed that indoor vector activity peaked between 19:00 and 23:00 (Additional file 2: Table S2), so this period overlapped with the time most respondents went to bed. Sixty-nine per cent (69%) of the respondents indicated that they woke up between 04:00 and 05:00.

Economic activities at household level

The majority (78%) of the household heads indicated that the most common economic activities at the household level were mining, farming and vending in all the districts. A total of 10% of the respondents were involved in mining. The respondents indicated that 46% of the activities were done at dawn, while 14% were done at dusk.

These economic activities were mostly practised during the night by all age groups of both sexes. Women participated in economic activities more than men and children.

Socio-cultural factors

Socio-cultural activities in the communities

Church services (41%) and funerals (29%) were the most frequently mentioned social activities practised during the night by all age groups in all districts. Traditional rituals (mabira and kurovaguva; 5%) were also night-time cultural activities reported across the districts. Chegutu was the only district that reported a cultural dance (zvigure; 5%) as an additional night-time socio-cultural activity.

Masvingo reported water shortages as the main cause of night-time gatherings at boreholes. Seventy per cent (70%) of the households indicated that women and children were the most affected. Women usually queue for water at 04:00 before their daily activities and at 20:00 after completing them. The exposure times for the women coincided with the vector biting times.

Mosquito human host-seeking behaviour

Mosquito densities were generally low in all sampled districts. However, the highest number (55%, n = 74/135) of culicine mosquitoes was collected in Chegutu district. On the other hand, the highest number of *Anopheles gambiae* species was collected in Gokwe South district (Table 4). Masvingo district was the only district where the *Anopheles funestus* group was collected.

Table 4
Diversity and abundance of mosquitoes by district

Mosquito species	Study sites			
	Masvingo	**Chegutu**	**Gokwe South**	**Overall total**
An. gambiae s.l.	6	2	22	30
An. funestus group	7	0	0	7
An. pretoriensis	6	0	2	8
An. maculipalpis	0	0	1	1
Culicine	15	74	46	135
Total	**34**	**76**	**71**	**181**

The majority of mosquitoes were collected outdoors (96 vs 85 mosquitoes; Additional file 1: Table S1), and 57% (n = 17/30) of *Anopheles gambiae* s.l. were also collected outdoors. The *Anopheles funestus* group population was slightly higher outdoors (57%, n = 4) than indoors (43%, n = 3). In Masvingo, most (83%, n = 5) An. *gambiae* s.l. were collected indoors. In contrast, in Gokwe South the majority (73%, n = 16/22) of *An. gambiae* s.l. were collected outdoors.

Most indoor mosquitoes were collected in Chegutu (45/85). The fewest indoor mosquitoes were collected in Masvingo district (Additional file 1: Table S1). However, the majority of *Anopheles gambiae* s.l. were collected in Gokwe South, while Chegutu had the fewest *Anopheles gambiae* collections. All *Anopheles funestus* group mosquitoes collected were from Masvingo district. Both the *Anopheles gambiae* complex and *Anopheles funestus* group were predominantly active indoors between 19:00 and 23:00. Hourly indoor catches are provided in Additional file 2: Table S2.

The bulk (47.9%, n = 46/96) of outdoor mosquito collections came from Gokwe South (Additional file 1: Table S1). The fewest outdoor collections came from Masvingo District, while Gokwe South had the highest number of *Anopheles gambiae* mosquito species collected outdoors. Indoors, the *Anopheles funestus* group was collected only in Masvingo district. Outdoors, 75% of the *An. funestus* group was active between 03:00 and 05:00. Meanwhile, *An. gambiae* s.l. had a bimodal activity pattern. The first active period was between 19:00 and 23:00, and the second was between 03:00 and 05:00. Hourly outdoor catches are provided in Additional file 3: Table S3. The populations of anopheline and culicine mosquitoes in the investigated area were generally low.

Social and behaviour change

Sources of information and education on malaria

The study sought to establish whether household heads had received information and education on malaria; 77.1% of respondents indicated that they had, while 22.9% had not received any information on

malaria. The main sources of malaria information as indicated by the respondents were VHWs (55.7%), health facilities (36.9%) and EHTs (30.9%). Broadcast media (2.5%) and pamphlets (1%) were the least common sources of information.

Channels used to receive information

When asked how they received information on malaria, the majority (76.8%) stated that they received it verbally during community meetings or home visits, followed by broadcast (11.1%) and written (8.9%) channels, while social media (0.6%) was the least used channel.

Topics addressed during malaria education

The main topics addressed during health education sessions were malaria prevention (86.4%) and malaria disease (82.2%) (Table 5). This was supported by most of the VHWs (12/14), who stated that they had a programme to implement SBC for malaria; the other two had none. The two VHWs who did not have a programme to guide SBC implementation stated that they used personal notes received from health workers and information, education and communication (IEC) materials.

All 11 EHTs stated that they conducted malaria SBC. Prevention of malaria, malaria disease and transmission were the main topics covered. The content of the IEC materials did not cover ITN utilisation or the challenges faced in using nets, for example, hanging the net, itching and heat under the net.

Table 5
Main topics addressed

Topic	%
Malaria disease	82.2
Malaria prevention	86.4
Antenatal health	2.1
WASH	1.7
COVID-19	0.8
Don’t remember	5.0

ITN information

Sixty-one per cent (61%) felt they received adequate information about ITNs, while 39% felt the information was inadequate. The frequency of receiving information on ITNs is shown in Table 6. The most common response was that ITN information was received monthly (37.5%). This agreed with the frequency of health education reported by VHWs and EHTs, who indicated that they conducted malaria SBC mostly on a monthly basis (VHWs 7/14, 50%; EHTs 6/10, 60%).

Table 6
Frequency of receiving ITN information

Frequency of receiving ITN information	Responses n = 176*	%
Weekly	13	7.4%
Monthly	66	37.5%
Every 3 months	29	16.5%
Every 6 months	7	4.0%
Annually and above	34	19.3%
Don't remember	27	15.3%

*Respondents who reported receiving malaria information (n = 242) and answered this question; 66 did not respond. Percentages are of respondents answering (n = 176).

Language used for information dissemination on ITNs

The majority (90.1%) of the respondents received information in a local language, while 5% received information in English. Most respondents (73.9%) stated that messages were easy to understand while 15% felt the messages were not easy to understand.

Preferred source of information on ITNs

VHWs were the most preferred source of ITN information (73.9%), followed by EHTs (60.2%) and health facilities (53.2%), while broadcast media (5.1%) and pamphlets (3.5%) were the least preferred (Fig. 2). Figure 2 compares respondents' current primary source of malaria information with their preferred source of ITN information (n = 242). VHWs were both the most common current source (55.7%) and the most preferred source. For every source, the proportion of respondents who preferred it exceeded the proportion currently receiving information from it, with the largest gaps for EHTs (60.2% preferred vs 30.9% current) and health facilities (53.2% vs 36.9%). Broadcast media and pamphlets were both rarely used (2.5% and 1.0%, respectively) and rarely preferred.

Of the 10 EHTs who answered this question (one of the 11 did not respond), eight (80%) indicated that they had adequate resources to implement SBC activities.

Ability to adequately cover catchment area with SBC activities

Of the 10 EHTs who responded, six stated that they were moderately satisfied with the coverage of their catchment area, one was very satisfied, two were satisfied and one was unsatisfied. The majority of VHWs (8/14) stated that they were moderately satisfied.

Additional resources needed to strengthen SBC activities reported by EHTs included fuel (6/10), incentives (4/10), motorbike service (4/10), IEC materials (2/10) and motorbike and rider's kit (2/10).

Effects of climate on malaria incidence

Climate variables

Temperature and humidity

The three districts' minimum, maximum and mean temperatures showed slight variations. In all districts, the highest temperatures occurred in October, while the coldest month was July. Masvingo recorded the highest temperature, 42°C, in October 2019. The monthly mean temperatures showed a similar fluctuating seasonal trend from 2016 to 2020, with October being the warmest month and July being the coldest month for all districts (Additional file 4: Figure S1). The mean temperatures ranged from 16°C to 27°C.

Humidity also varied seasonally, with February and March being the most humid months, while September and October had the lowest humidity in all districts (Additional file 4: Figure S1). In October, the minimum humidity was 29% (Gokwe South), and the maximum humidity was 75%.

Precipitation

Monthly rainfall trends for each district over 2016–2020 are provided as Additional file 5: Figure S2. Precipitation is seasonal, with most rainfall occurring between December and February. Chegutu District generally receives more precipitation than the other districts; however, this was not the case in 2020. Monthly rainfall peaked between November and February in all three study districts. For all three districts, the wettest month of the year was February 2018. The year 2017 recorded the highest total annual precipitation in all districts. Chegutu had the highest total annual precipitation of approximately 1092 mm.

Statistical analysis of the climate variables

The results of the Mann–Kendall test for the precipitation, temperature and humidity data are shown in Additional file 6: Table S4. There were no statistically significant trends in the time series for precipitation, temperature and humidity in the areas considered, as the p-values for all the climate variables were above 0.05.

NDVI trends

Most NDVI values were lower than 0.3 during the five years (Fig. 3), indicating low vegetation cover.

Figure 3: NDVI trends

Chegutu had the highest NDVI value (0.366) in 2017, and the NDVI trend was similar in all years.

Determinants of ITN utilisation

Overall, 154 of 314 respondents (49.0%) reported using an ITN on the night preceding the survey. In the bivariate screen, net use varied strongly by district. Net use was also associated with perceived net adequacy, receiving malaria information, perceiving ITN information as adequate, and finding ITN messages easy to understand (all $p < 0.05$). In the multivariable GEE model accounting for ward-level clustering (Table 7), respondents who received malaria information were more likely to use a net (aOR 1.75, 95% CI 1.18–2.59; $p = 0.006$), as were older respondents (> 35 years: aOR 1.63, 95% CI 1.12–2.38; $p = 0.011$). Female respondents were less likely to use a net than males (aOR 0.73, 95% CI 0.55–0.96; $p = 0.024$). Agreement that nets adequately protect showed a borderline positive association (aOR 1.61, 95% CI 0.93–2.79; $p = 0.089$). After accounting for ward-level clustering, the strong crude district differences (ward-level net use ranged from 3% to 89%) were attenuated to non-significance, indicating that much of the district variation operated at the ward level. Education, employment, perceived net adequacy and perceived ITN information adequacy were not independently associated with ITN use after adjustment.

Table 7
Crude and adjusted associations between household characteristics and ITN utilisation (self-reported net use on the night before the survey)

Characteristic	Used net, n/N (%)	cOR (95% CI)	p†	aOR (95% CI)	p
District			**< 0.001**		
Masvingo	53/99 (53.5)	1.00 (ref)		1.00 (ref)	
Chegutu	77/107 (72.0)	2.23 (1.25–3.97)		2.29 (0.63–8.34)	0.209
Gokwe South	24/108 (22.2)	0.25 (0.14–0.45)		0.26 (0.05–1.32)	0.104
Age group			**0.126**		
≤ 35 years	47/109 (43.1)	1.00 (ref)		1.00 (ref)	
> 35 years	107/205 (52.2)	1.44 (0.90–2.30)		1.63 (1.12–2.38)	0.011
Sex			**0.466**		
Male	61/118 (51.7)	1.00 (ref)		1.00 (ref)	
Female	93/196 (47.4)	0.84 (0.53–1.33)		0.73 (0.55–0.96)	0.024
Marital status			**0.908**		
Unmarried	30/62 (48.4)	1.00 (ref)		–	
Married	124/252 (49.2)	1.03 (0.59–1.80)		–	
Education			**0.163**		
Primary or less	63/141 (44.7)	1.00 (ref)		1.00 (ref)	
Secondary or higher	91/173 (52.6)	1.37 (0.88–2.15)		1.04 (0.71–1.52)	0.849
Employment status			**0.167**		
Unemployed	69/156 (44.2)	1.00 (ref)		1.00 (ref)	
Employed	76/138 (55.1)	1.55 (0.97–2.45)		1.23 (0.81–1.86)	0.337
Retired/Other	9/20 (45.0)	1.03 (0.40–2.63)		1.24 (0.52–2.99)	0.626
Children under 5			**0.607**		

Characteristic	Used net, n/N (%)	cOR (95% CI)	p†	aOR (95% CI)	p
District			**< 0.001**		
None	66/130 (50.8)	1.00 (ref)		–	
≥ 1 child	88/184 (47.8)	0.89 (0.57–1.39)		–	
Pregnant member			**0.945**		
No	140/284 (49.3)	1.00 (ref)		–	
Yes	13/26 (50.0)	1.03 (0.46–2.30)		–	
Perceived net adequacy			**0.021**		
Not adequate	71/165 (43.0)	1.00 (ref)		1.00 (ref)	
Adequate	83/148 (56.1)	1.69 (1.08–2.65)		1.26 (0.65–2.45)	0.497
Challenges using nets			**0.776**		
No	104/211 (49.3)	1.00 (ref)		–	
Yes	49/96 (51.0)	1.07 (0.66–1.74)		–	
Receives malaria information			**0.026**		
No	27/72 (37.5)	1.00 (ref)		1.00 (ref)	
Yes	127/242 (52.5)	1.84 (1.07–3.16)		1.75 (1.18–2.59)	0.006
Perceived ITN information adequate			**0.041**		
No	51/122 (41.8)	1.00 (ref)		1.00 (ref)	
Yes	103/192 (53.6)	1.61 (1.02–2.55)		0.84 (0.48–1.47)	0.542
ITN messages easy to understand			**< 0.001**		
No	12/48 (25.0)	1.00 (ref)		–	
Yes	120/232 (51.7)	3.21 (1.59–6.49)		–	

Characteristic	Used net, n/N (%)	cOR (95% CI)	p†	aOR (95% CI)	p
District			**< 0.001**		
Agrees nets adequately protect			**0.101**		
No/neutral	26/65 (40.0)	1.00 (ref)		1.00 (ref)	
Agree	128/249 (51.4)	1.59 (0.91–2.76)		1.61 (0.93–2.79)	0.089

Discussion

The evidence from these elimination districts suggests that malaria resurgence is unlikely to be explained by a single failure in knowledge, ITN access, vector control or climate. Rather, the overall pattern is consistent with a combination of gaps between ITN ownership and effective use, human activities that occur outside the protection of nets, vector activity at times when people are not fully protected, and implementation constraints that affect sustained malaria prevention. This interpretation is aligned with the current global emphasis on subnational tailoring, which recommends using local epidemiological, entomological, behavioural and operational information to select intervention packages rather than relying on a uniform approach [1, 4, 15]. It is also relevant to Zimbabwe, where recent reviews have emphasised the need to sustain effective vector control while responding to heterogeneous malaria transmission and emerging threats to elimination [16].

Community knowledge about malaria appeared broadly supportive of prevention and prompt treatment, but persistent misconceptions and uncertainty about practical aspects of ITN use indicate that knowledge alone is insufficient to ensure protective behaviour. The important issue is therefore not simply whether communities have heard malaria messages, but whether those messages address the decisions people make in everyday settings, including when to use a net, how to manage discomfort, where to obtain a replacement, and how to maintain a net in serviceable condition. Recent African evidence similarly shows that education, socio-economic position and other household characteristics can influence ownership and utilisation of insecticide-treated nets; at the same time, systematic reviews continue to identify a gap between access and consistent use [17–19]. These observations support a shift from general awareness messaging towards audience-segmented SBC that addresses specific behavioural barriers and reinforces practical actions.

The apparent separation between ITN availability and consistent use is particularly important in settings approaching elimination. A household may possess one or more ITNs and still have unprotected sleeping spaces, periods of non-use, or family members who are not covered. Qualitative literature shows that ITN non-use commonly reflects discomfort from heat, perceived low mosquito density or low malaria risk, difficulties with net set-up, unsuitable ITN characteristics, inadequate access, travel and

social activities [20]. Seasonal use is therefore a critical programmatic concern because malaria risk can persist outside the period that communities perceive as the main transmission season. In elimination-oriented settings, SBC should explicitly promote consistent use whenever malaria vectors are present and should correct the assumption that ITNs are unnecessary during the winter period. Routine monitoring should also distinguish household ownership from population access, functional ITN availability and actual use, because these indicators capture different barriers to protection [1, 20].

Practical challenges related to ITN shape, hanging, heat and irritation should be treated as intervention design and service-delivery issues rather than simply as non-compliance. The 2024 qualitative review of ITN non-use identified physical properties of ITNs and their installation as recurrent barriers across malaria-endemic countries [20]. Programmes can respond by demonstrating hanging solutions appropriate to local housing structures, ensuring that distribution teams provide adequate hanging information, and using community follow-up to troubleshoot problems after campaigns. Where procurement choices allow, user preferences and local housing characteristics should be considered alongside entomological efficacy and cost. These measures are likely to be more effective than repeating generic messages about the benefits of ITNs without addressing the reasons people remove or avoid them.

Knowledge about ITN replacement and the ability to obtain a replacement are also central to maintaining effective coverage. The common assumption that every ITN will remain fully protective for a fixed three-year period is increasingly inadequate for programme planning, as physical survival and insecticidal performance vary by product, household use and local conditions. Recent durability studies have documented substantial variation in fabric integrity, attrition and insecticidal activity over time, supporting routine durability monitoring and replacement strategies that respond to functional condition rather than relying solely on campaign dates [21, 22]. This has two implications for the study districts. Firstly, continuous distribution channels should be sufficiently visible and accessible so that households know where and how to replace lost or damaged nets. Secondly, SBC on care and repair should be linked to a clear replacement pathway, because encouraging households to identify damaged ITNs has limited value if replacement is difficult to obtain.

Reported alternative uses of ITNs should also be interpreted carefully. The discrepancy between personal reporting and observations about what other community members do is compatible with social desirability bias, particularly when alternative uses are perceived as unacceptable. A recent qualitative synthesis confirms that ITNs are sometimes repurposed for fishing, animal husbandry, agriculture and other household functions, and that such practices can coexist with limitations in access, dissatisfaction with net characteristics or competing livelihood needs [20]. It would therefore be inappropriate to attribute all repurposing to ignorance. A more useful programme response is to identify whether the ITNs being repurposed are new and serviceable, old and damaged, or genuinely surplus to sleeping-space needs, and then tailor communication and commodity management accordingly. Community engagement should emphasise the protective value of serviceable ITNs while avoiding stigmatising households whose practices may reflect material or economic constraints.

The overlap between human behaviour and mosquito biting is a potentially important pathway for residual transmission. Livelihood activities, water collection, religious gatherings, funerals and other social events can keep people outdoors during the evening, night or early morning, when an ITN cannot provide protection. This interpretation is strongly supported by recent studies from different African settings. In south-eastern Tanzania, infectious-vector exposure was shown to depend on the timing of both mosquito biting and human use of interventions [23]. Studies in Zanzibar, western Zambia and south-western Mali have likewise documented early-evening, outdoor, daytime or public-space exposure that can sustain malaria transmission despite high use of conventional indoor vector control [24–26]. The consistency of these findings with the behavioural patterns described in the study districts suggests that malaria prevention strategies should explicitly consider where people are and what they are doing during vector-active periods, rather than defining exposure only by whether people sleep under an ITN.

This does not reduce the importance of ITNs or IRS. Both remain core malaria vector-control interventions, and WHO now recommends more effective ITN classes where appropriate in response to pyrethroid resistance [1, 4]. The implication is instead that core interventions may need complementary measures when a meaningful proportion of exposure occurs outside sleeping hours or outside treated houses. The 2025 WHO malaria guidelines introduced a conditional recommendation for indoor spatial emanators as an additional intervention alongside ITNs in areas with ongoing transmission, while also identifying outdoor use as an important evidence gap [4]. For the Zimbabwean districts studied here, complementary interventions should therefore be selected only after local assessment of exposure patterns, feasibility, acceptability and evidence, rather than assuming that any single outdoor-control tool will solve residual transmission. This is consistent with WHO guidance on subnational tailoring [15].

The entomological observations strengthen the plausibility of residual transmission but should be interpreted cautiously. The presence of *Anopheles gambiae* sensu *lato* and the *Anopheles funestus* group, together with activity occurring both indoors and outdoors and at the margins of normal sleeping hours, is consistent with the behavioural plasticity described in major African malaria vectors. Recent work has demonstrated that *An. funestus* can expose people in public spaces and outside conventional sleeping periods, while *An. arabiensis* and other members of the *An. gambiae* complex can sustain transmission through outdoor and early-evening biting [24–26]. However, collection patterns alone cannot establish that IRS or ITNs caused a behavioural shift, nor can they demonstrate insecticide resistance. Such explanations require species-level identification, insecticide susceptibility testing, resistance-mechanism characterisation, sporozoite testing, host-source analysis and longitudinal sampling. This distinction is important because attributing observed behaviour directly to intervention pressure without these data could overstate the evidence.

Strengthening entomological surveillance should therefore be a priority in districts where malaria persists or resurges despite high reported vector-control coverage. Surveillance should characterise vector species composition, indoor and outdoor biting, hourly biting profiles, resting behaviour, insecticide susceptibility and the infective status of collected mosquitoes. Linking these data with routine malaria surveillance and intervention coverage would allow the national programme to identify

whether transmission is being sustained by behavioural avoidance, insecticide resistance, insufficient intervention quality, importation, local receptivity, or a combination of these factors. WHO's updated surveillance guidance positions surveillance as a core intervention and specifically emphasises the use of vector and insecticide-resistance information to guide decisions [27].

The study also highlights the strategic importance of village health workers, environmental health personnel and health facilities as channels for malaria communication. Their proximity to households makes them well placed to deliver repeated, locally relevant messages, identify practical barriers and support replacement or referral pathways. Recent evidence reinforces this approach. A 2026 systematic review found that SBC interventions can improve malaria-related knowledge, preventive practices and care seeking when strategies are adapted to context [28]. In Uganda, exposure to malaria messages was associated with improved ITN use among women and young children [29]. In addition, a cluster-randomised trial in Burkina Faso and Côte d'Ivoire reported that intensive behaviour change communication added to ITNs reduced malaria incidence compared with ITNs alone, providing trial-based evidence that well-designed SBC can contribute to malaria control [30]. These findings support investment in the quality, reach and consistency of frontline SBC rather than treating communication as an ancillary campaign activity.

The communication strategy should nevertheless be broadened rather than relying on one channel. Interpersonal communication appears particularly appropriate in the rural communities represented in this study, but radio, mobile platforms and other channels can reinforce messages, reach mobile or working populations and improve message frequency. The most useful content is likely to be highly practical: year-round ITN use when vectors are present, safe and acceptable net care, correct hanging, how to respond to itching or heat concerns, where to obtain replacement nets, the importance of early diagnosis and treatment, and protection during outdoor or overnight activities. Messages should be delivered in locally understood language and should be segmented for groups whose work or social roles create distinct exposure patterns. The observed prominence of women in household-level malaria activities also argues for communication that supports women without placing the entire responsibility for prevention on them, while engaging men, adolescents, workers and community leaders in shared malaria-control responsibilities.

The climate analysis should be interpreted as evidence against a simple long-term climatic explanation for resurgence, rather than evidence that climate is irrelevant. Malaria transmission is highly climate-sensitive because temperature, rainfall and humidity affect mosquito survival, breeding and parasite development. However, these relationships are non-linear, spatially heterogeneous and often mediated by land use, water management and human behaviour [31]. The absence of a statistically detectable monotonic trend over a relatively short time series does not exclude the possibility that short-term anomalies, seasonal extremes or local micro-environments influenced transmission. Climate and remote-sensing indicators should therefore remain part of routine early-warning and stratification systems, but the absence of a clear long-term trend strengthens the case for examining intervention

effectiveness, human–vector contact and programme implementation as more immediate explanations for resurgence in these districts [15, 31].

This study has several strengths. It brings together household perspectives, information from frontline health workers, direct observations, entomological data and environmental trends, allowing malaria resurgence to be considered as a system in which human behaviour, intervention delivery and vector ecology interact. This triangulation is particularly valuable in elimination settings, where aggregate coverage indicators may conceal small but epidemiologically important gaps in protection. The inclusion of both indoor and outdoor mosquito collection also provides information that would be missed by surveillance focused only on indoor-resting vectors.

Several considerations should be taken into account when interpreting these findings. Household-level information was largely self-reported, which may have introduced some recall or social desirability bias, particularly for behaviours such as ITN use and alternative uses of nets. However, the inclusion of household observations and qualitative information from community-level health workers provided additional context for interpreting reported practices. Entomological collections yielded relatively small numbers of malaria vectors, so species-specific and time-specific biting patterns should be interpreted as indicative of local behavioural patterns rather than definitive estimates of vector behaviour across the three districts. In addition, identification at the species-complex or species-group level did not allow differentiation of sibling species with potentially different ecological and behavioural characteristics.

The absence of insecticide susceptibility, resistance-intensity, sporozoite and blood-meal analyses limited the assessment of the mechanisms underlying the observed vector behaviours and their direct contribution to malaria transmission. These data were beyond the scope of the present study and therefore represent important areas for complementary entomological investigation. Similarly, the environmental analysis used district-level climate and vegetation indicators over a five-year period and may not fully capture short-term or highly localised environmental variation. Nevertheless, integrating household behaviour, entomological observations, social and economic factors, SBC information and environmental trends provided a broad assessment of the multiple factors that may contribute to malaria resurgence in elimination settings. Future studies could build on these findings through longitudinal behavioural and entomological surveillance, molecular vector identification, insecticide-resistance monitoring, and finer-scale geospatial linkage of vector, intervention and malaria surveillance data.

Conclusion

Malaria resurgence in the three elimination districts is multifactorial. Although the programmatic coverage was 95% and the survey reported household ownership of 83%, correct and consistent utilisation was low (29.4%). The level of knowledge of how malaria is transmitted was high (81.8%), yet protection from malaria remained incomplete. The majority (88.2%) were not aware of the correct three-year ITN replacement interval, and 68% of households needing replacement of ITNs failed to obtain

them, mainly because of lack of time and not knowing where to collect replacements. Outdoor livelihood, water-collection and socio-cultural activities coincided with peak mosquito-biting hours, and the majority (53%) of host-seeking mosquitoes were caught outdoors, a pattern consistent with residual outdoor transmission. No statistically significant long-term trends in temperature, rainfall or humidity were detected.

These findings point to clear priorities. ITN replacement should be continuous and accessible, and social and behaviour change communication should be practical, segmented, and led by well-supported village health workers, who were the main source of malaria information (55.7%). Entomological and insecticide-resistance surveillance should be strengthened, and complementary interventions should be tailored contextually to address exposure that persists outdoors. Overall, a combination of behavioural, socio-economic, entomological and environmental intervention measures is crucial to sustain progress towards malaria elimination in Zimbabwe.

Abbreviations

aOR
Adjusted odds ratio
API
Annual parasite incidence
CDC
Centers for Disease Control and Prevention
CI
Confidence interval
cOR
Crude odds ratio
EHT
Environmental health technician
EPI
Expanded Programme on Immunisation
GEE
Generalised estimating equation
IEC
Information, education and communication
IRS
Indoor residual spraying
ITN
Insecticide-treated net
KAP
Knowledge, attitudes and practices
NDVI

Normalised Difference Vegetation Index
OLI
Operational Land Imager
PCR
Polymerase chain reaction
SBC
Social and behaviour change
VHW
Village health worker
WHO
World Health Organization

Declarations

Ethics approval and consent to participate:

The Medical Research Council of Zimbabwe approved the study (MRCZ/A/2784), and permission to conduct it was obtained from the Ministry of Health and Child Care through the National Malaria Control Programme. Verbal informed consent was obtained from all participants before enrolment, and additional consent was obtained from household heads for placement of CDC light traps in their homes.

Consent for publication:

Not applicable.

Competing interests:

The authors declare no competing interests.

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Author Contribution

RM and MM conceptualised the study and supervised data collection. TC, VM, DFG and FM performed the data analysis. MM and BC offered academic guidance during the research process. All authors contributed to manuscript preparation, reviewed the final draft, and provided critical feedback. All authors have read and approved the final manuscript.

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Data Availability

All data supporting the findings of this study are available within the paper and its Supplementary Information.

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Figures

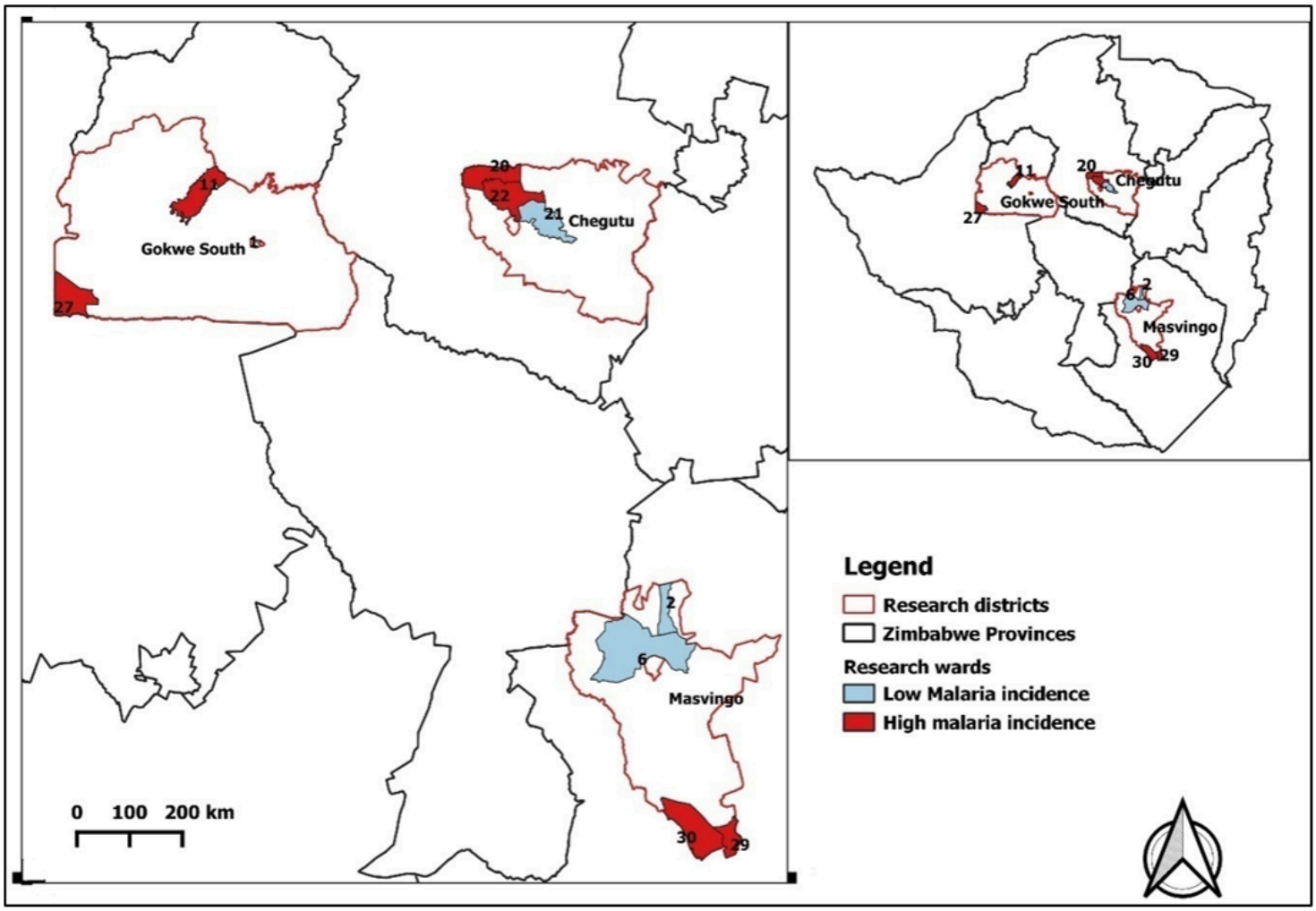


Figure 1

Map of Zimbabwe showing the locations of Masvingo, Chegutu and Gokwe South.

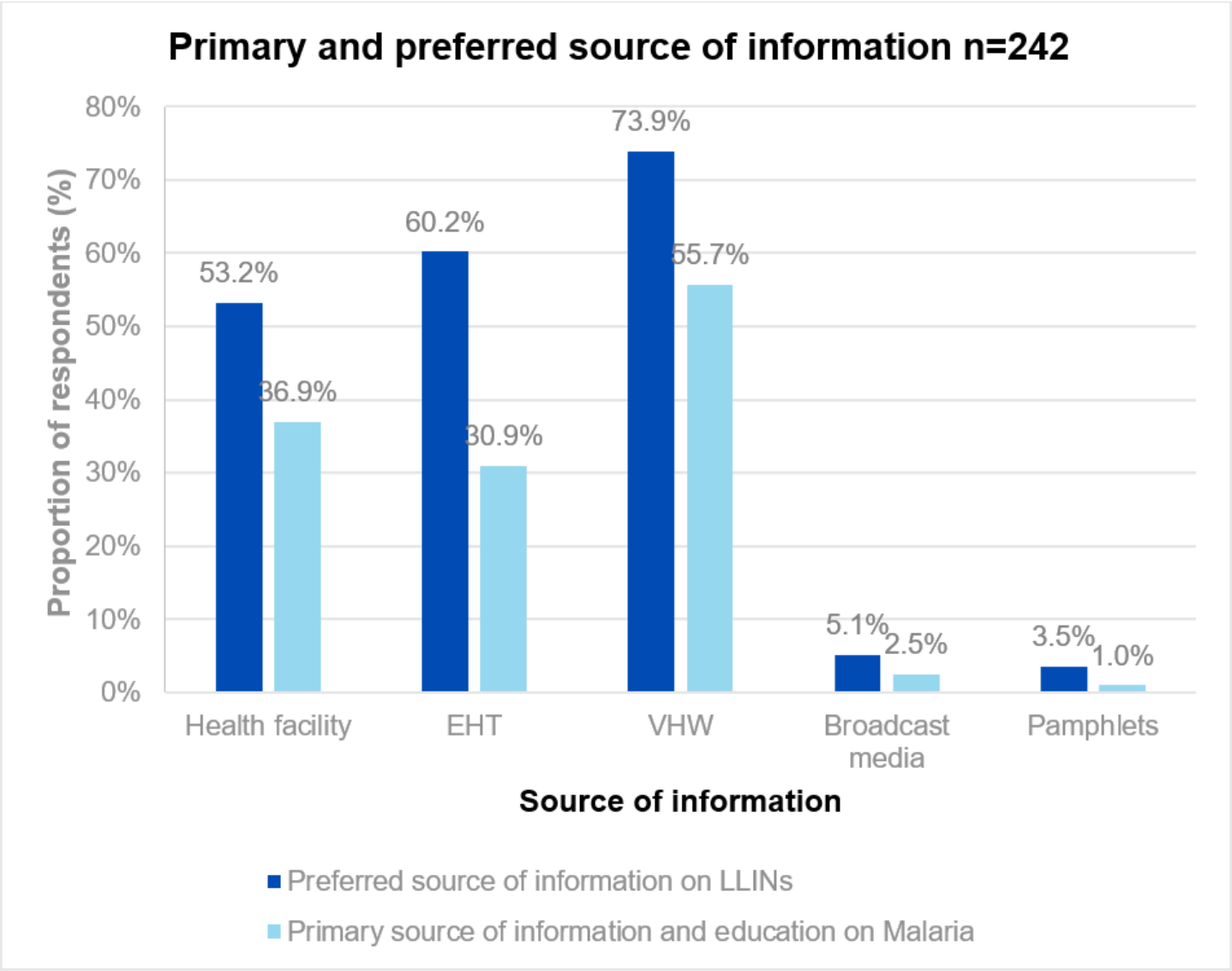


Figure 2

Primary and preferred sources of information

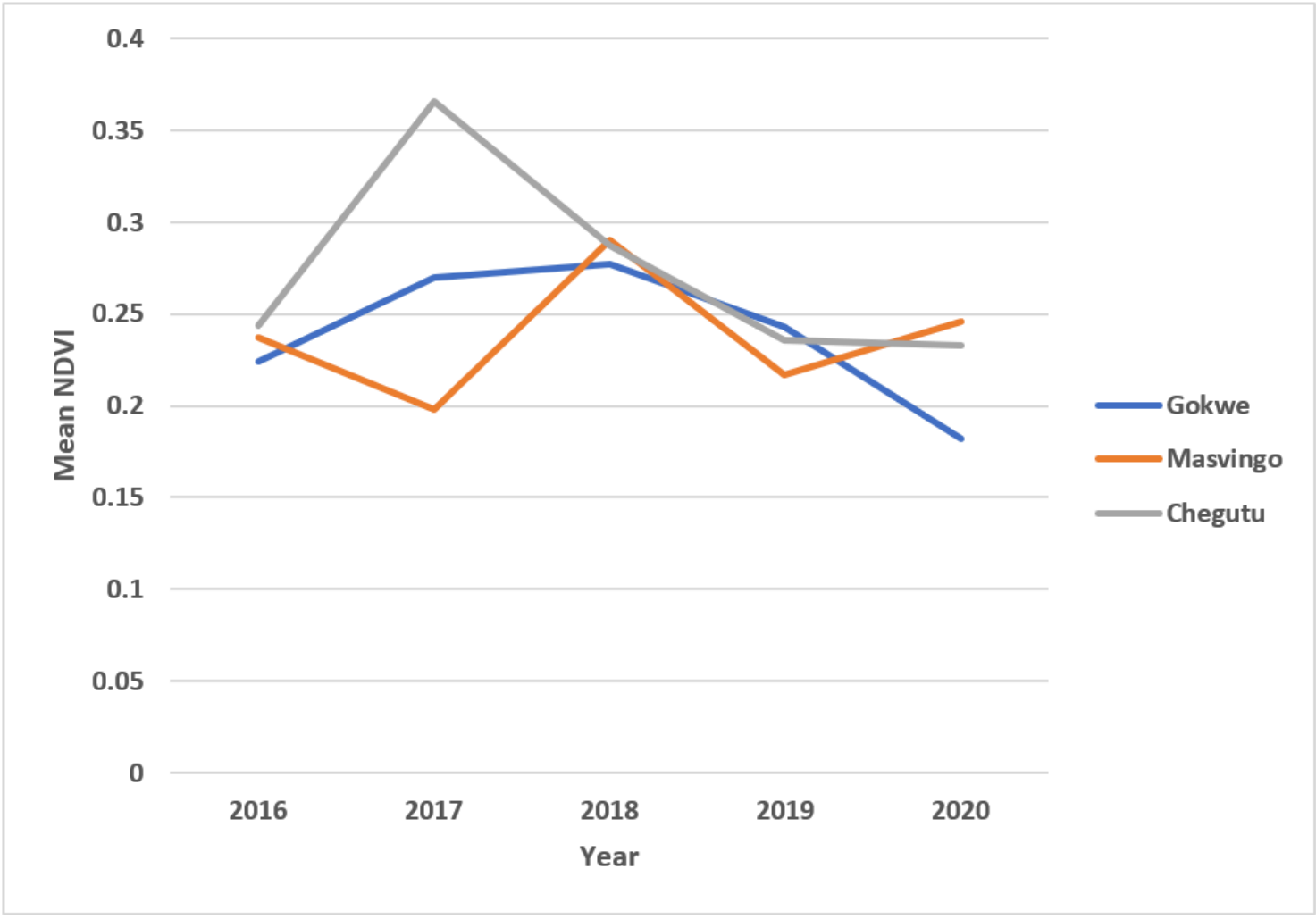


Figure 3

NDVI trends

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