Socioeconomic inequalities, equity effect, and cost-effectiveness of malaria control interventions in an endemic area of western Kenya

This thesis is submitted in accordance with the requirements of the Liverpool School of Tropical Medicine for the degree of Doctor in Philosophy by

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Contents

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Above all, I thank the Almighty God for the gift of life and good health.

Candidate's statement on research contributions

1.1 Application of Multiple Correspondence Analysis for assessing the relationship between malaria infection and socioeconomic status

The first new idea in this thesis was the application of Multiple Correspondence Analysis (MCA) to classify households in socioeconomic status. I came up with this idea after reading a lot of literature about the methodological challenges applied by other scholars which led to uncertain conclusions. The approach was recommended already in other domains that this model is better and the results are more reliable. So, I developed the application for the health field.

1.2 Publication of manuscript entitled: *Socioeconomic health inequality in malaria indicators in rural western Kenya: evidence from a household malaria survey on the burden and care-seeking behaviour*

I participated in the development of the protocol, development of tools, training of research assistants, data management. I personally analyzed the data based on the objective of my study, I drafted the first manuscript, presented it as the KEMRI centre scientific committee and to the national scientific and ethics committee for approval. After the input from co-authors and approvals, I submitted it to the malaria journal. I was the corresponding author with the primary responsibility to address all reviewer comments until the paper was published by the malaria journal. I got guidance from my supervisors and inputs from my co-authors who shared with me some of the ideas on the content of the paper which I integrated. The paper can be found in the link below

https://malariajournal.biomedcentral.com/articles/10.1186/s12936-018-2319-0

1.3 The reclassification of wealth quintiles into 'poorest 'or less-poor"

After applying the MCA model to classify households in five socioeconomic strata, I later decided to classify them into two distinct groups, poorest and less poor where the poorest were a merge of lowest three quintiles (60%) and less poor was a merge of the highest two quintiles (40%). This made it easier to compare the prevalence rates between the two groups and for modelling purposes. This was my decision following a study by the World Bank that showed that about 60% of the population in the study area were living below the poverty line. This approach can be adopted by other researchers who wish to collapse some groups into two. The use of localised data can help in this classifications

1.4 The study on the trends in socioeconomic health inequalities in malaria-related health events from 2006 to 2013, using repeated routine cross-sectional data

There was no previous study that had assessed trends in socioeconomic inequalities in malaria-related health events as part of efforts to monitor the process in achieving the targets of sustainable development goals and universal health coverage. This was my idea and was supported by my supervisors. The analysis revealed that the poorest individuals have borne the heaviest burden of malaria over time. This has implications in the sense that efforts on malaria reduction must also focus on the poorest populations to ensure universal health is equitable besides being cost-effective

I developed a manuscript, personally analyzed eight years of data, took the manuscript through scientific and ethics committees at KEMRI and CDC, addressed all queries as the corresponding author, ensured the paper was published by a peer review journal (BMJ Open) The publication can be accessed using the link below;

https://bmjopen.bmj.com/content/9/9/e033883

1.5 Publication of LLIN study protocol to document methods and study procedures

Title: Large-scale implementation of disease control programmes: a cost-effectiveness analysis of long-lasting insecticide-treated bed net distribution channels in a malaria-endemic area of western Kenya—a study protocol

My next contribution was the publication of the research protocol for evaluating the cost and equity effects of LLIN distribution channels in western Kenya. This effort was to document methods and procedures other scholars may want to refer to when conducting this kind of evaluation. There was no previous publication of similar work.

I developed the original proposal as the principal investigator. I took the proposal through institutional review boards, received approvals and together with co-investigators we secured funds to conduct the study.

The idea of publishing this proposal was floated by Dr. Elvis Gama, a health economist who was working at LSTM. We discussed and agreed that he takes lead in formatting the proposal as a manuscript and he became the first author and I was the second author. The ideas in this paper are largely from the proposal of which I was the PI. Although Dr. Elvis was the leading author, I responded to most questions being the person who was the PI. This joint effort led to the publication of the protocol at the BMJ Open. The paper can be accessed through the link: https://bmjopen.bmj.com/content/6/11/e012776.short

1.6 The evaluation of MTAT in a cluster-randomized trial in terms of reducing socioeconomic inequalities. The manuscript title is: *Equity effect of intermittent mass test-and-treat on the household burden of malaria and quality of life: Results from a cluster-randomized trial in western Kenya*

Most clinical trials are focused on epidemiological outcomes and there has been little evidence on un-intended economic benefits of such a large scale mass drug administration to

the community. The initial design of MTAT was to reduce the prevalence of malaria with no intention of assessing any economic outcomes. I came up with the idea of assessing potential equity gains for the poorest individuals. There was no previous study that had assessed the equity effects of a large drug administration would be to households.

Previous studies had only focused on general assessment at the population level but no studies have considered the potential economic benefit to the poorest individuals, in terms of free access to medicines, ITN and less cost to seek care. The use of data from a clinical trial was best suited to assess the unintended economic benefits and contribute to promoting such mass campaigns through economic perspectives.

Dr. Meghan Desai was the PI of the main protocol and I was a co-investigator whose roles included developing methods sections of economic evaluations, training staff, statistical analysis, data collection. I developed the manuscript, analyzed the data and presented the results in this chapter. The paper is undergoing review and publication processes

1.7 Socioeconomic inequalities in population burden of malaria: analyses of disability-adjusted life years in a health and demographic surveillance, 2006-2014, western Kenya

My other research contribution presented in Chapter 5. Previously global disease burden had presented disease burden for the general population and no studies had assessed the total disease burden in terms of DALYs (mortality and morbidity) between socioeconomic groups and showing trends over time. I came up with this idea to provide evidence on the existence of socioeconomic inequalities for total disease burden at population using data from Health and Demographic surveillance targeting a population of 220,000 and about 65,000 households. I conducted further assessment of the economic effect of malaria infection and mortality by estimation of DALYs averted by socioeconomic groups and gender. This is also an original contribution from my side. I personally assembled data sets from surveys, HDSS, and grey literature, developed and set-up a model framework for analysis, conducted the

analysis, developed the manuscript and presented the results in the paper. The manuscript is to be published but is in the review process. I am the first author and other authors have provided input and their ideas have been incorporated.

1.8 Universal household coverage with insecticide-treated bed nets - efficiency and equity outcomes in malaria-endemic western Kenya.

Lastly, it was observed that there was a lack of data on the cost-effectiveness and efficiency in combination with the equity effect of LLIN distribution channels in endemic areas. The gap in knowledge was that most studies had only assessed the cost-effectiveness of LLIN, but no previous studies had evaluated the unit cost of each distribution, compared unit costs or even cost-effectiveness or equity effects of the distribution methods. I came up with the idea of bringing in an equity perspective, using local reference standards. This had not been done before. The results have shown that none of the distribution channels was pro-poor yet probably contributed to a reduction of inequities in achieving universal coverage. The cost of distribution one LLIN to achieve universal coverage was the least for mass distribution, compared to other channels. We concluded that the use of community health volunteers was closest to achieving equity in UC between the poorest and less poor households.

I developed the proposal, conducted data collections and data analysis on equity effect and cost analysis, and developed the first draft of the manuscript. Dr. Eva Worrell is the lead author and I am the second authour. I have continued to respond to reviewer comments given my experience taking lead in being the principal investigator. Dr. Ann Buff contributed information on net distribution numbers and Dr. Meghna also provided insights into the distribution approaches being used. My supervisors provided guidance throughout the process. The manuscript is under the internal publication review process at the CDC for possible publication in the Lancet Global Health.

The finding from this specific study contributes to news ideas of reducing socioeconomic inequalities in LLIN distributions through a mixture of approaches to achieve universal coverage and sustainable development goals.

Glossary in alphabetical order

ACTS	Aartemisinin-based combination therapies
AL	Artemetherisinin -lumefantrine
ANC	Antenatal care
CHV	Community health volunteer
CO	Commercial outlet
DALYs	Disability adjusted life years
HDSS	Health demographic surveillance system
IPT	Intermittent preventive treatment
ITNs	Insecticide treated mosquito nets
LLIN	Long lasting insecticide nets
MCA	Multiple component analysis
MD	Mass distribution
MTAT	Mass testing and treatment
PCA	Principal component analysis
RDT	Rapid diagnostic test
SDG	Sustainable development goals
SES	Socioeconomic Status
SM	Social marketing
WHO	World health organization

Chapter 1: General introduction

Abstract

Background

Malaria control in endemic areas still faces the challenge of ensuring that scale-up of interventions is sustainable, cost-effective and equitable. However, there have not been adequate studies monitoring equity effects or changes in socioeconomic inequalities of these Interventions over time even. The existence of socioeconomic health inequalities is a barrier to achieve universal health coverage and sustainable development goals.

Methods: Secondary datasets have been used in these microeconomic evaluations including eight years of repeated annual cross-sectional surveys from 2006 to 2013 involving 19,000 individuals in Siaya County, western Kenya. Data from a two-year cluster randomized Mass Test and Treat (MTAT) study conducted between 2013 and 2015 were also used. Further, malaria-related mortality and morbidity data from health and demographic surveillance system (HDSS) surveys from 2006 to 2014 have been used. Lastly, data on costs and effects of Long-Lasting Insecticide Nets (LLIN) distribution channels were collected from national to local levels in Busia County, western Kenya to assess the cost-effectiveness of LLIN distribution channels from a provider and household perspectives. Household socioeconomic status (SES) was established using multiple correspondence analysis (MCA), socioeconomic inequalities were assessed using concentration indices, and multi-level mixed-effects generalized linear regression models (GLM) were used to compare prevalence ratios with 95% confidence intervals. Disability-adjusted life years and cost-effectiveness ratios were calculated to answer research questions. Data were compared between the poorest and less poor individuals at the household and population level.

Results: The poorest individuals, children, and women, bore the greatest burden of malaria measured in terms of morbidity, mortalities and disability-adjusted life years but the health inequality gap between the poor and less poor has reduced over time. There were no significant inequalities in medication use and care-seeking for fever between the poorest and less poor which represents equity gains for the poorest individuals. The MTAT intervention resulted in equity gains amongst the socio-economic groups in terms of access to medication, care-seeking, use of LLINs and averting malaria deaths in the participating communities. Mass distribution of LLINs combined with the use of community health volunteers remains the most cost-effective and equitable method of achieving universal coverage.

Discussion. Malaria remains a disease of poor individuals across age groups and gender but is mostly concentrated amongst children and women. While intensification of malaria control activities has resulted in a reduction of socioeconomic inequalities in rates of infections, mortality, care seeking and medication for fever, pro-poor and mass campaigns for control interventions should be to be integrated to reduce inequalities and inequities. The results from these studies are vital for monitoring socioeconomic inequalities and equity trends towards achieving universal health coverage and sustainable development goals.

Introduction

Malaria burden over time

Malaria is a global health problem, with 3.2 million people at the risk of malaria infections [1]. World Health Organization (WHO) estimated that between 2010 - 2016, 216 million (95% confidence interval CI=196-263 million) malaria cases occurred globally, incidence rates fell by 18% globally and by 20% in Africa, malaria mortality rates fell by 25% globally and by 66% in the African region [1]. Sub-Saharan Africa has been disproportionally affected by the burden of malaria despite the falling mortality with over 90% of the estimated 445,000 malaria deaths worldwide occurring in the region in 2016 [1]. Similarly, in sub-Saharan Africa, 3.1% of all disability-adjusted life-years (DALYs) were lost to malaria in 2002[2]. In Kenya, despite remarkable achievements in malaria prevention and control over the last 10 years, malaria remains a leading cause of morbidity and mortality with more than 70 per cent of the population at risk [3]. In 2015, while the prevalence of microscopically-confirmed malaria was 8% amongst children less than 15 years (13% by malaria rapid diagnostic test [RDT]s) nationally, it was 27% (43% by malaria RDT) in the lake-endemic region of western Kenya [4].

Scale-up of malaria control interventions over time

There have been intensified scale-up of malaria control interventions in Kenya over time including use of long-lasting insecticide nets (LLINs), indoor residual spraying (IRS), improved case management with rapid diagnostic tests (RDTs), use of effective artemisinin-based combination therapy (ACT) and intermittent preventive treatment (IPT) for high-risk groups [1] and recently the use of mass test and treat (MTAT) has been suggested for evaluations [5]. Empirical studies om who profits from the distribution of public goods

(whether drugs or bed nets) suggest that such programs tend to favour those who are better-off [6], and this results in socioeconomic inequalities in access and utilization of these interventions. There have not been adequate studies evaluating equity effects or monitoring socioeconomic inequalities of these interventions on malaria indices in endemic areas despite recent studies assessing their effects on reducing malaria burden.

Relationship between malaria infection and socioeconomic status

The relationship between malaria disease and poverty has often been described as a vicious cycle, and whether malaria infection is a consequence of or a cause for, low household socioeconomic status (SES) has been debated for decades [7, 8]. Malaria imposes substantial costs on governments, households, and individuals. Globally in 2015, the total funding for malaria control and elimination efforts was estimated at US$2.9 billion; governments in malaria-endemic countries provided 32% of the total funding, of which 65% or US$612 million was the expenditure incurred by national malaria control programs for program implementation and 35% or US$332 million was the cost of health service delivery[9]. The results of analyses assessing the relationship between malaria burden and socioeconomic status have been mixed and contradictory [6, 7, 10-12]. In a systematic review of nine studies to establish the relationship between malaria and poverty, two studies found a significant relationship between poverty and malaria, four studies found no significant relationship and three studies demonstrated mixed results[7]. Lack of consistency in these findings have been partly been attributed to inconsistency in the application of methods for measuring household SES, variations in population subgroups studied, and objective measurement for malaria infection [7, 13-15]. Different methods of establishing household or individual SES employing quantitative and qualitative aspects of poverty have been suggested by various researchers [10, 16-22]. For instance, a study in rural western Kenya compared three methods

of ranking households into SES Multiple Correspondence Analysis, Polychoric Principal Analysis, and principal component analysis and found that there were no significant variations in their results but MCA gave the highest percentage of the total variation in the outcome variable [22]. Recent studies have also established that the MCA model is more flexible as it allows for both quantitative and qualitative variables to be included in the model, it produces larger factor weights hence allowing larger values to distinguish cut-offs for classification of households into wealth quintiles [22, 23]. Despite this advantage, there were no studies to the best of our knowledge that had applied MCA to investigate the relationship between socioeconomic status and malaria-related indices including socioeconomic inequalities in malaria infection, use of malaria prevention, treatment interventions and expenditures.

Effectiveness of interventions to control malaria and their effects on equity

Equitable distribution of health services or interventions is a principle advocated for in most national policy documents aimed at achieving universal health coverage [24]. Monitoring socioeconomic inequalities and equity effect is part of Sustainable Development Goals (SDGs) related to poverty reduction, health, and wellbeing for all, equitable education, gender equality, and reduction of inequalities within and between countries [25, 26]. However, the lack of longitudinal data on SES and malaria-related indices have hampered these analyses. In some cases, health inequality variables have been collected but have not been assessed through economic perspectives to establish the effectiveness of control interventions in achieving equity between socioeconomic groups over time. Mass Test and Treat (MTAT) is a community-based intervention that has been evaluated in some countries and has been showed to be effective in the control of malaria in addition to known interventions such as the use of ITNs, ACTs, IPTp and IRS. Yet there are limited analyses

which have evaluated the effects of these interventions in reducing socioeconomic inequalities and equity effect.

Cost-effectiveness of interventions to control malaria

Studies from various parts of Africa indicate that the use of LLINs has a beneficial effect on malaria transmission, severe malaria and mortality [27, 28]. Similarly, there are numerous studies demonstrating the cost-effectiveness of LLINs in different parts of the world and in various contexts [29]. However, while various LLIN distribution methods have been used before, there is limited evidence on the actual costs of parallel distribution channels in the same context and coverage results that can realistically be achieved from each channel based on financial inputs [30]. Similarly, there are no studies that have evaluated the cost-effectiveness of various ITN distribution channels, and equity effects in a malaria-endemic area in sub-Saharan Africa.

Figure 1 below shows the conceptual relationship between malaria and poverty, illustrating and their inter-relationship. The framework depicts a dual relationship whereby the effects of malaria disease can result in households falling into poverty, due to factors such as treatment costs, death or disability of household breadwinners. At the same time, low socioeconomic status has been shown to be a risk factor for malaria infection, as those in low SES live in impoverished conditions, with residence in poor houses or environments, poor access to information, low education and lack of proper care-seeking behaviours, and lack of resources to buy effective preventive and treatment options. Malaria transmission and poverty are also influenced by geographical conditions, macro-economic factors, household and individual factors of which poor individuals may be disproportionately affected [8]

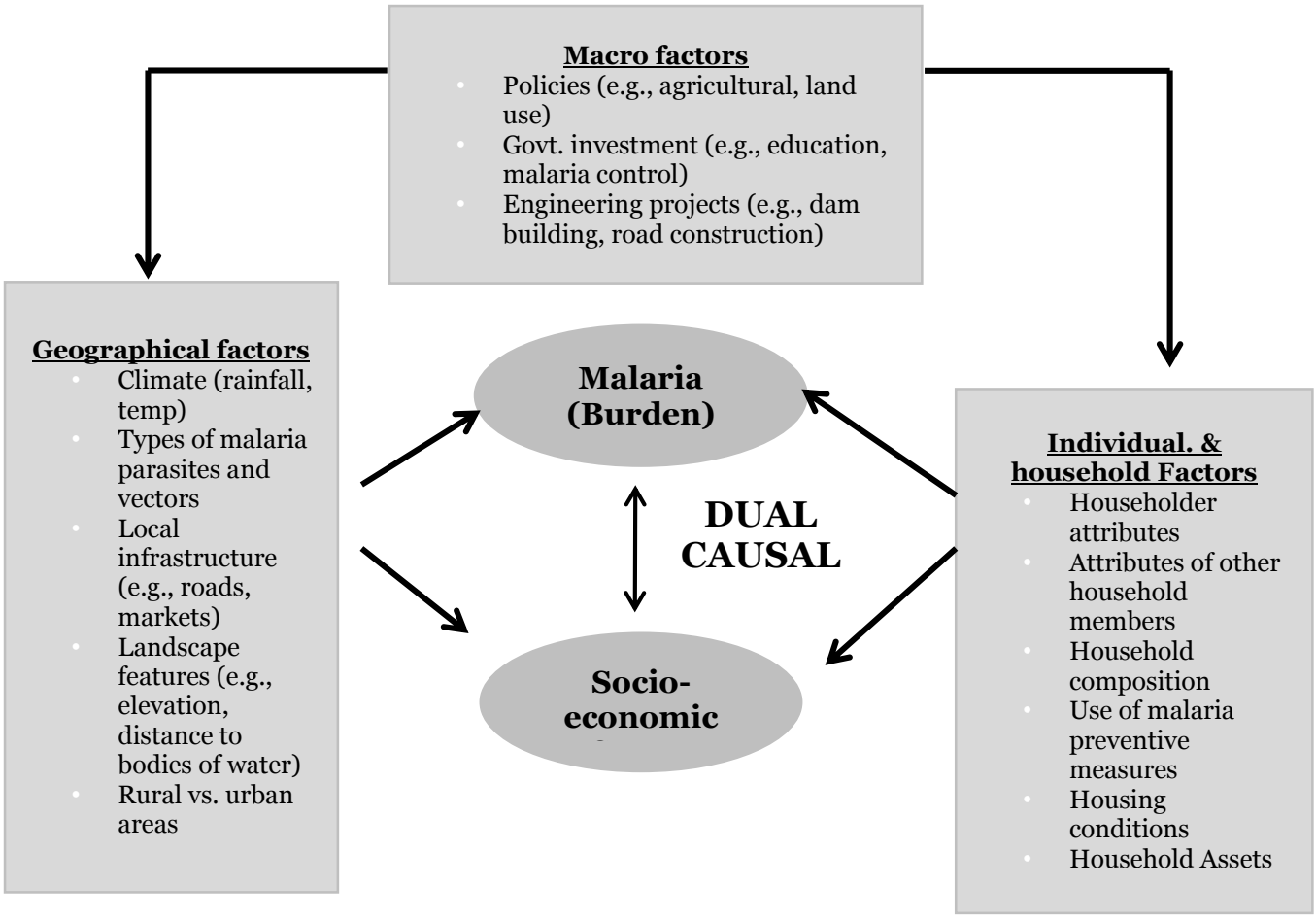

Figure 1: Conceptual framework of the relationship between malaria burden and socio-economic status. Source: de Castro and Fisher (2012) [8]

The rationale for the Study

Despite the intensification of malaria control programs in recent years, the burden of malaria remains high in western Kenya yet factors leading to a lack of significant reduction in burden, remains unclear and there are few studies looking at economic perspectives of malaria control in endemic areas. The existence of socioeconomic inequalities between the poor and less poor individuals are known to be a barrier to achieving universal health coverage and SDGs. Monitoring socioeconomic inequalities and equity effects of such programs contribute to global, regional and local efforts towards malaria reduction strategies. The results of studies presented in this thesis have implications on monitoring five key SDGs related to the

reduction of health inequalities at both national and global levels including poverty reduction, health and wellbeing for all, equitable education, gender equality, and reduction of inequalities within and between countries [26] The results of these studies also contribute to the objectives of Kenya National Malaria Strategy 2009-2017, which aimed to reduce mortality for children less than five years of age by two-thirds by 2015 and to eradicate malaria in Kenya by 2017, although these aims were not attained [31]. The success of the Kenyan strategy required monitoring of the epidemiological and economic benefits of malaria control programs. In the context of intensified malaria control efforts and due to the competing uses of the scarce resources in the health sector, policymakers are increasingly requesting that economic impact evaluation of interventions be conducted before decisions are taken to adopt new interventions.

The effects of malaria interventions on the burden may have economic benefits or losses to households which may promote inequities or inequalities between the socioeconomic classes. The strategies and methods for monitoring inequalities or inequities in health outcomes have been outlined by both the World Bank and WHO. However, there is still a need for continuous assessment of these methods and strategies to advance knowledge in monitoring socioeconomic inequalities and equity gains due to interventions. The use of longitudinal data or clinical trial data will provide an opportunity to measure the existence of socioeconomic inequalities or equity effects and cost-effectiveness of malaria control programs. The findings from these studies provide evidence on the relationship between malaria and poverty status, equity patterns of malaria indices between the poor and less poor. The findings also provide evidence on equity effects of community-based mass test-and-treat interventions, and the compilation and measurement of health loss due to malaria morbidity and mortality. The results presented in this thesis further provides evidence about the effects of LLIN

distribution channels on equitable universal coverage and the costs associated with each distribution channel.

Aim, themes, objectives, and hypotheses of the thesis

Aim of this thesis

The aim of this thesis was to assess socioeconomic inequalities in the malaria burden, treatment, and prevention, effectiveness of interventions to control malaria and their effects on equity and lastly to assess the cost-effectiveness of interventions to control malaria an endemic area of western Kenya.

The thesis is organized around the following themes

- Establish the socioeconomic inequalities in the burden, treatment, and prevention of malaria
- Assess the effectiveness of interventions to control malaria and their effects on equity
- Conduct studies to determine the cost-effectiveness of interventions to control malaria
- Make recommendations for policy, practice and future research to reduce socioeconomic inequalities and achieving universal health coverage

Specific Objectives and Hypotheses

1. To establish socioeconomic inequalities in malaria burden, treatment, and prevention in the malaria-endemic area of western Kenya

1.1 *Hypothesis 1:* Risk of malaria disproportionally occurs among individuals in lower socio-economic status

1.2 *Hypothesis 2*: Seeking care for fever, medication use, and expenditure of treatment disproportionally occurs amongst individuals in lower household socio-economic status

1.3 *Hypothesis 3*: Over time, socioeconomic inequalities in malaria burden, ITN use, drug use, and related expenditure have occurred disproportionally amongst individuals in the lowest socioeconomic status strata

2. To assess the effectiveness of interventions to control malaria and their effects on equity for malaria-related events at the household level

2.1 Hypothesis 1: Mass testing and treatment had no effect on socioeconomic inequalities in malaria burden and related expenditure among households in western Kenya

3.2. Hypothesis 2: Cumulative malaria occurrence and related expenditure disproportionally occurs amongst a cohort of households in the lowest socioeconomic strata over time

3.3. Hypothesis 3: Cumulative malaria exposure, household expenditures, medication use, and health-seeking shows benefits to the poorest households in the intervention sites

4. To establish socioeconomic inequalities in the population burden of malaria in terms of disability-adjusted life years in a health and demographic surveillance, 2006-2014, western Kenya

4.1. Hypothesis 1: Due to malaria interventions, there would be a decline in years of life lost (YLL) from morbidity and mortality among households in western Kenya over time

4.2. Hypothesis 2: The reduced Disability Adjusted Life Years (DALYs) burden disproportionately occurred among households in lower economic strata in the population

5. Evaluating the costs and effects of long-lasting insecticide-treated bed net distribution channels in a malaria-endemic area of western Kenya

5.1. Hypothesis 1: Costs, cost-effectiveness, and equity outcomes are not significantly different between various channels of LLIN distributions.

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Chapter 2: Socioeconomic health inequality in malaria indicators in rural western Kenya: evidence from a household malaria survey on the burden and care-seeking behaviour

Socioeconomic health inequality in malaria indicators in rural western Kenya: evidence from a household malaria survey on the burden and care-seeking behaviour

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Abstract

Background: Health inequality is a recognized barrier to achieving health-related development goals. Health-equality data are essential for evidence-based planning and assessing the effectiveness of initiatives to promote equity. Such data have been captured but have not always been analyzed or used to manage the programming. Health data were examined for microeconomic differences in malaria indices and associated malaria control initiatives in western Kenya.

Methods: Data were analyzed from a malaria cross-sectional survey conducted in July 2012 among 2,719 people in 1,063 households in Siaya County, Kenya. Demographic factors, history of fever, malaria parasitaemia, malaria medication usage, insecticide-treated net (ITN) use and expenditure on malaria medications were collected. A composite socioeconomic status (SES) score was created using multiple correspondence analyses (MCA) of household assets; households were classified into wealth quintiles and dichotomized into the poorest (lowest 3 quintiles; 60%) or less-poor (highest 2 quintiles; 40%). Prevalence rates were calculated using generalized linear modelling.

Results: Overall prevalence of malaria infection was 34.1%, with significantly higher prevalence in the poorest compared to less-poor households (37.5% versus 29.2%, adjusted prevalence ratio [aPR] 1.23; 95% CI=1.08–1.41, p=0.002). Care seeking (aPR=0.95; 95% CI: 0.87–1.04, p=0.229), medication use (aPR=0.94; 95% CI: 0.87–1.00, p=0.087) and ITN use (aPR=0.96; 95% CI=0.87–1.05, p=0.397) were similar between households. Among participants with malaria infection, 36.4% reported taking malaria medicines in the prior 2 weeks; 92% took artemether-lumefantrine, the recommended first-line malaria medication. In

the poorest households, 4.9% used non-recommended medicines compared to 3.5% in less-poor (p=0.332). Mean and standard deviation [SD] for expenditure on all malaria medications per person was US$0.38 [US$0.50]; the mean was US$0.35 [US$0.52] amongst the poorest households and US$0.40 [US$0.55] in less-poor households (p=0.076). Expenditure on non-recommended malaria medicine was significantly higher in the poorest (mean US$1.36 [US$0.91]) compared to less-poor households (mean US$0.98 [US$0.80]; p=0.039).

Conclusions: Inequalities in malaria infection and expenditures on potentially ineffective malaria medication between the poorest and less-poor households were evident in rural western Kenya. Findings highlight the benefits of using MCA to assess and monitor the health-equity impact of malaria prevention and control efforts at the microeconomic level.

Keywords Socioeconomic, malaria, medication, inequalities, Kenya

Background

Malaria is one of the most important diseases in many low- and middle-income countries, primarily affecting children and pregnant women in sub-Saharan Africa. In 1999, approximately 60% of global malaria deaths were concentrated among the poorest 20% of the global population[32]. In sub-Saharan Africa, 3.1% of all disability-adjusted life-years (DALYs) were lost to malaria in 2002[2]. Although preventable and treatable, the number of deaths due to malaria remains high. In 2015, there were an estimated 429,000 malaria deaths (range: 235,000–639,000) worldwide, and most (92%) of these deaths occurred in Africa [33].In Kenya, despite remarkable achievements in malaria prevention and control over the last 10 years, malaria remains a leading cause of morbidity and mortality[3]. In 2015, while the prevalence of microscopically-confirmed malaria was 8% amongst children less than 15 years (13% by malaria rapid diagnostic test [RDT]) nationally, it was 27% (43% by malaria RDT) in the lake-endemic region of western Kenya [4].

The relationship between malaria disease and poverty has often been described as a vicious cycle and whether malaria infection is a consequence of or a cause for low household socioeconomic status (SES) has been debated for decades [8]. In a systematic review of nine studies to establish the relationship between malaria and poverty, two studies found a significant relationship between poverty and malaria, four studies found no significant relationship and three studies demonstrated mixed results [7]. Malaria also imposes substantial costs to individuals, households, and governments. Globally in 2015, total funding for malaria control and elimination efforts was estimated at US$2.9 billion; governments in malaria-endemic countries provided 32% of the total funding, of which 65% or US$612 million was expenditure by national malaria control programmes for programme implementation and 35% or US$332 million was expenditure on health service delivery [33].

In high malaria-transmission settings in Kenya where the average annual household expenditure was less than US$800[34], households spent an average of US$10 (range: US$9–12) monthly and approximately US$120(range: US$108-144) annually on malaria treatment in 2010[35].

The microeconomic relationship between malaria burden and composite wealth indices is also mixed and contradictory [7]. A study among Tanzanian children, using principal component analysis (PCA) to rank households, established that malaria was associated with household SES when SES was the dependent variable, but an individual's SES was not associated with malaria risk when malaria was the dependent variable [8]. Another study in Tanzania, which investigated causality between malaria and SES, established that the higher the household wealth quintile the lower the prevalence of malaria in individuals in the household [10]. The lack of consistent findings may partly reflect the inherent difficulty in measuring SES and differences in the populations studied, methods used to measure malaria infection and malaria intensity in the study areas [7, 13, 14, 36].

Various methodologies for assessing SES employing broad quantitative and qualitative aspects of poverty have been recommended including PCA, Polychoric PCA, and multiple component analysis (MCA) [16-18, 20, 21, 37]. A study from rural western Kenya compared the three methods of ranking households into SES quintiles and established that although the methods produced similar results, MCA gave the highest percentage of the total variation for the household asset variables and thus the largest weights for the variables. The study concluded that MCA was a better model for generating asset weights than PCA or Polychoric PCA [22]. The study further conducted comparison between ordinary PCA and MCA and established that 93% of households were placed in the same quintile by both methods, 87% of

the households by ordinary PCA and Polychoric, and 91% by Polychoric and MCA and that ordinary PCA asset index was statistically significantly correlated with the index based on MCA ($r = 0.997$, $p<0.01$) [22]. The MCA model also allows both quantitative and qualitative variables, which is not possible with traditional PCA methods [22, 23, 38]. However, studies using MCA methods to investigate socioeconomic inequalities related to malaria indicators are lacking.

Multiple correspondence analysis descriptions

MCA can be used for both nominal, continuous and categorical data. It applies a correspondence analysis algorithm to an indicator matrix, where the rows represent individuals and columns are dummy variables representing categories of the variables in a geometric frame. Association between variables is uncovered by calculating the chi-square distance between individual categories of the variables and between individual observations. In the MCA approach, quantitative variables are recorded as bib taking value taking a 0 or 1. In contract, PCA uses orthogonal transformation to convert a set of observations correlated asset variables of linearly uncorrelated variables called principal components [22, 23, 38]

The main difference between MCA and PCA is that PCA decomposes relations between columns only (covariance matric) treating rows as ‘case’, while MCA decomposes both rows and columns of a matrix simultaneously, treating them symmetrically as cross-tabulations of ‘categories’. The MCA model considers the number of variables used and the number of observations in a dataset and hence its ability to get better factors weights than PCA [22, 23, 38].

Health inequality data, including malaria parasitaemia prevalence, use of malaria prevention and treatment interventions and expenditures on malaria medication, are often collected but not analyzed from an economic or equity perspective. Yet, such data and analysis are important for monitoring health inequalities and the impact of malaria control interventions at the microeconomic level. The aim of this study was to establish the relationship between household SES and inequalities in malaria-related health indicators including morbidity, use of insecticide-treated nets (ITNs), care-seeking, and expenditure on malaria medications in a malaria-endemic area of rural western Kenya.

Methods

Study site

A community-based cross-sectional survey was conducted in mid-2012, a year after a mass ITN distribution in Siaya County. The survey was conducted within the Kenya Medical Research Institute (KEMRI) and the Centers for Disease Control and Prevention (CDC) health and demographic surveillance system (HDSS) in Siaya County, western Kenya. The HDSS has been described in detail elsewhere [22, 39-41]. Briefly, the HDSS area covers a population of approximately 223,000 people residing in 393 villages in three sub-counties of Siaya County, spread over approximately 700 km^2 along the shores of Lake Victoria. The vast majority of the population earns their living through subsistence farming and fishing. Residents of the HDSS were visited in their homes every 4 months to record births, deaths, pregnancies, immigration, and out-migration. Health indicators in Siaya county, formerly part of Nyanza Province, are poor compared to the national averages [42, 43]. Nyanza Province had the highest rate of child mortality at 72 deaths per 1,000 live births in 2008–2009, and an estimated 60% of the population lived below the poverty line during the study period [26, 27].

Population, sampling strategy, and sample size

The sampling frame obtained from the HDSS included all households with children <5 years of age because many malaria interventions target this age group. Households were selected for participation by systematic random sampling, stratified by sub-county (i.e., Rarieda, Gem or Siaya). The sampling interval was calculated by dividing the total number of selected compounds by the target sample size. A random start number was selected from the ordered compound listing. Households were selected based on systematically adding the sampling interval to the random start number until the required sample size had been achieved. In total, 998 compounds comprising 1,063 households were sampled. A sub-sample of all household members were surveyed (5-14 years and 15+ years), except for children <5 years, who for ethical reasons were all included. If an individual of any age group (<5 years, 5-14 years and ≥15 years) was sampled in a household, then all children <5 in that household were also included in the survey.

Data collection

Study participants were interviewed face-to-face by trained field staff using a structured questionnaire, programmed into a personal digital assistant, to collect data on demographic factors, socioeconomic factors including asset ownership and utilities, ITN ownership and usage night before the survey, history of fever in the past 14 days, care-seeking behaviors and medication use in the past 14 days. A finger prick blood specimen was obtained from all individuals in the sampled households; haemoglobin was measured by HemoCue® (Ängelholm, Sweden) and the presence of malaria parasitaemia was evaluated using RDT (Carestart™ Malaria HRP-2/pLDH (Pf/PAN) Combo, Somerset, NJ, USA). Individuals with a positive malaria RDT were treated in accordance with the 2010 Kenya national malaria treatment guidelines for uncomplicated malaria while complicated cases were referred to

nearby health facilities for treatment [44]. Additionally, thick and thin blood smears were taken for screening, malaria species' identification and enumeration of parasite density.

Medication prices used to estimate expenditures were obtained from a separate survey in the same area, which assessed the availability and cost of antimalarial medications in September 2013 [45]. Medication prices were estimated using the local prices in Kenya shillings and converted to U.S. dollars using the October 2013 exchange rate of 85 Kenya shillings to US$1.00 [45]. Non-recommended medications for uncomplicated malaria included Amodiaquine, chloroquine, Sulphadoxine-Pyremethamine, and quinine (not recommended for use by non-pregnant women). In Kenya, quinine is only recommended as a first-line malaria medication for women in the first trimester of pregnancy [28]. The variables used to generate household SES index included the occupation of household head (doing business, commercial ,farming, housewife, salaried worker, Skilled labour, unskilled labour and subsistence farming) primary source of drinking water, type of cooking fuel, ownership of household assets (e.g., lantern lamp, radio, television, bicycle) and ownership of livestock (e.g., cattle, chicken, pigs, donkey) [22].

Data management and analysis

Data were downloaded into a Microsoft Access (Version 2010, Microsoft, and Seattle, WA, USA) database for management. Laboratory analyses of microscopy results were recorded in an Excel (Version 2010, Microsoft, Seattle, WA, USA) spreadsheet. All the datasets underwent validation and consistency checks to identify and resolve errors before they were merged using the HDSS unique identifiers or sample codes as appropriate.

Using the MCA model, households were characterized into five socio-economic quintiles with the first quintile as the poorest and the fifth quintile as the least-poor based. Household SES index included the occupation of household head (which included; doing business,

commercial, farming, housewife, salaried worker, skilled labour , unskilled labour and subsistence farming) primary source of drinking water, type of cooking fuel, ownership of household assets (e.g., lantern lamp, radio, television, bicycle) and ownership of livestock (e.g., cattle, chicken, pigs, donkey) [22, 23]. A generalized linear model, customized with a log-link function, was used to estimate and compare adjusted prevalence ratios (aPR). Dependent variables included malaria infection, care-seeking, medication, and ITN use, while SES, study areas (i.e., sub-counties), sex and age groups (<5, 5–14 and ≥15 years) were included as independent variables. As described in detail elsewhere, SES quintiles were aggregated into dichotomous groups [9]. A binary variable was created with the first three SES quintiles (i.e., poorest, second and third poorest) grouped as the 'poorest' category and the fourth and fifth quintiles grouped into the 'less-poor' category, with the latter as the reference category in the models. Proportions and 95% confidence intervals were generated, and p-values <0.05 were considered statistically significant. Proportions were compared using Fisher's exact test, and the costs of medications compared using a generalized linear model. Medians and interquartile ranges were generated if data were not normally distributed; medication expenditures were compared using Wilcoxon rank-sum test because price data were not normally distributed.

Ethics, consent, and permissions

The HDSS protocol and consent procedures, including surveillance, were approved by KEMRI (SSC#1801) and CDC (#3308) institutional review boards (IRB) annually. The malaria-specific survey, including the collection of blood samples, received approval from the KEMRI scientific steering committee (#2031) and CDC IRB (#6012). Written consent was obtained in the local language prior to the administration of the questionnaires.

Results

Characteristics of study participants

A total of 1,063 households and 2,719 individuals were surveyed in July 2012, approximately 1 year after a mass ITN distribution in the study area. Participants ages were categorized into <5 years (56.8%; n=1,545), 5–14 (17.4%; n=437), and ≥15 years (25.8%; n=701) (Table 1).

Table 1 Socio-demographic characteristics of the study population in Siaya County, Kenya, 2012

	Categories	n[a]	Per cent
Age groups	<5 years	1,545	56.8
	5–14 years	437	17.4
	≥15 years	701	25.8
Sex	Female	1,494	54.9
	Male	1,225	45.1
Wealth quintiles (SES)			
	1 (Poorest)	458	20.6
	2	434	19.5
	3	459	20.6
	4	436	19.6
	5 (Least poor)	441	19.8
Sub-counties			
	Rarieda	834	30.7
	Gem	872	32.0
	Siaya	1,013	37.3

[a] N=2,719 total population surveyed.

Descriptive epidemiology

The prevalence of malaria parasitaemia by microscopy was 34.1% overall, 34.4% among children <5 years, 54.8% in 5–14 year olds and 19.3% in persons aged ≥15 years (Table 2). Fever in the 14 days prior to the survey was self-reported by 53.9% (n=1,463) of the survey population; this was highest (60.6%) among children aged <5 years (Table 2). Of those reporting fever, 70.4% (n=1,032) had sought care. Of those who sought care, 51.8% sought

care from health facilities, 30.4% from pharmacies, and 15.4% from shops. Use of any medication among those who reported having fever was 77.3% overall, with the highest proportion among young children (81.9%), and lowest (65.2%) among persons aged ≥15 years. Overall, 64.9% of the population reported that they used ITN the night prior to the survey (Table 2).

Table 2 Descriptive epidemiology of malaria-related indicators in Siaya County, Kenya, 2012

	<5 years n (%)	**5–14 years n (%)**	**≥15 years n (%)**	**Total n (%)**
Fever in prior 2 weeks[a]	935 (60.6)	209 (44.2)	319 (45.5)	1,463 (53.9)
Malaria parasitaemia	532 (34.4)	259 (54.8)	135 (19.3)	926 (34.1)
Care seeking	708 (75.6)	134 (64.1)	190 (59.6)	1,032 (70.4)
Medication usage[b]	766 (81.9)	157 (75.1)	208 (65.2)	1,131 (77.3)
ITN use	1,033 (66.9)	251 (53.1)	481 (68.6)	1,765 (64.9)

[a] Self-reported fever.

[b]Of the 1,463 persons who reported that they had a history of fever, 1,131 took medication.

ITN insecticide-treated net

Multivariable analysis

Overall, 37.6% of persons from the poorest households had malaria infection compared to 29.2% of persons from less-poor households (adjusted prevalence ratio [aPR] =1.23; 95% CI=1.08-1.41, p=0.002), when adjusting for age, geographic area, gender and ITN use (Table 3).

In multivariate analysis of care-seeking (n=1,182), children <5 years were significantly more

Table 3 Multivariate analysis of socioeconomic status and association with malaria infection in Siaya, Kenya, 2012.

Characteristic	n	(N)	Malaria parasitaemia percent	Adjusted prevalence ratio	95% confidence interval		p-value
Overall	926	2,228	34.1				
SES							
Poorest[a]	401	1,070	37.5	1.23	1.08	1.41	0.002
Less poor[b]	338	1,158	29.2	Ref			
Age group							
<5 years	395	1,177	33.6	1.76	1.46	2.14	<0.001
5–14 years	227	427	53.2	2.74	2.27	3.31	<0.001
≥15 years	117	624	18.8	Ref			
Sub-county							
Gem	278	685	40.6	1.38	1.14	1.65	0.001
Siaya	268	842	31.8	1.12	0.93	1.35	0.241
Rarieda	193	701	27.5	Ref			
ITN usage							
Yes	429	1,449	29.6	0.84	0.73	0.96	0.010
No	310	779	39.8	Ref			

[a] 'Poorest' was constituted by collapsing the poorest three quintiles.
[b] 'Less-poor' was constituted by collapsing the wealthiest two quintiles.
ITN insecticide-treated net*; SES* socioeconomic status

likely to seek care (aPR=1.27; 95% CI=1.14-1.41, p<0.001) compared to adults ≥15 years. There were no significant differences in care-seeking by SES, gender or geographic area (Table 4). Among persons who reported fever in the prior 14 days, the prevalence of medication use was significantly higher in children <5 years (aPR=1.27; 95% CI=1.15-1.40, p<0.001) compared to adults ≥15 years. The poorest persons reported less medication use, but it was not significantly different compared to the less-poor (aPR 0.94, 95% CI=0.88-1.0; p=0.05) (Table 4).

Table 4 Association of socioeconomic status with care-seeking and medication usage in Siaya County, Kenya, 2012

	Care seeking[a] (n=1,182)							Medication use[a] (n=1,180)						
	n	N	%	aPR	95% CI		p-value	n	N	%	aPR	95% CI		p-value
SES														
Poorest	411	598	68.7	0.95	0.87	1.04	0.229	447	598	74.8	0.94	0.87	1.00	0.087
Less-poor	414	584	70.9	Ref				457	582	78.5	Ref			
Age group														
<5 years	535	716	74.7	1.27	1.14	1.40	<0.001	582	714	81.5	1.27	1.15	1.40	<0.001
5–14 years	124	188	66.0	1.11	0.97	1.29	0.120	142	188	75.5	1.17	1.04	1.32	0.008
≥15 years	166	278	59.7	Ref				180	278	64.8	Ref			
Sub-county														
Gem	301	407	74.0	1.05	0.94	1.17	0.391	326	406	80.3	1.10	1.01	1.20	0.037
Siaya	301	459	66.8	0.91	0.82	1.02	0.110	347	458	75.8	1.02	0.94	1.10	0.657
Rarieda	223	316	70.6	Ref				231	216	73.1	Ref			
Sex														
Female	460	656	70.1	1.03	0.96	1.11	0.350	500	655	76.3	1.02	0.95	1.08	0.617
Male	365	526	69.4	Ref				404	525	77.0	Ref			

[a]Among the surveyed population who self-reported fever in the prior 2 weeks.
SES socioeconomic status; *aPR* adjusted prevalence ratio; *CI* confidence interval

Ownership of at least one ITN per household overall was very high at 93.9%; ITN ownership was not different between the poorest and less-poor households (93.5% versus 94.3, p=0.72). Use of ITNs was also common; overall, 65.0% of persons reported using nets the night before the survey. In multivariate analysis of the association between SES and ITN usage, 63.2% of persons in the poorest group used ITNs compared with 66.8% amongst the less-poor, but the difference was not statistically significant (aPR=0.96; 95% CI=0.90–1.02, p=0.18). Significant differences were observed in reported ITN use by sub-county, with a significantly higher proportion of persons from Rarieda (80.5%) using ITNs compared to Gem (56.5%) or Siaya (59.1%) (p<0.001 for both) (Table 5).

Of the 1,180 individuals with a reported history of fever in the 14 days prior to the survey who had malaria infection and had SES data available, 34.5% (n=505) took the recommended

Table 5 Association between household socioeconomic status and insecticide-treated net use in Siaya County, Kenya, 2012

	n	N	ITN use percent	aPR	95% confidence interval		p-value
SES							
Poorest	676	1,070	63.2	0.96	0.87	1.05	0.397
Less-poor	773	1,158	66.8	Ref			
Age group							
<5 years	790	1,117	67.1	1.00	0.94	1.07	0.976
5-14 years	231	427	54.1	0.79	0.71	0.89	<0.001
≥15 years	428	624	68.6	Ref			
Sub-county							
Gem	387	685	56.5	0.70	0.63	0.79	<0.001
Siaya	498	842	59.1	0.73	0.65	0.81	<0.001
Rarieda	564	701	80.5	Ref			
Sex							
Female	802	1,225	65.5	1.00	0.95	1.07	0.811
Male	647	1,003	64.5	Ref			

SES socioeconomic status; *ITN* insecticide-treated net; *aPR* adjusted prevalence ratio

first-line malaria medication, artemether-lumefantrine (AL) (Table 6). Among those who took AL, 30.9% were from the poorest households compared to 36.2% from less-poor households (p=0.43). Amongst individuals who used any malaria medicines, the use of non-recommended medicines was 4.9% in the poorest households compared to 3.5% in less-poor households (p=0.32). The expenditure on any type of malaria medications in the 14 days prior to the survey was not statistically different between the poorest and less-poor household members (mean US$0.35, standard deviation [19] US$0.52 *versus* mean US$0.40 [US$0.55]; p=0.076, respectively). However, persons in the poorest households spent significantly more purchasing non-recommended malaria medicines compared to persons from less-poor households (mean=US$1.36 [US$0.91] *versus* mean US$0.98 [US$0.80]; p=0.039).

Table 6 Use of and expenditure on malaria medication in the surveyed population who reported fever in prior 2 weeks in Siaya County, Kenya, 2012

Utilization of medication (N=1,180)	All n (%)	Poorest households n (%)	Less-poor households n (%)	p-value[c]
Artemether-lumefantrine	396 (33.6)	185 (30.9)	211 (36.2)	0.434
Sulphadoxine-Pyremethamine	8 (0.7)	6 (1.0)	2 (0.3)	0.119
Amodiaquine	11 (0.9)	7 (1.2)	4 (0.7)	0.284
Quinine	14 (1.2)	6 (1.0)	8 (1.4)	0.721
Chloroquine	5 (0.4)	3 (0.3)	2 (0.3)	0.557
Overall (any malaria medicine)	429 (36.4)	205 (34.3)	224 (38.4)	0.133
Non-recommended medicine [a]	38 (4.2)	22 (4.9)	16 (3.5)	0.332
	Mean (SD) in USD	Mean (SD) in USD	Mean (SD) in USD	
Expenditure on all malaria medications per person	0.38 (0.50)	0.35 (0.52)	0. 40 (0.55)	0.076
	Mean (SD) Median (IQR) in USD	Mean (SD) Median (IQR) in USD	Mean (SD) Median (IQR) in USD	p-value[d]
Expenditure on all medications per person among only those who paid for drugs (n=424) [b]	1.04 (0.32) 1.01 (1.01-1.01)	1.02 (0.32) 1.01 (1.01-1.01)	1.05 (0.33) 1.01 (1.01-1.01)	0.345 0.926
Expenditure on non-recommended malaria medicines per person (n=38)	1.14 (0.86) 0.62 (0.42-2.24)	1.36 (0.91) 1.43 (0.45-2.24)	0.98 (0.80) 0.62 (0.42-2.24)	0.039 0.018

[a]Non-recommended medicine for malaria treatment included Sulphadoxine-Pyremethamine, Amodiaquine, quinine used by non-pregnant women and chloroquine.
[b] Mean prices of adult formulation were artemether-lumefantrine=USD 1.01; Sulphadoxine-Pyremethamine= USD 0.62; Amodiaquine=USD 0.42; quinine=USD 2.24; chloroquine=USD 0.40.
[c] Fisher's exact test
[d] Wilcoxon rank-sum test to compare medians and t-test to compare means; excludes children who received medicine for free from public health facilities.
USD United States dollars; *SD* standard deviation; *IQR* interquartile range

Discussion

The study evaluated the relationship between the burden of malaria infection and household SES within a rural of western Kenya. This is the first published paper to assess the relationship between malaria indicators and SES using the MCA model to generate household wealth quintiles based on continuous and categorical variables. The findings show that individuals in the poorest households had a higher burden of malaria infection compared to those from less-poor households. Persons from the poorest households also spent significantly more money to purchase medications that are not recommended for malaria

treatment, which are likely to have less clinical efficacy and lead to unnecessary risk of adverse effects and complications of taking inappropriate medications. No significant associations between care-seeking and SES or medication use and SES were observed, and the study found high access to and use of ITNs, irrespective of household SES. The prevalence of malaria infection was significantly higher in Gem sub-county compared to Rarieda sub-county. This could be due to high vegetation coverage and the presence of River Yala which cuts across the sub-county. These findings contribute to the scarce published literature on malaria and socioeconomic inequalities. Although there is extensive literature on health inequalities and health outcomes more generally, no previous study has evaluated the relationships between malaria indicators and SES using MCA to analyse microeconomic data.

The study results are similar to findings by Somi and colleagues who reported a large variation in parasitaemia rates between socioeconomic groups, where individuals with the lowest SES were significantly more likely to have malaria parasites than less-poor individuals [8]. Findings from this analysis, however, contrast with those of de Castro and Fisher who found that SES had no association with malaria infection [8]. The de Castro study, however, was limited to children aged 6–59 months whereas a study by Somi *et al*, in which the analysis was not restricted to a specific age group [5, 8]. Both cross-sectional studies used household assets and proxies to measure SES using the PCA model [8, 10, 20]. This study addressed some of the limitations of these previous studies by using malaria confirmed by microscopy, as the main outcome of interest controlling for age group, and using generalized linear models instead of traditional concentration indices and Lorenz curves to estimate the risk of health indicators as a measure of inequity as recommended by World Bank and World Health Organization [13, 17, 19].

Previous studies on health outcomes, including malaria, and SES have traditionally used the

PCA model to generate a household SES index. The PCA model relies heavily on dichotomous socioeconomic variables to achieve a composite household SES index [16, 17, 20]. The benefits of using the MCA model are the inclusion of both continuous and categorical variables and larger weights for assets, which increases statistical power [23, 38]. Using PCA models to generate household SES indices was anticipated to facilitate a more robust evidence base for assessing the associations between health outcomes and poverty, especially at the household and community levels [16, 17, 20, 38]. However, recent literature has demonstrated the weaknesses of PCA models including the inability to accommodate continuous variables such as number of assets owned and generation of low asset weights, which makes it difficult to determine clear wealth quintile cut-offs particularly in settings where most households have the same assets and therefore the same or very similar SES scores [23, 38]. Based on evidence already published elsewhere [22] that MCA is a better model than PCA. The study has applied MCA to establish the socioeconomic related inequalities in malaria outcomes.

The study determined that nearly two-thirds of persons had a fever in the past 2 weeks, and the majority (81%) of them took the medication with an equal proportion of individuals among the poorest and less-poor households. Nearly half of those who sought care went to health facilities, but the other half sought care from pharmacies and informal drug shops. Research from Kenya shows that people who seek care from health facilities are more likely to get tested for malaria and receive the first-line recommended medications for treatment compared to those who go to pharmacies and informal drug shops [45-48]. There were no differences observed in the expenditure on all malaria medications per person between SES groups, and less than 5% of persons purchased non-recommended malaria medicines overall, which is a positive finding. However, the poorest households spent more to purchase potentially ineffective medicines compared to less-poor households; ineffective treatments

potentially prolong parasitaemia or fail to clear parasitaemia, which can lead to recrudescence or severe malaria and increased expenditures on additional treatments or hospitalizations. The findings of this study suggest that there is a need to encourage healthcare seeking in the formal health sector, especially among the poorest households.

No significant differences in ITN ownership or usage between the poorest and less-poor households were observed in this rural western Kenya community in 2012, which was less than a year after the first universal coverage ITN distribution in Siaya County. Ownership of at least one ITN per household overall reached near full coverage (94%) and was well above the national target of 80% [31]. Subsequent national household surveys have consistently demonstrated significant differences in ITN ownership, access and use between the lowest and highest wealth quintiles [4, 26]. Because this cross-sectional study was conducted in a relatively small geographic area (i.e., three sub-counties) of rural Siaya County, there is probably much less socioeconomic variation compared to the national population and more uniformity in programmatic distribution within a single county.

A key principle of the Kenya Health Policy 2014–2030 is to achieve equity in the distribution of health services and interventions by 2030 [49]. Findings from this study illustrate existing socioeconomic inequalities in the burden of malaria infection and expenditures on non-recommended malaria medication in this rural western Kenya setting. However, the lack of differences between SES groups in care-seeking, overall medication use, and expenditures, and ITN ownership and use demonstrate the progress toward achieving equitable access to health services and distribution of free malaria commodities, including first-line medicines for treatment and ITNs, in western Kenya. Analysis of malaria indicators in relation to household SES using MCA methodology can be used to monitor progress towards achieving health equity goals in line with the Kenya Health Policy 2014–2030 and global sustainable development goals [50].

The study has a number of limitations. Findings were based on one cross-sectional survey preventing any evaluation of cause-and-effect of SES on malaria indicators over time. A longitudinal or trend analysis of repeated surveys would have provided an opportunity to study changes in SES and monitor the gap in malaria indicators between the poorest and less-poor households over time as malaria control interventions, including free first-line malaria treatment at health facilities and ITNs, were implemented. The other limitation was the inclusion of only households with children <5 years of age based on protocol-specific objectives. While this study advances the knowledge related to the association between malaria, control interventions, and microeconomics, under these limitations, it reduces generalizability. Additionally, expenditures were calculated per person rather than per household because not all persons in the household were interviewed or tested for malaria. Although all children <5 years of age were surveyed, only a small proportion of persons ≥5 years of age were included in the survey sample. Finally, the use of assets as proxies for SES also has limitations including, most importantly, that the monetary value of assets was not collected, and hence the net worth of the household might be over- or under-estimated. Asset-based proxies, however, have been shown as a reasonable way to measure wealth status in the absence of household income or expenditure data, which is not commonly available in informal economies [19]. The study did not compare the current results with any other results which could have been analyzed using other methods besides MCA because there is already evidence that MCA is a better model compared to PCA. Such comparison would not be statistically different in assigning households into the quintiles[22]

Conclusion

In rural western Kenya, individuals in the poorest households had a higher burden of malaria prevalence compared to those in the less-poor households. However, no significant

differences were observed in care-seeking, overall medication use and expenditure, or ITN ownership and use between households based on SES. This study demonstrates that the MCA model can be a useful tool for assessing malaria-related health inequalities at the microeconomic level and to monitor progress towards achieving equitable access to health services and distribution of malaria interventions in line with national and global health and development goals.

Declarations

Ethics approval and consent to participate

The HDSS protocol and consent procedures were approved by the KEMRI scientific steering committee (SSC) (#1801) and CDC institutional review board (IRB) (#3308) annually. The malaria-specific survey, including the collection of blood samples, received approval from the KEMRI SSC (#2031) and CDC IRB (#6012).

Abbreviations

AL: artemether-lumefantrine; aPR: adjusted prevalence ratio; CDC: Centers for Disease Control and Prevention; DALY: disability-adjusted life year; HDSS: health and demographic surveillance system; IRB: institutional review board; ITN: insecticide-treated net; KEMRI: Kenya Medical Research Institute; MCA: multiple correspondence analysis; PCA: principal correspondence analysis; RDT: rapid diagnostic test; SES: socioeconomic status; SSC: scientific steering committee.

Conflicts of interest

The authors declare that they have no competing interests.

Authors' contributions

MD, VW, SK conceived and designed the study. MD, VW, SK coordinated and performed the study. VW analyzed the data. VW, MD, SK, AMB, AS, SPK, FtK, PPH and LN drafted the manuscript. All authors read and approved the final manuscript.

Disclaimer

The findings and conclusions presented in this manuscript are those of the authors and do not necessarily reflect the official position of KEMRI, Liverpool School of Tropical Medicine, U.S. President's Malaria Initiative, U.S. Agency for International Development or CDC. The corresponding author had full access to the study data and had final responsibility for the decision to submit for publication.

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Availability of data

Requests for the data may be made to the KEMRI data manager, Vincent Were, vwere@kemricdc.org.

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Chapter 3: Trends in socioeconomic-related health inequality in rural western Kenya: data from repeated household malaria surveys 2006–2013

Trends in socioeconomic-related health inequality in rural western Kenya: data from repeated household malaria cross-sectional surveys from 2006–2013

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Abstract

Objective: The objective of this analysis was to examine socioeconomic inequalities in malaria indicators from 2006 to 2013 during a period of intensified malaria control interventions in Siaya County, western Kenya.

Methods: Data were analyzed from eight independent annual cross-sectional surveys and participants were 19, 315 individuals in 7,253 households. The study setting was a health and demographic surveillance area of western Kenya. Data collected included demographic factors, household assets, and characteristics, a recent history of fever. The primary outcome was malaria parasitaemia by microscopy and secondary outcomes were medication usage, insecticide-treated bed net (ITN) use, and care-seeking behaviour. A composite socioeconomic status (SES) score was created using multiple correspondence analysis of household assets. Households were classified into wealth quintiles and dichotomized into poorest households (poorest 60%) and less poor households (richest 40%). Adjusted prevalence ratios (aPR) were calculated using a multivariate generalized linear model, which accounted for household clustering for each year and for the pooled data.

Results: Overall, malaria infection prevalence was 36.5%and higher among poorest persons compared to those in less poor (39.9% versus 33.5%, aPR=1.17; 95%CI=1.11-1.23). Care-seeking (61.1% versus 62.5%, aPR=0.99; 95%CI=0.95-1.03) and use of any medication (73.2% versus 76.2%, aPR=0.95; 95% CI=0.92-1.00) was similar among the poor and less poor. However, the poorest were less likely to use Artemether-Lumefantrine or quinine for pregnant women (18.8% versus 22.1%, aPR=0.81, 95%CI=0.72-0.91). Use of ITNs was

lower among the poor compared to less poor (54.8% versus 57.9%; aPR=0.95; 95%CI=0.91-0.99).

Conclusions: Despite similar ITN use by SES, malaria parasitaemia prevalence was higher among the poorest individuals, which might be due in part to a lower likelihood of treatment with an effective antimalarial. Although equity was achieved in ITN use, a key malaria control intervention, the burden of malaria remains greater among the poor in rural western Kenya suggesting additional strategies are necessary to achieve equitable population health outcomes.

Keywords: Socioeconomic, equity, inequalities, malaria, medication, Kenya

Article Summary

Strengths and limitations of the study

- Eight years of repeated annual cross-sectional pooled data provided more power to assess socioeconomic inequalities and equity
- Equity assessment has used multivariate regression models accounting for clustering
- Longitudinal monitoring provided an opportunity to monitor the effectiveness of policy intervention over time
- The main limitations include; Use of cross-sectional surveys prevented any evaluation of cause-and-effect of SES on malaria indicators over time and
- Only households with children <5 years and a portion of persons ≥5 years were included in the surveys based on protocol-specific objectives due to logistics reasons.

The transition from chapter 2 to chapter 3

Results presented in chapter 2 are from a single cross-sectional study conducted in mid-2012. However, the results presented in chapter 3 is a pooled analyses of repeated cross-sectional surveys from 2006 to 2013.

Background

Malaria is a global health problem with 3.2 billion people at risk of malaria infection.[1] The World Health Organization (WHO) estimated that between 2010- 2016, 216 million (95% CI=196-263 million) malaria cases occurred globally and incidence rates fell by 18% globally and by 20% in Africa, while malaria mortality rates fell by 25% globally and by 66% in the African region[1]. Sub-Saharan Africa is disproportionally affected, and despite falling mortality, over 90% of the estimated 445,000 malaria deaths worldwide occurred in Africa in 2016.[33] In Kenya, malaria remains a major cause of morbidity and mortality with more than 70 per cent of the population at risk[4]. In 2015, the prevalence of microscopically-

confirmed malaria among children <15 years of age was eight per cent nationally and 27% in the lake-endemic region of western Kenya[4].

Government of Kenya (GoK) and international partners spent approximated USD 810million on malaria preventions and treatment programmes[51] which included distribution of long-lasting insecticide-treated bed nets (ITNs), indoor residual spraying (IRS) in selected areas, intermittent preventive treatment during pregnancy (IPTp) in malaria-endemic areas, and prompt and effective malaria case management [4, 52, 53]. Since 2014, there have been key policy changes in Kenya. First-line treatment for malaria changed to artemisinin-based combination therapies (ACT) [54-56]. By 2006, Artemether-Lumefantrine (AL), the first-line ACT, started becoming available in the public sector at no cost to patients, and the first free mass net distribution campaign targeting children <5 years and pregnant women were conducted in malaria-endemic and epidemic-prone areas [40, 56, 57]. The second free mass net distribution campaign, with a goal of universal coverage (i.e., one net per two people per household), was conducted in a phased approach from 2011 to 2012, with households in western Kenya receiving LLINs in 2011[58]. Equitable distribution of health services or interventions is a principle advocated for in most national policy documents to achieve universal health coverage [24]. A recent paper outlined the five Sustainable Development Goals (SDGs) set of targets that relate to the reduction of health inequalities nationally and worldwide [26]. The study listed the SDG targets as poverty reduction, health, and wellbeing for all, equitable education, gender equality, and reduction of inequalities within and between countries[26].

However, despite a national policy of free antimalarial medications for children <5 years in the public sector in Kenya, access, and utilization of health services has been shown to vary substantially across socioeconomic groups, which undermines achieving health equity[59].

A key pillar of the Kenya Health Policy 2014–2030 is to improve health indicators through equitable distribution of health services and interventions in line with the Sustainable Development Goal (SDG) to achieve universal access to safe, effective, quality and affordable health care services for all [15].

Health inequality and equity data on malaria indicators are often collected but not analyzed from an economic or equity perspective. Yet, such data and analyses are important for monitoring health inequalities and assessing the impact of malaria control interventions at the microeconomic level[60]. However, analysis of longitudinal data and multiple repeated survey data has not been done especially in malaria-endemic areas to assess the potential effect of the intensified control program of equity at the household over time. The specific objectives of this analysis were to evaluate the existence of socioeconomic inequalities and vertical equity patterns in relation to malaria indices using data from annual malaria surveys conducted in a malaria-endemic region of western Kenya between 2006–2013.

Methods

Study design and site

Independent annual community-based, cross-sectional surveys were conducted between 2006 and 2013, between the months of April to July within the Kenya Medical Research Institute (KEMRI) and Centers for Disease Control and Prevention (CDC) Health and Demographic Surveillance System (HDSS) in Siaya County in western Kenya. The HDSS has been described in detail elsewhere.[39, 41]Briefly, HDSS covers a population of approximately 223,000 people residing in 393 villages located in three of six sub-counties of Siaya County, an area of approximately 700 km^2 along the shores of Lake Victoria. The vast majority of the population are subsistence farmers and fishermen. Health indicators in Siaya County, part of the former Nyanza Province, are poor compared to national standards[42, 43]. Nyanza

Province had the highest rates of child mortality and an estimated 60% of the population lived below the poverty level during the survey period.[61]

Population and sampling strategies

For each year from 2006-2013, different sampling strategies were selected for logistical purposes. A systematic sampling technique was used from a sample frame of eligible households and individuals enrolled in HDSS except in 2009 when a cluster sampling was used. Households were selected for participation if they had children <5years because of many malaria control interventions that targeted this age group. Surveys were conducted in Rarieda, Gem and Alego-Usonga sub-counties in Siaya County except in 2006 when Alego-Usonga sub-county was not included. The sample size for each year is shown in Table 1.

Data collection

During the surveys, study participants were interviewed by trained staff using personal digital assistants (PDA) and tablets. Data collected included demographic factors, socioeconomic factors including asset ownership, characteristics and utilities, care-seeking behaviours, history of fever in the 2 weeks before the survey, ITN use and antimalarial medication use both recommended and non-recommended by polices.

During each survey, a blood specimen was obtained from all individuals providing consent in the sampled households using a finger prick and used for measurement of haemoglobin (HemoCue®; Ängelholm, Sweden) and to measure malaria parasitaemia by rapid diagnostic test(RDT) (Carestart™ Malaria HRP-2/pLDH (Pf/PAN) Combo, Somerset, NJ, USA). Individuals with a positive malaria RDT were treated in accordance with the Kenya national malaria treatment guidelines[44, 55, 57]. Thick and thin blood smears were obtained for malaria species' identification and parasite density.

Data management and analysis

Data coding, recoding, merging and analysis were conducted in Stata 14 (StataCorp, College Station, TX). A generalized linear model (GLM), using a Poisson distribution with a log-link function, was used to estimate adjusted prevalence ratios (aPR) accounting for clustering at the household level in multivariate analysis for pooled data which addresses selection bias. Study outcomes included malaria parasitaemia infection, care-seeking, medication, and ITN use. The independent variables were SES, study areas (sub-counties), sex and age groups (<5, 5–14 and ≥15 years. SES indices were generated using MCA using the following variables; Occupation of household head, the primary source of drinking water, and type of cooking fuel, ownership of household assets and ownership of livestock. The households were categorized into five socioeconomic quintiles and then classified into two groups for ease of comparisons. The first three poor quintiles were classified as the 'poorest' and the fourth and fifth quintiles classified as the 'less-poor' [22, 23, 62].

Results

Characteristics of study participants

A total of 19,315 individuals in 7,253 households were surveyed between 2006 and 2013.Overall, 33.9% were children aged <5 years, 26.6% were children aged 5-14 years and the remaining 39.5% were 15 years old adults. Sample size in 2006 to 2013 were (2006 n=1,113; 2007 n =1,270; 2008 n=1,830; 2009 n=2,508; 2010 n=5,334; 2011 n=2,129; 2012 n=2,719; 2013 n=2,412 and the mean annual sample was 2414 (Table 1).

Descriptive epidemiology

The prevalence of parasitaemia microscopy was 36.5% overall with substantial variation by age group (38.4% in children <5 years; 56.9% in children 5–14 years; 20.9% for adults ≥15

years). The prevalence of malaria parasitaemia was relatively stable between 2006 (38.3%) and 2011 (39.8 %) but reduced from 36.3% in 2012 to 34.5% in 2013. The proportion of individuals who received the first-line antimalarial medication, AL, in the two weeks prior to the survey increased from 0% in 2006to 44.0 %in 2013(Table 1).

Table 1 Socio-demographic characteristics of study populations in Siaya County, Kenya, 2006-2013

Year	2006	2007	2008	2009	2010	2011	2012	2013	Total
Total [a]	1,113	1,270	1,830	2,508	5,334	2,129	2,719	2,412	19,315
Age in years Mean (SD)[b]	18.7 (20.1)	16.2 (18.2)	22.0 (31.4)	20.4 (20.8)	18.5 (19.2)	16.7 (18.9)	13.5 (17.3)	13.9 (17.6)	18.2 (21.3)
Percent	%	%	%	%	%	%	%	%	%
Malaria infection (Overall)	38.3	29.6	27.5	39.0	39.7	39.2	34.1	34.5	36.5
<5 years	40.6	35.0	32.9	43.6	42.6	42.4	35.5	34.9	38.4
5–14 years	62.7	50.8	47.4	60.7	60.2	55.2	60.3	50.8	56.9
≥15 years	21.9	15.7	14.9	23.3	21.6	26.2	21.2	22.2	20.9
Fever in last 2 weeks	33.8	50.6	39.3	46.3	50.9	50.8	53.9	51.9	49.3
Sought care	61.0	50.0	68.8	40.6	66.9	70.6	70.4	69.6	47.6
Medications for fever	88.7	76.8	75.3	33.6	42.3	46.9	46.3	43.5	46.8
AL/Coartem [c]	0.0	4.7	6.0	9.0	14.7	21.4	25.3	44.0	18.3
Chloroquine	2.1	1.3	2.1	2.9	0.6	0.2	0.4	0	0.93
Amodiaquine	3.4	8.1	7.7	5.8	3.4	2.2	1.2	0.8	3.4
Fansidar/SP [d]	5.6	9.8	3.2	11.8	-	0	0	0	2.5
Panadol	58.4	54.5	41.1	42.9	48.6	58.2	34.4	28.7	46.0
Quinine	2.6	1.6	1.8	5.4	3.6	1.9	0.82	0.75	2.5
Septrin	-	-	-	1.9	5.4	7.7	6.0	6.1	3.4
ITN use	41.4	25.5	37.1	37.6	56.5	62.2	65.0	77.4	55.5
Wealth quintiles (SES) [e]									
Poorest 1	20.6	20.1	21.1	20.2	20.3	20.3	20.3	20.6	20.4
2	20.0	21.1	19.2	19.9	19.8	19.7	19.7	19.5	19.9
3	20.2	19.0	19.7	19.9	20.4	19.9	19.9	20.6	20.0
4	19.5	20.1	20.0	20.0	19.6	20.8	20.8	19.6	20.1
Least Poor 5	19.6	19.8	19.9	20.0	20.0	19.1	19.1	19.8	19.7

[a] <5 year: n=6,523 (33.9%); 5-14 years: n=5,116 (26.6%); ≥15 years: n=7,584 (39.5%); missing age: n=92

[b] SD=standard deviation [c] AL=artemether-lumefantrine [d] SP=Sulphadoxine-Pyremethamine [e] SES=socioeconomic status

Association of malaria infection, care-seeking, medication use, and ITN use with socioeconomic status

The prevalence of malaria infection was significantly higher among poor individuals compared to less-poor overall (39.9% versus 33.5%; aPR=1.17; 95%CI=1.11-1.23). The prevalence of malaria infection was also significantly higher in poor individuals in each age group (children <5years: aPR=1.20[95%CI=1.11-1.31]; children 5-14 years: aPR=1.13[95%CI=1.06-1.21]); adults≥15years: aPR=1.18[95%CI=1.05-1.33]). There was no clear trend in malaria prevalence by SES either overall or stratified by age group over time for the pooled analysis (Figure 1 and Table 2).

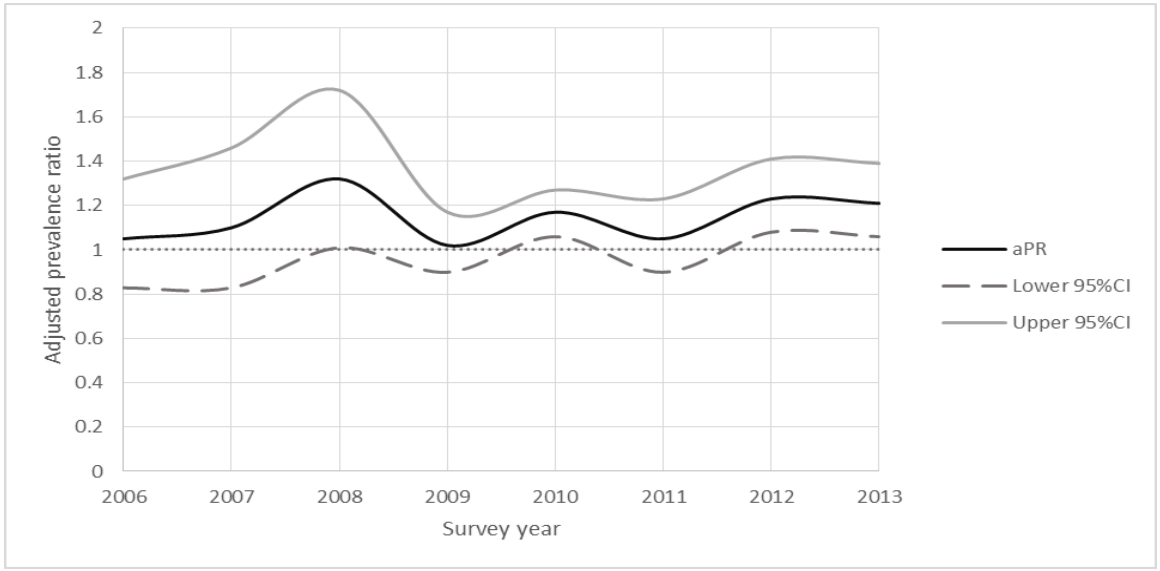

Figure 1. Patterns of adjusted prevalence ratios for malaria infections in western Kenya: 2006-2013

aPR =adjusted prevalence ratio for the poorest compared to the less poor; CI =confidence interval; aPR=1 is the reference category for less poor

Table 2 Prevalence of malaria infection by household socioeconomic status and age group in Siaya County, western Kenya from 2006 to 2013

	Year	2006	2007	2008	2009	2010	2011	2012	2013	Total
Overall	N	690	707	677	1629	2681	991	2228	1778	11383
Poorest	%	183/435(42.1)	103/353(29.3)	106/361(29.4)	350/870(40.2)	619/1363(45.4)	240/536(44.8)	401/1070(37.5)	319/825(38.7)	2321/5813(39.9)
Less Poor	%	90/255(35.3)	99/354(28.0)	72/316(22.8)	286/761(37.6)	498/1318(37.8)	183/455(40.2)	338/1158(29.2)	300/953(31.5)	1866/5570(33.5)
	aPR[ł]	1.05	1.1	1.32	1.02	1.17	1.05	1.23	1.21	1.17
	(95%CI)	(0.83-1.32)	(0.83-1.46)	(1.01-1.72)	(0.90-1.17)	(1.06-1.29)	(0.90-1.23)	(1.08-1.41)	(1.06-1.39)	(1.11-1.23)
<5 years	N	169	162	127	393	695	407	1177	801	3931
Poorest	%	54/121(44.6)	34/93(36.6)	27/73(37.0)	100/225(44.4)	189/392(48.2)	107/224(47.8)	218/586(37.2)	150/393(38.2)	879/2107(41.7)
Less Poor	%	17/48(35.2)	21/69(30.4)	12/54(22.2)	69/168(41.1)	123/303(40.6)	73/183(39.9)	177/591(30.0)	137/408(33.6)	629/1824(34.5)
	aPR[ł]	1.1	1.17	1.79	1.06	1.17	1.18	1.22	1.13	1.2
	(95%CI)	(0.69-1.17)	(0.72-1.89)	1.03-3.09)	(0.82-1.36)	(0.98-1.39)	(0.94-1.48)	(1.03-1.45)	(0.93-1.37)	(1.11-1.31)
5-14 years	N	201	228	200	487	911	257	427	403	3114
Poorest	%	83/131(63.4)	53/99(53.5)	49/102(48.0)	152/268(56.7)	303/457(66.3)	91/145(62.8)	126/203(62.1)	105/189(55.6)	962/1594(60.4)
Less Poor	%	46/70(65.7)	55/129(42.6)	43/98(43.9)	138/219(63.0)	258/454(56.8)	67/112(59.8)	101/224(45.1)	102/214(47.7)	810/1520(53.3)*
	aPR[ł]	0.92	1.26	1.1	0.91	1.16	0.99	1.8	1.2	1.13
	(95%CI)	(0.73-1.17)	(0.91-1.73)	(0.80-1.52)	(0.78-1.07)	(1.04-1.30)	(0.79-1.24)	(1.31-2.74)	(0.98-1.47)	(1.06-1.21)
≥15 years	N	320	316	345	751	1075	327	624	574	4315
Poorest	%	46/183(25.1)	16/160(10.0)	15.8	98/377(26.0)	127/514(24.7)	42/167(25.2)	57/281(20.3)	64/243(26.3)	479/426(22.7)
Less Poor	%	27/137(19.7)	23/156(14.7)	9.9	79/374(21.1)	117/561(20.9)	43/160(26.9)	60/343(17.5)	61/331(18.4)	426/2223(19.2)
	aPR[ł]	1.27	0.7	1.57	1.22	1.16	0.87	1.1	1.43	1.18
	(95%CI)	(0.83-1.95)	(0.37-1.34)	(0.89-2.77)	(0.94-1.60)	(0.93-1.46)	(0.60-1.27)	(0.77-1.57)	(1.07-1.94)	(1.05-1.33)

[ł] aPR adjusted prevalence ratio; CI confidence l interval; covariates in regression model included socioeconomic status, age group, sub-county, sex and insecticide-treated bed net use

For the pooled data, there was no significant difference in the proportion of individuals who sought care for illness between poor and less-poor households (61.1% versus 62.5%, aPR=0.99 [0.95-1.03]) overall or by age group and year (Table 3). Overall, medication use was similar among the poorest individuals and less poor (73.2% versus 76.2%, aPR=0.95 [0.92-1.00]). However, the poorest individuals were less likely to use a recommended first-line antimalarial medication (i.e., AL or quinine for pregnant women) among those who reported fever in the 2 weeks prior to the survey (18.8% versus 22.1%, aPR=0.81 [0.72-0.91]). Poorest households were slightly less likely to report ITN usage the night prior to the survey(55.2% versus 57.8%, aPR=0.95 [0.91-0.99]).

Table 3 Care seeking, medication and ITN use by household socioeconomic status in Siaya County, western Kenya from 2006 to 2013

	Year	2006	2007	2008	2009	2010	2011	2012	2013	Total
Care Seeking										
	n	1044	707	1145	1631	1343	498	1182	893	8443
Poorest	%	401/647(62.0)	164/354(46.3)	416/772(53.9)	357/652(54.8)	470/886(53.1)	189/350(54.0)	411/825(49.8)	277/617(44.9)	2685/5103(52.6)
Less Poor	%	249/397(63.0)	189/353(53.5)	174/373(46.7)	513/979(52.4)	250/457(54.7)	94/148(63.5)	187/357(52.4)	134/276(48.6)	1790/3340(53.6)*
	aPR‡	0.97	0.84	1.11	1.04	0.96	0.9	0.95	0.91	0.99
	(95%CI)	(0.86-1.11)	(0.70-1.00)	(1.00-1.23)	(0.90-1.20)	(0.88-1.05)	(0.80-1.01)	(0.87-1.04)	(0.85-1.04)	(0.95-1.03)
Took any medications for fever										
	n	138	111	176	736	1343	497	1180	834	5441
Poorest	%	77/118(65.3)	31/73(42.5)	60/127(47.2)	288/536(53.7)	501/944(53.1)	205/374(54.8)	447/904(49.6)	307/665(46.2)	2588/5018(51.6)*
Less Poor	%	10/20(50.0)	15/38(39.5)	32/49(65.3)	116/200(58.0)	218/399(54.6)	78/123(63.4)	151/276(54.7)	83/169(49.1)	2853/5651(50.5)*
	aPR‡	1.03	0.74	0.72	0.91	0.94	0.85	0.94	0.99	0.95
	(95%CI)	(0.80-1.33)	(0.43-1.27)	(0.51-1.02)	(0.78-1.06)	(0.84-1.05)	(0.75-0.97)	(0.87-1.00)	(0.74-1.11)	(0.92-1.00)
Took AL or Quinine										
	n	138	111	176	647	1343	374	904	665	4358
Poorest	%	4/5(80.0)	1/4(25.0)	6/12(50.0)	49/88(55.7)	105/235(44.7)	44/85(51.8)	189/404(46.8)	133/297(44.8)	531/1130(46.9)*
Less Poor	%	83/133(62.4)	45/107(42.1)	86/164(52.4)	292/559(52.2)	614/1108(55.4)	161/289(55.7)	258/500(51.6)	174/368(47.3)	1713/3228(53.1)*
	aPR	1.29	1.03	0.78	1.13	0.66	0.95	0.95	0.92	0.81
	(95%CI)	(0.30-5.5)	(0.37-2.89)	(0.29-2.09)	(0.74-1.72)	(0.51-0.85)	(0.66-1.38)	(0.76-1.20)	(0.77-1.09)	(0.72-0.91)
ITN Use	n	1044	707	1145	1631	2726	1003	2228	1811	12295
Poor	%	256/425(60.2)	110/198(55.6)	232/455(50.9)	455/844(53.9)	795/1580(50.3)	306/611(50.1)	676/1449(46.7)	625/1355(46.1)	3455/6313(54.7)*
Less Poor	%	394/619(63.7)	243/509(47.7)	358/690(51.9)	415/787(52.7)	598/1146(52.2)	236/392(60.2)	394/779(50.6)	220/456(48.3)	3462/5982 (57.9)*
	aPR‡	0.91	1.25	0.97	1.02	0.96	0.85	0.96	0.98	0.95
	(95%CI)	(0.71-1.16)	(0.83-1.87)	(0.80-1.18)	(0.90-1.18)	(0.87-1.05)	(0.75-0.96)	(0.87-1.05)	(0.91-1.05	(0.91-0.99)

‡ aPR adjusted prevalence ratio; CI confidence l interval; covariates in regression model included socioeconomic status, age group, sub-county, sex and insecticide-treated bed net use; * Cochran Armitage trend, significant result at $p<0.05$

Discussion

A key principle of the Kenya Health Policy 2014–2030 is to achieve equity in the distribution of health services and interventions by 2030 [49]. Monitoring socioeconomic trends in the uptake and utilization of malaria interventions are important to identify gaps in equity at the microeconomic level.

Individuals in the poorest households had a higher burden of malaria infection compared to those from less-poor households; this was consistent across age groups and over time. No significant differences were observed in care-seeking behaviour between socioeconomic groups. However, persons from poor households were less likely to use the most effective antimalarial medications, AL and quinine, which have been the recommended first-line therapies in Kenya since 2006[44, 57]. Although differences in ITN use between the poor and less poor were statistically significant, they were very small which suggests that ITNs are equitably distributed and used among these relatively poor rural communities.

The results are comparable to findings from the Kenya malaria indicator surveys, which showed that increased care-seeking behaviour for fever, use of first-line antimalarial medications and ITN ownership and use between 2007 and 2015as well as higher malaria prevalence in the lower wealth quintiles [4, 52, 53]. In 2011, the national malaria control program launched the first nationwide mass distribution of free ITNs with the goal of universal coverage[58] and as a result, this study showed an increase in the use of ITNs across the study period and near equity in ITN use across SES. Results are also comparable with a multi-country study which showed that household ownership of insecticide-treated mosquito nets (ITNs) varied from 5% to greater than 60%, and was equitable by urban/rural and wealth quintile status among 13 (52%) of 25 countries[17].

Although there were no significant differences in care-seeking behaviour for fever between individuals from poor compared to less-poor households, poor individuals were less likely to use the recommended first-line antimalarial medications, AL and quinine for pregnant women[44, 55, 57]. A previous study has suggested that the use of AL was higher in children from the lowest wealth quintile compared to the highest wealth

quintile because of policies that systematically affected access to malaria treatment for children[31]. Prior to the 2010 introduction of the Affordable Medicine Facility– malaria (AMFm) in Kenya, AL was significantly more expensive than other non-recommended antimalarial medicines in the private sector[63]. Evidence from a study from rural western Kenya showed that when adults are uncertain that fever is due to malaria, they tend to choose the lowest-priced antimalarial medicine from private-sector pharmacies and retail outlets[47]. Therefore, when antimalarial medications were not available in public health facilities during the study period, individuals from poor households might have preferentially purchased non-recommended antimalarial medications in the private sector due to lower prices[40]. But despite equity, universal coverage or use does not appear to have been attained. Therefore, even perfectly equitable access to interventions could have an inequitable impact since the risk is so strongly linked to poverty.

Strengths and limitations

The main strength is the use of eight years of pooled data which provided more power to assess socioeconomic inequalities and equity. Equity assessment had used multivariate regression models accounting for clustering and lastly longitudinal monitoring provides an opportunity to monitor the effectiveness of policy intervention over time. The study has three main limitations. First, the findings were based on data from cross-sectional surveys preventing any evaluation of cause-and-effect of SES on malaria indicators over time. Second, only households with children <5 years were included in the surveys based on protocol-specific objectives. Although all children <5 years in a household were surveyed every year, only a small proportion of persons ≥5 years were included in the survey samples and lastly these results are generalizable to study area and not nationally.

Conclusion

Despite equity ITN use and care-seeking for fevers, malaria parasitaemia prevalence remains highest amongst poorest individuals in all age groups, which might be due in part to a lower likelihood of treatment with effective antimalarial medications when compared to less-poor individuals. Although equity has been

achieved in ITN use, the level of usage still falls short of universal expectations, suggesting that additional strategies are necessary to achieve equity in malaria controls or pro-poor population health outcomes.

Declarations

Ethics approval

KEMRI and CDC institutional review boards (IRB) approved the HDSS protocol (# 1801, Nairobi, Kenya) and (# 3308, Atlanta, GA), respectively; the malaria-specific surveys were also approval by KEMRI (#2031) and CDC (#6012). These protocols were approved by the respective IRBs annually. Following cultural customs, compound heads participating provided informed written consent for all compound members, including children, to participate in KEMRI/CDC HDSS activities. Any individual could refuse to participate at any time by verbal request. Additionally, written informed consent was obtained for adult participants providing biological samples.

Abbreviations

aPR: adjusted prevalence ratio; AL: Artemether-Lumefantrine; AMFm: Affordable Medicine Facility–malaria; CDC: Centers for Disease Control and Prevention; GOK: Government of Kenya; HDSS: health and demographic surveillance system; IRB: institutional review board; ITN: insecticide-treated bed net; KEMRI: Kenya Medical Research Institute; MCA: multiple correspondence analysis; RDT: rapid diagnostic test; MOH: Ministry of Health; SES: socioeconomic status; WHO: World Health Organization.

Competing interest

The authors declare that they have no competing interests.

Authors' contributions

MD, VW, SK conceived and designed the study. MD, VW, SK coordinated and performed the study. VW analyzed the data. VW, MD, SK, AMB, AS, SPK, PPH, FtK, and LN drafted the manuscript. All authors read and approved the final manuscript.

Disclaimer

The findings and conclusions presented in this manuscript are those of the authors and do not necessarily reflect the official position of KEMRI, Liverpool School of Tropical Medicine, U.S. President's Malaria Initiative, U.S. Agency for International Development or CDC. The corresponding author had full access to the study data and had final responsibility for the decision to submit for publication.

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Data Sharing

Requests for the data used for this analyses may be made to the KEMRI data manager, Vincent Were, vwere@kemricdc.org and can be shared

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Chapter 4: Equity effect of intermittent mass test-and-treat on the household burden of malaria and quality of life: Results from a cluster-randomized trial in western Kenya

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Equity effect of intermittent mass test-and-treat on the household burden of malaria and quality of life: Results from a cluster-randomized trial in western Kenya.

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Abstract

Background: Mathematical simulations have shown that mass testing and treatment (MTAT) can have a significant impact on malaria transmission, particularly in areas with the hypo-endemic transmission or low to moderate transmission. However, there is limited data on the equity impact of MTAT on malaria indices in households. The aim of this study was to asses the equity effect of MTAT on the prevalence of malaria infection, care-seeking, use of medications, and expenditure on treatment and on disability-adjusted life years (DALYs) between the poor and less poor households in a malaria-endemic region of western Kenya.

Methods: MTAT was a community-based cluster-randomized trial consisting of three cross-sectional surveys done at baseline in mid-2013 and endline in 2015 targeting persons in 400 compounds who lived within 3 km of 10 selected health facilities within the health and demographic surveillance system (HDSS) in Siaya County, western Kenya. It was implemented in 10 intervention clusters which received mass testing and treatment in 3 rounds per year. Both primary data on morbidity and secondary data on malaria-related mortality were used to estimate outcomes. We used multiple correspondence analyses (MCA) to establish wealth quintiles (Q1- Q5) of households, which were collapsed into poor (Q1-Q3) and less poor (Q4-Q5). A difference in difference (DID) approach was integrated into a generalized linear model (GLM), with a poison distribution and a log link function, to account for clustering when modelling net equity effect. Adjusted prevalence ratios (aPR) are reported. The concentration index was used to measure inequalities. DALYs were calculated as a sum of years of life lost (YLL) and years lived with disability (YLD) adjusted, for each age group and sex. Reference life-table for Kenya has been used to estimate life expectancies. The cost of treatment was converted into US Dollars.

Results: Parasitemia malaria prevalence was not different between 2013 and 2015 (35.9% versus 35.3%, respectively p=0.829). Uptake of anti-malarial drugs declined by 26% amongst individuals in poorer households and by 30% in less poor households. Overall net uptake of drugs declined by 28%. Overall

parasitemia reduced by 0.5% but the reduction was not significant in the regression model. Children <5 years of age had the highest malaria burden and more DALYs were lost by females than males. However, no SES group dominated DALYs lost, representing equity gains for the poorest.

Conclusion: After two years of implementation, MTAT resulted in no change in the malaria burden in the overall population. However, there was no difference in access to medication and no change in DALYs lost between SES groups. Despite not being effective in reducing overall prevalence, the poorest and less poor individuals benefited from access to ITN and medication use.

Introduction

Malaria is one of the most important diseases in many low- and middle-income countries, primarily affecting children and pregnant women in sub-Saharan Africa. In 1999, approximately 60% of global malaria deaths were concentrated among the poorest 20% of the global population[64]. In sub-Saharan Africa, 3.1% of all disability-adjusted life-years (DALYs) were lost to malaria in 2002[2]. Although preventable and treatable, the number of deaths due to malaria remains high. In 2015, there were an estimated 429,000 malaria deaths (range: 235,000–639,000) worldwide, and most (92%) of these deaths occurred in Africa[33]. Malaria is a huge economic burden to households and to economies [13, 65]. It has been described as a disease of poverty and current control and elimination efforts are considered a contribution to effective and sustained poverty alleviation[66]. In Kenya, malaria remains a major cause of morbidity and mortality with more than 70% of the population at risk[67]. In 2015, the prevalence of microscopically-confirmed malaria among children <15 years of age was 8% nationally and 27% in the lake-endemic region of western Kenya.[68]. There has been scale-up of malaria control interventions including long-lasting insecticide-treated nets (LLINs), indoor residual spraying (IRS), improved case management with rapid diagnostic tests (RDTs), Artemisinin-based combination therapy (ACT) and intermittent preventive treatment (IPT) for high-risk groups [33]. These efforts are predicted to have had an effect on the burden resulting in an estimated 40% decline in the malaria case burden in Africa from the year 2000 to 2015[5, 56, 69].

Despite the scale-up of these malaria control interventions, the prevalence of malaria has remained relatively high since 2009 in western Kenya[68]. It is known that individuals with asymptomatic parasitemia play an important role in sustaining malaria transmission during the dry season when the population of Anopheles mosquitoes has decreased, and provide a parasite reservoir at the beginning of the wet season when anopheles populations rebound[70]. Asymptomatic *Plasmodium* infections may occur in between 12% and 39% of the population and systematic identification and treatment of individuals with asymptomatic infections could reduce transmission of malaria.[71, 72]. One strategy under evaluation is the community-based mass testing and treatment (MTAT)[5], in which individuals are tested and those who test positive but

have not shown any symptom of malaria are given ant- malarial drugs to clear the parasitaemia in their blood system. Mathematical simulations have shown that MTAT can have a significant impact on malaria transmission, particularly in areas with the hypoendemic transmission or low to moderate transmission achieved through vector control [71, 73].

Having identified a range of interventions with proven efficacy, the challenge remains to scale-up their implementation in a sustainable, cost-effective and equitable manner[74]. Empirical studies of who profits from the distribution of public goods (whether drugs or bed nets) suggest that, even though such programs are always intended for the poor, they more often than not tend to benefit the rich more than the poor[75]. Socioeconomic inequalities are known barriers to successful malaria elimination and control of other diseases.[76, 77]. Complete elimination of malaria will clearly achieve equity, however, an inadvertent unequal distribution of benefits needs to be avoided to ensure that the situations of those most disadvantaged are not compromised further[78]. Most equity gains from the receipt of goods would result in a successful universal coverage, which is already part of many control strategies however, this is not unique to elimination. However, the overall, appraisal of these strategies has provided limited information [78]. A recent systematic review on costs and cost-effectiveness of malaria control intervention had established that from a health system perspective, the median financial cost of protecting one person for one year was $2.20 (range $0.88-$9.54) for LLTNs, $6.70 (range $2.22- $12.85) for IRS, $0.60 (range $0.48-$1.08) for IPT in infants, $4.03 (range $1.25-$11.80) for IPT in children, and $2.06 (range $0.47-$3.36) for IPT in pregnant women[74]. The median financial cost of diagnosing a case of malaria was $4.32 (range $0.34-$9.34). The study also established that the median financial cost of treating an episode of uncomplicated malaria was $5.84 (range $2.36-$23.65) and the median financial cost of treating an episode of severe malaria was $30.26 (range $15.64-$137.87) [74]. However, there is a need for the establishment of an equity effect of control interventions to assess progress towards achieving sustainable development goals aimed at ensuring equity gaps are reduced [21]. Current costs and cost-effectiveness analyses have not taken socioeconomic

differences in access and utilization of malaria control interventions into account and still remain an area of further research [6, 77-80].

The disability-adjusted life year (DALY) is a summary measure of public health widely used to quantify the burden of disease[81]. In the DALY philosophy, every person is born with a certain number of life-years potentially lived in optimal health. People may lose these healthy life years through living with illness and/or through dying before a reference life expectancy [81]. DALY estimates are a sum of morbidity and mortality and measure the total health status of populations rather than the effects of either morbidity or mortality separately [82].

The concentration index is defined as twice the area between the concentration curve and the line of equality (the 45-degree line)[83]. The concentration index in this paper has been used to measure the socioeconomic difference in malaria-related outcomes between the poor and the least poor households. The concentration index varies from +1 to -1. The negative sign indicates that the health variable is concentrated among the poor while the positive sign shows that it is concentrated among the rich. The larger the magnitude of the concentration index, the greater is the inequality in the health variable A concentration index of 0 shows that there is no socioeconomic-related inequality in the health variable while a concentration index of either +1 or -1 indicates a perfect inequality in favour of the rich and the poor groups respectively. A value of zero implies a complete lack of inequalities and hence the health variable is equitable.

While previous studies have focused on the cost-effectiveness of malaria control interventions, the data on the assessment of the equity impact of malaria control interventions at the microeconomic level is still lacking. The current analysis was aimed at assessing the equity effect of MTAT as malaria control intervention on prevalence of infection, care-seeking, medication use, DALYs lost or gained, expenditure on medication, comparing differences between the poor and less poor at the household level.

Methods and materials

Study site and population

The methodology for this study has been described elsewhere [5]. In brief, this study was conducted within the Health and Demographic Surveillance System (HDSS) of KEMRI/CDC in Siaya County, western Kenya. Communities surrounding a sub-sample of 10 health facilities were selected for inclusion. The selected villages were within 3km of each health facility. All households within the study area were enumerated and GPS-mapped.

Residents are mainly of the Luo ethnic group who earn their living through subsistence farming and small businesses. Malaria transmission in the area is high and perennial, with peak transmission in May–July and in October-November. *Plasmodium falciparum* is the dominant malaria species, and the estimated EIR in this area, where household ITN ownership is over 80%, and use among children under 5 years old is over 60%, is <20 infectious bites per person per year (Bayoh, unpublished data). ACTs (artemether-lumefantrine) were introduced as the first-line treatment of uncomplicated malaria provided in government and mission health facilities in July 2006 [44].

Study design

MTAT was a community-based cluster-randomized trial consisting of three cross-sectional surveys done at baseline in mid-2013 and endline in 2015 targeting persons in 400 compounds who lived within 3 km of 10 selected health facilities within the health and demographic surveillance system (HDSS) in Siaya County, western Kenya. It was implemented in 10 intervention clusters which received mass testing and treatment in 3 rounds per year.

After appropriate sensitization, all households within the selected communities were invited to participate in the trial. Around each of the 10 health facilities, approximately one-third of the communities were randomly allocated to the intermittent community test and treat (MTAT) and the other two-thirds to the control arm. To avoid potential contamination between the intervention and control arms, a buffer was designated within each

study area so that only individuals/houses living in the core area are to be included in evaluation activities. To evaluate the equity effects of MTAT intervention data from three rounds of cross-sectional surveys was analyzed between the baseline, midline, and endline of the intervention. The collected data were subjected to equity analysis to compare the level of disparity in malaria-related outcomes between the baseline and end line.

Data collection methods

The cross-sectional surveys were conducted at baseline in 2013 and at endline 2015 in communities that were selected for MTAT. During each cross-sectional survey, selected participants were tested for malaria parasitemia using the Kenya Ministry of Health recommended rapid diagnostic tests, or RDTs (currently, CareStart Malaria HRP2/ pLDH Pf). Women of childbearing age who were not visibly pregnant were tested with either a urine pregnancy test or malaria and pregnancy combo RDT test depending on its availability. Residents who tested positive for malaria by RDT were provided with ACTs, excluding women in their first trimester of pregnancy who received quinine as per national guidelines. Because pregnant women and young infants are at higher risk of infectious febrile diseases, all pregnant women, regardless of gestational age, and all children <3 months of age with a history of fever or a positive RDT test, were referred to a health facility for full assessment and treatment, even if treatment has been provided. Likewise, anyone who had a fever and was RDT negative was referred to a health facility for care. All participants in the intervention arm were screened and treated with an ACT for malaria; at two to three-time points in the subsequent years, 2014 and 2015, ideally occurring during the low transmission season. The non-intervention arm received standard of care, which is the treatment of symptomatic malaria cases presenting at local health facilities [5].
Following informed consent/assent cross-sectional surveys were conducted in all communities within the core area surrounding the selected health facilities. A total of 400 compounds were randomly selected in the study area, 200 from intervention and 200 from control arms. All residents of the compounds who have been resident in the HDSS for at least 4 months were included in the study. Questionnaires were programmed for

use on PDA and tablets using ODK programming software and administered to the participants. The variables collected included socio-demographics, history of pregnancy, a recent history of fever (prior 2 weeks and 48 hours) and antimalarial treatment, use of and opinions about preventive interventions such as LLITNs, IPTp, residual spray, and repellent use. Data was also collected on all concurrent medications that may have an impact on malaria parasitemia within 14 days prior to the survey. Data socioeconomic variables were also collected. All individuals included in the cross-sectional survey were tested for malaria by RDT and treated if positive. Blood samples were collected for detection of *P. falciparum* (both asexual and sexual stage parasites) by microscopy [5].

Definition of equity effect

Equity effect is used in this context to refer to 'lack of statistically significant difference in health events between poorest and less poor individuals'. When the estimate of concentration index and 95% confidence intervals range from negative to positive, we have reported lack of socioeconomic inequalities and used this interpretation as a proxy to refer to equity effect from a provider perspective". Differences that exist between socioeconomic groups may be considered inequities if they are unfair to the poorest individuals and creates a barrier to achieving universal health coverage. MTAT intervention was delivered by the program to the community and the effect was ease in access of medicines and ITNs to the individuals. In this analysis, when socioeconomic differences in the prevalence of health events are not evident, we have reported an equity effect.

Data management and analysis

Data recorded on the personal digital assistants and tablets were downloaded each evening into a secured access database by the data team. The collected data was thoroughly checked by the data team for inconsistent and inaccurate entries. The inconsistencies were resolved by sending queries forms to be responded to by the field teams. SAS codes and Microsoft Access queries were used to clean the data.

Descriptive statistics and frequency distributions were used to describe the prevalence and socio-demographic factors.

Using the MCA model, households were categorized into five socio-economic quintiles with the first quintile as the poorest and the fifth quintile as the least-poor, based on asset ownership, utilities and occupation[22, 23]. As described in detail elsewhere, SES quintiles were aggregated into dichotomous groups [33]; creating a binary variable from the poorest three SES quintiles (i.e., poorest, second and third poorest) and the fourth and fifth quintiles grouped into the 'less-poor' category, with the latter as the reference category in the models. Proportions and 95% confidence intervals were generated, and p-values <0.05 were considered statistically significant. Proportions were compared using generalized linear model (GLM) Poisson distribution with a log link and to compare adjusted prevalence ratios (aPR), which allowed for robust standard error correction accounting for clustering at the household level [84]. Dependent variables included malaria infection, care-seeking, medication, and ITN use. SES, study areas (i.e., sub-counties), sex and categorized age groups (<5, 5–14 and ≥15 years) were included as independent variables. Medians and interquartile ranges were generated if data were not normally distributed; medication expenditures were compared using Wilcoxon rank-sum test because price data were not normally distributed.

Description and interpretation of interaction term

The net effect of the intervention is the net change represented by the interaction term (a product of study arm by study period). A prevalence ratio of the interaction term greater than one in the regression model represents a higher prevalence of the health events in the intervention arm compared to the control arm and between the study periods. In this analysis, A PR greater than 1 with 95% confidence intervals above 1 represents the increased prevalence in the poorest individuals compared to less poor. Conversely, PR less than 1 with 95% confidence intervals below one represents lower prevalence rates amongst the poorest.

The theoretical framework describing the **interaction term** in the regression model is as below

P(Y=1|y=0)= β_1Studyarm($\frac{intervention=1}{Control=0}$)+ β_2Period($\frac{Endline=1}{Baseline=0}$)+ $\boldsymbol{\beta_3}$Interaction[Studyarm*Period]+ $\beta_4\chi_1$ + $\beta_5\chi_2$+…+ $\beta_6\chi_n$ +ε

Where Y is a binary outcome,(χ_1 +χ_2+…+ χ_n) are other independent variables included in the model, β_1, β_2 to β_n are the marginal effects measured using prevalence ratios in this study (PR).

Hence Interaction term=$\begin{cases} 1\ if\ intervention = 1\ and\ endline = 1 \\ 0\ otherwise \end{cases}$

Overall intervention effect [interaction term] =($\boldsymbol{Intervention\ site}$: $\%endline - \%baseline$)-

($\boldsymbol{control\ site}$: $\%\ endline - \%baseline$)

If the measure of effect (PR of β_3) is >1 then the intervention has a higher PR compared to control

If the measure of effect (PR of β_3) is <1 then the control sites have higher PR than intervention

DALYs represent the number of years lost due to premature death plus years lived with disability due to malaria infection. DALYs were calculated by summing up YLD and YLL. Computation of YLD was done by multiplying prevalence of malaria in each age group and sex by a disability weight for malaria of 0.191 [81]**.** YLL was calculated as a product of the total number of malaria deaths in each age group and the mean life expectancy using the local standard life table at an average age of death. DALYs were estimated for each age group by sex and socioeconomic status. DALYs estimate and 95% Confidence intervals are reported [82]. Socioeconomic related inequalities in DALYs lost were measured using the concentration index (Cind). The concentration index also indicates the level of dominance by SES groups.

Calculation of 95% Confidence Interval of the concentration index

The 95% confidence interval of the concentration index was estimated using Stata software through Simulation (repeated resampling) methods. The simulated confidence intervals for the concentration index was calculated from a Lorenz plot of the cumulative share of health event in the population (on the y-axis; eg DALYs or years lived with a disabilities etc.) against the cumulative proportion of the population ranked by a socioeconomic variable (on the x-axis; e.g wealth quintile). If health event or outcome is distributed perfectly

equally across the socioeconomic groups, the Lorenz curve coincides with the diagonal – the equality line. The further the curve is away from the diagonal equality line, the greater the degree of inequality. The concentration index is the area between the Lorenz curve and the line of equality, measured and reported as a proportion of the total area beneath (or above) the line of equality. The concentration index shows how unevenly health events or outcomes are distributed according to population share. It takes a value between zero and 1 (or 100%), where zero indicates perfect equality and 1 indicates 'ultimate inequality' (ie the hypothetical situation where all the 'good health' is in the least deprived group). A negative value represents the concentration of the health event amongst the poorest individuals and a positive value represents the concentration of the events amongst the wealthier individuals. When 95% confidence intervals overlap with zero, there are no inequalities, the event is fairly distributed

The 95% confidence interval formula is: CI±1.96*(SD/$\sqrt{n}$) where the CI is the concentration index, SD is the standard deviation associated with a mean estimate of the Concentration index and n is the number of samples. However (SD/$\sqrt{n}$) represents the standard error of the estimate.

CInd was calculated as twice the covariance of the health variable and the fractional household or groups ranking variable divided by sample mean of the health variable. It can also be described as twice the area between the concentration curve and the line of equality. A value of 0 indicated that there were no socioeconomic inequalities and a value of 1 indicated perfect equality. A negative value show health outcome in concentrated amongst the poor and a positive value represents the dominance of the health outcome by the less poor. The exchange rate of USD in 2013 (Present Value PV was USD1=Ksh 85) was discounted at a rate of 3% to estimate the true value of a dollar in 2014 and 2015 [85].

Results

Socio-demographic characteristics of the study population

A total of 1970 individuals participated in the pre-intervention baseline survey in mid-2013. Of these 17.3% were persons aged <5 years, 50.5% persons aged 5-14 years and the rest 32.1% were aged ≥15 years. In the 2015 post-intervention endline survey, a total of 1844 persons participated in the survey and out of these, 14.4% were persons aged <5 years, 53.2% were aged 5-14 years and the rest 32.7% were aged ≥ 15 years. For equity analysis, 1181 (60%) persons were classified as poor at baseline in 2013 and 1062 were poor 57.6% in the 2015 endline survey. Similarly, 789 (40%) of individuals were classified as less poor at baseline surveys (2013) and 38.0% (n=700) in the 2015 endline survey (table 1).

Descriptive analysis of equity effect of MTAT on malaria infection, health-seeking, ITN use and expenditure on treatment

The differences in proportions of indicators at baseline (2013) were compared to the differences in proportions at endline 2015, irrespective of the study arms (table 1). The results showed that overall, the prevalence of malaria amongst children <5 years was 17.3% at the baseline survey and 14.1% at endline. Amongst children <5 years from poor households, the net change in the prevalence of malaria was a reduction of 2.6% (baseline 14.6% vs endline 12.0%). The overall prevalence reduction of malaria infection amongst 5-14 years was similar (baseline 50.5% vs 53.2% endline). Prevalence of malaria infection amongst children aged 5-14 years from poor households increased by 3.2% (baseline 52.1% vs 55.3% endline), while there was a 0.8% increase amongst those from less poor households (baseline 48.4% vs endline 49.2%).The net change in prevalence amongst the adults aged ≥15 years from poor households was a reduction of 0.3% compared to a 3.5% reduction amongst the less poor.

Differences between poor and less poor over time were more marked for uptake and use of interventions. The proportion of individuals who sought care for fever increased by 10.2% amongst the poor compared to 22.9% amongst the less poor, a net change of 12.6% in favour of the less poor. Uptake AL (recommended first-line

treatment for malaria) increased by 0.48% amongst the poor (baseline 13.7% vs endline 14.2%) compared to reduction of 1.15% amongst the less poor households (baseline 14.7% vs endline 13.6%). The overall net effect was a reduction of 1.63% in the use of AL for malaria treatment in favour of the poor. Overall, ITN usage increased by 42.0%. However, the use of ITN reduced amongst poor households from 61.2% at baseline to 39.0% at the endline of the survey. This represents a similar margin of reduction (22.2%) in ITN use by the least poor households. (Table 1)

Table 1 Socio-demographic characteristics of the study population and malaria indices between poor and less Poor in Siaya County, Kenya

		Poor households				Less Poor households				
		Overall Baseline 2013 n(%)	Baseline (A) n (%)	Endline (B) n(%)	% Change (B-A)	Overall Endline n(%)	Baseline (C) n (%)	Endline (D) n (%)	%change (D-C)	Net Change (B-A)-(D-C)
Number of Participants	**N**	1893	726[d]	1018[e]		1844	482 [d]	678 [e]		
	<5 years	300 (15.85)	107(53.23)	131(12.87)	NA	229(12.42)	94 (46.77)	91(13.42)	NA	NA
	5-14 years	599(31.64)	235(61.04)	277(27.21)	NA	459(24.89)	150(38.96)	165(24.34)	NA	NA
	≥15 years	994(52.51)	384(61.74)	610(59.92)	NA	1156(62.69)	238(38.26)	422(62.24)	NA	NA
Malaria infection	<5 years	89(19.69)	48(18.46)	32(12.03)	-6.43	67(14.14)	41(21.35)	35(18.13)	-3.22	-3.21
	5-14 years	221(48.89)	126(48.46)	147(55.26)	6.8	252(53.16)	95(49.48)	95(49.22)	-0.26	7.06
	≥15 years	142(31.42)	86(33.08)	87(32.71)	-0.37	155(32.7)	56(29.17)	63(32.64)	3.47	-3.84
Fever last 2 weeks	Yes	878(46.38)	337(46.42)	324(41.01)	-5.41	600(43.26)	222(46.06)	251(45.64)	-0.42	-4.99
	No	1015(53.62)	389(53.58)	465(58.86)	5.48	786(56.67)	260(53.94)	299(54.36)	0.42	5.06
Sought Care	Yes	542(61.73)	206(61.31)	226(69.75)	8.44	400(66.67)	122(54.71)	159(63.35)	8.64	-0.20
	No	336(38.27)	130(38.69)	98(30.25)	-8.44	200(33.33)	101(45.29)	92(36.65)	-8.64	0.20
Medications Use	AL[c]	264(30.07)	122(36.20)	46(14.20)	-22.0	83(13.83)	61(27.48)	34(13.55)	-13.93	-8.07
	SP[b]	12(1.37)	7(2.08)	0(0.00)	-2.08	-	1(0.45)	0(0.00)	-0.45	-1.63
	Quinine	9(1.03)	5(1.48)	1(0.31)	-1.17	2(0.33)	2(0.90)	1(0.40)	-0.50	-0.67
	Ibuprofen	49(5.58)	22(6.53)	5(1.54)	-4.99	8(1.33)	10(4.50)	3(1.20)	-3.30	-1.69
	Acetominophen	452(51.48)	180(53.41)	68(20.99)	-32.42	136(22.67)	115(51.80)	62(24.70)	-27.1	-5.32
	Septrin	54(6.15)	18(5.34)	6(1.85)	-3.49	6(1.00)	13(5.86)	0(0.00)	-5.86	1.87
ITN Use	Yes	1200(63.39)	446(61.43)	422(41.00)	-20.43	719(38.99)	288(59.75)	596(59.00)	-0.75	-19.68
	No	693(36.61)	280(38.57)	297(43.81)	5.24	1125(61.01)	194(40.25)	381(56.19)	15.94	-10.70

[a] Net change is the Difference-in-Difference (DID) in proportions between surveys and studies arms; [b]SP= Sulphadoxine-Pyrimethamine; [c]AL=Artemether-Lumefantrine; [c]NA = Not Applicable; [d] In 2013, n=1208 individuals had complete SES data out of 1893; [e] in 2015, n=1696 individuals had SES data of 1844

Multivariate regression analysis of the equity effect of MTAT on malaria-related indices

MTAT resulted in a reduced prevalence of malaria by 10% overall but the reduction was not statistically significant [aPR=0.90; 95%CI=0.74-1.07]. Amongst the poorest individuals, malaria prevalence was lowered but not significantly [aPR=0.9; 95%CI= (0.70-1.21), p=0.548]. However there was no significant change in risk of prevalence amongst the less poor individuals [aPR=1.0; 95%CI= (0.76-1.41), p=0.837]. Proportion of poor individuals who sought care for fever increased by 30% (aPR=1.30; 95%CI=1.06-1.65, p=0.014) compared to non-significant change amongst the less poor (aPR=1.00; 95%CI=0.72-1.31, p=0.851). Overall use of medication for treatment declined significantly (aPR= 0.80; 95%CI=0.74-0.98, p=0.022). However there was no significant change in use of medications amongst poorest (aPR=0.80; 95%CI=0.67-1.01, p=0.063) and similarly no significance change amongst less poor (aPR=0.9; 95%CI=0.72-1.25, p=0.698). There was a significant change in the use of ITN overall and between the SES groups (Table2)

Table 2. Descriptive Analysis of equity Effect of MTAT on malaria infection, care-seeking, and expenditure on treatment, Siaya County, western Kenya

	Baseline (2013)		Baseline Difference[a]	Endline (2015)		Endline Difference[b]	Net-Change[b-a]	Interaction term[c] (Net effect)	
	Intervention %	Control %	Change %	Intervention %	Control %	Change %	DID[b] %	aPR(95%CI)	P value
Malaria Infection									
Overall	47.73	52.27	-4.54	45.46	54.54	-9.08	-4.54	0.9(0.74-1.07)	0.223
Poor	35.05	36.55	-1.50	31.46	38.21	-6.75	-5.25	0.9(0.70-1.21)	0.548
Less poor	33.47	46.75	-13.28	28.75	41.47	-12.72	0.56	1.0(0.76-1.41)	0.837
Care seeking									
Overall	48.63	51.37	-2.37	46.67	53.33	-6.66	-4.29	1.1(0.92-1.24)	0.415
Poor	58.13	64.20	-6.07	75.63	64.02	11.61	17.68	1.3(1.06-1.65)	0.014
Less poor	53.98	55.45	-1.47	60.36	65.71	-5.35	-3.88	1.0(0.72-1.31)	0.851
Medication									
Overall	47.50	52.50	-5.00	46.67	53.33	-6.66	-1.66	0.8(0.74-0.98)	0.022
Poor	41.82	36.29	5.53	80.00	85.37	-5.37	-10.9	0.8(0.67-1.01)	0.063
Less poor	35.1	37.99	-2.89	71.17	82.14	-10.97	-8.08	0.9(0.72-1.25)	0.698
Affordability of health care services									
Overall	48.01	51.99	-3.98	48.00	52.00	-4.00	-0.02	0.9(0.82-1.08)	0.376
Poor	75.29	81.82	-6.53	71.90	84.76	-12.86	-6.33	0.9(0.77-1.10)	0.352
Less poor	75.70	75.34	0.36	74.63	79.35	-4.72	-5.08	0.9(0.75-1.14)	0.476
ITN use									
Overall	47.70	52.30	-4.6	46.53	53.47	-6.94	-2.34	1.2(1.04-1.35)	0.011
Poor	62.15	57.14	5.01	46.30	41.69	4.61	-0.40	1.0	0.999
Less poor	59.21	63.29	-4.08	45.32	37.99	7.33	11.41	1.0	0.999

[b-a] DID implies Difference in Difference between study periods and the study arms. [c] The interaction term is defined as the product of study arm (intervention=1, control=0) and study period (endline=1; Baseline=0). If PR is significant and greater, the intervention arm has resulted in increased cases of the health event and vice versa).

Equity effect of MTAT on Disability-Adjusted Life Years (DALYs) amongst males

Amongst the poorest males, there was a net reduction of 107.5 (95% CI=16.5-198.5) DALYs overall, a net reduction of 124 (95% CI=33-215) DALYs amongst children <5 years, 1.5 (95% CI=-89.5 -92.4) DALYs reduction in those 5-14 years old and 18.1 (95% CI=-72-105) DALYs amongst adults aged at least 15 years. Overall, the least poor male individuals had a net equity gain of 205 DALYs; 307 amongst the children under 5 years, 4.3 amongst 5-14 years and 105.5 amongst the adult at least 15 years. The DALYs were concentrated amongst the poor males' individuals overall represented by a negative concentration index (CInd) = (-0.4599); However, the concentration amongst the poor does not show statistically significant dominance (95%CI= {-2.9-1.96]). DALYs were concentrated amongst the least poor male children under 5 years (CInd=0.1). However there no significant dominance of DALYs lost by the least poor compared to the poor (95%CI=-29-0.5) and DALYs lost were more concentrated amongst the poor male children aged 5-14 years old (Table 3)

Table 3: Equity effect of MTAT on the disability adjusted-life years amongst the male population in Siaya County, Kenya.

SES Quintiles	Age groups	Control Sites					Intervention Sites					
		Baseline (2013)		Endline (2015)			Baseline (2013)		Endline (2015)			
		DALYs	95%CI	DALYs	95%CI	**Change**	DALYs	95%CI	DALYs	95%CI	**Change**	**Net Change**
Poorest	<5years	181.3	90 -272	183.9	137 -231	2.6	121.7	56.5-187	0.2	-19-19.4	-121.6	-124.2
	5-14years	1.1	-89-92	3.2	-44 -50	2.1	1.7	-63.5-67	2.3	-17-22	0.6	-1.5
	≥15years	21.7	-61-113	17.3	-30 -64	-4.4	20.4	-44.9-86	34.1	15-53	13.8	18.2
	All ages	**204.1**	**113-294**	**204.5**	**158 -251**	**0.3**	**143.8**	**79-209**	**36.6**	**16.3-55.3**	**-107.2**	**-107.5**
2rd poor	<5yrs	61.4	-29-152	122.2	75 -169	60.8	247.8	183-313	0.6	-18.6-19.8	-247.2	-308.0
	5-14years	120.7	29-211	3.1	-44 -50	-117.6	1.5	-64-66.7	1.5	-18-21	0.0	117.6
	≥15yrs	40.7	-50-131	47.0	.0237 -94	6.3	16.3	-49-81.5	1.0	-18-20	-15.3	-21.6
	All ages	**222.8**	**132-312**	**172.2**	**125 -219**	**-50.6**	**265.6**	**200-331**	**3.1**	**-16-22**	**-262.6**	**-212**
3rd Poor	<5yrs	242.0	151-333	250	203 -297	8.0	63	-2.2-128	62.7	44.4-82	-0.4	-8.4
	5-14years	60.8	-30-152	59.5	13 -106	-1.3	3.2	-62-68.4	1.3	-17-21	-1.9	-0.6
	≥15years	94.3	3-185	0.0	-47 -47	-94.3	1.0	-64-66	1.1	-18-20	0.2	94.5
	All ages	**397.1**	**306-488**	**309.5**	**263 -356**	**-87.6**	**67.2**	**1.95-132**	**65.2**	**46-84**	**-2.1**	**85.5**
4th poor	<5yrs	664.8	574-756	0.8	-47 -48	-664.1	424	358-489	125.6	106-145	-298.4	365.6
	5-14years	60.8	-30 -152	3.2	-44 -50	-57.8	1.7	-64 -67	1.9	-17-21	0.2	57.9
	≥15years	70.9	-20 -162	1.3	-46 -48	-69.6	27.2	-38-92	1.1	-18-20	-26.0	43.6
	All ages	**796.6**	**706 -887**	**5.2**	**-42 -52**	**-791.4**	**452.9**	**387-518**	**128.6**	**109-148**	**-324.3**	**467.1**
Least poor	<5yrs	1.3	-90 -92	188.3	141 -235	186.9	121.2	56-186	1.0	-18-20	-120.2	-307.1
	5-14years	58.4	-32 -149	2.5	-44 -49	-55.9	61.4	-3.8-127	1.1	-18-20	-60.2	-4.3
	≥15years	117.7	27 -209	1.3	-46 -48	-116.4	24.3	-41-90	13.5	-5.8-35	-10.9	105.5
	All ages	**177.5**	**87 -268**	**192.1**	**145 -239**	**14.6**	**206.9**		**15.6**	**-3.7-34.9**	**-191.3**	**-205.9**
Concentration Index	<5 years	-0.0295	-0.034-0.29	0.0207	-0.05-0.09		-0.0490	-0.20-0.10	0.1000	-0.29-0.50		
	5-14 years	-0.0772	-0.40-0.29	0.1710	-0.38-0.73		0.6842	0.54-0.80	-0.2210	-1.00-0.60		
	≥15 years	0.1657	-0.35-0.70	-0.4120	0.93-0.11		0.0001	-0.30-0.30	-0.3390	-1.58-0.90		
	All ages	0.0590	-1.45-1.50	-0.2203	-1.36-0.93		0.6356	0.02-1.20	-0.4599	-2.90-1.96		

Equity effect of MTAT on Disability-Adjusted Life Years (DALYs) amongst females

There was a concentration of DALYs amongst the males at the intervention sites during the endline (Cind. -0.46; 95%CI=-2.9-1.96). Amongst the female adults aged at least 15 years, there was equally no dominance of DALYs by either SES groups (CInd -0.339; 95%CI=-1.58-0.9). (Table 3). Amongst the poorest females, there was an increase of 135 DALYs overall, with the largest net increase of 127 DALYs observed amongst children <5 years. A very small increase of 0.2 was observed among the 5-14 years old and an increase of 7.6 DALYs amongst adults aged at least 15 years. However, when the first three quintiles are combined into one quintile ('Poor') and the last two quintiles are combined into one quintile ('Less poor'), the net equity gain among the poor female individuals was 32.8 DALYs overall; net equity gain of 66.8 DALYs was observed among the 2nd poor females, net equity gain of 101.1 among the 3rd poor females while a net equity loss of 135 DALYs was observed among the poorest female individuals. Amongst the least poor female individuals, a net equity loss of 457 DALYs was observed overall. The DALYs were concentrated amongst the poor female individuals <5 years overall in the intervention sites represented by a negative concentration index (CInd) = (-0.131); 95%CI=-0.32-0.054); However there was no dominance of concentration (Cind 0.029; 95%CI= {-0.686-0.74]) at endline in the intervention sites. However, there was no significant concentration of DALYs lost by the 5-14 years (Cind=0.216; 95%CI -0.094-0.53) (table 4).

Table 4: Equity effect of MTAT on the Disability Adjusted Life Years amongst the female population in Siaya County, Kenya

		Control Sites					Intervention Sites					
SES	**Age groups**	**Baseline (2013)**		**Endline (2015)**			**Baseline (2013)**		**Endline (2015)**			
		Estimate	95%CI	Estimate	95%CI	**Change**	Estimate	95%CI	Estimate	95%CI	**Change**	**Net Change**
Poorest	<5yrs	260.4	165.5 -355.2	134.2	83.6-184.8	-126.2	65.6	16.5-114.6	66.6	51.5-81.7	1.0	127.2
	5-14yrs	2.483	-92.4- 97.3	2.483	-48.1- 53.1	0.0	1.1	-47.9- 50.1	1.3	-13.9-16.4	0.2	0.2
	≥15yrs	23.3	-71.5-118.1	26.2	-24.4-76.8	2.9	12.0	-37-61	22.6	7.5-37.7	10.5	7.6
	All ages	**286.2**	**191.3-381**	**162.9**	**112.3-214**	**-123.3**	**78.8**	**29.8-127.8**	**90.5**	**75.4-105.6**	**11.7**	**135**
2rd poor	<5yrs	391.1	296.2-485.9	131.6	80.9-182.2	-259.5	325.2	276.1-374.2	67.5	52.4-82.6	-257.7	1.8
	5-14yrs	61.6	-33.2-156.4	65.6	14.9-116.2	4.0	191.8	142.7-240.8	60.9	45.8-76	-130.9	-134.9
	≥15yrs	71.5	-22.3-166.3	23.2	-27.4-73.8	-48.3	0.6	-48.4-49.6	18.6	3.5-33.7	18.0	66.3
	All ages	**524.3**	**429.4-619.1**	**220.4**	**169.7-271**	**-303.8**	**517.6**	**468.5-566.6**	**147**	**131.9-162.1**	**-370.6**	**-66.8**
3rd Poor	<5yrs	326.5	231.6-421.3	264.3	213.6-315	-62.2	65.6	16.5-114.6	66.8	51.7-81.9	1.2	63.4
	5-14yrs	64.3	-30.5-151.1	63.4	12.7-114	-0.8	129.3	80.2-178.3	2.9	-12.2-18	-126.4	-125.6
	>=15yrs	27.0	-67.8-121.8	2.7	-47.9-53.3	-24.3	90.5	41.4-139.5	27.2	12.1-42.3	-63.3	-38.9
	All ages	**417.8**	**322.9-512.6**	**330.4**	**279.7-381**	**-87.4**	**285.3**	**236.2-334.3**	**96.8**	**81.7-111.9**	**-188.5**	**-101.1**
4th poor	<5yrs	531.2	436.4- 626	268.7	218.1-319	-262.4	130.6	81.5-179.6	0.6	-14.5-15.7	-130.0	132.4
	5-14yrs	65.2	-29.6-160	2.9	-47.7-53.5	-62.3	2.3	-46.7-51.3	61.3	46.2-76.4	59.0	121.4
	>=15yrs	1.7	-93.1-96.5	2.3	-48.3-52.9	0.6	89.7	40.6-138.7	26.6	11.5-41.7	-63.1	-63.7
	All ages	**598.1**	**503.3-692.9**	**273.9**	**223.3-325**	**-324.2**	**222.6**	**173.5-271.6**	**88.5**	**73.4-103.6**	**-134.1**	**190.1**
Least poor	<5yrs	325.6	230.8-420.4	1.1	-49.5-51.7	-324.4	130.6	81.5-179.6	66.4	51.3-81.5	-64.2	260.2
	5-14yrs	3.1	-91.7-97.9	68.1	17.5-118.7	65.0	64.4	15.4-113.4	64.9	49.8-80	0.4	-64.6
	>=15yrs	59.9	-34.9-154.7	2.1	-48.5- 52.7	-57.8	1.7	-47.3-50.7	15.9	0.780-31	14.2	72.0
	All ages	**388.6**	**293.8-483.4**	**71.3**	**20.7-121.9**	**-317.2**	**196.7**	**147.6-245.7**	**147.1**	**132-162.2**	**-49.6**	**267.6**
Concentration Index	<5yrs	0.0107	-0.032-0.05	-0.0046	-0.24- 0.23		-0.0412	-0.20-0.120	-0.131	-0.32-.054		
	5-14yrs	-0.0570	-0.5-0.382	0.1662	-0.63 -0.96		-0.0511	-0.36-0.261	0.216	-0.094-.53		
	>=15yrs	-0.0462	-0.467-0.74	-0.531	-.72-(-0.34)		0.2540	-0.29-0.802	-0.056	-0.272-.16		
	All ages	**-0.0925**	**-0.994-1.17**	**-0.369**	**-1.36-0.85**		**0.1617**	**-0.85-1.183**	**0.029**	**-0.686-.74**		

Discussion

Results in this study revealed that intermittent mass test and treat for malaria infection resulted in equity gains in the general population and amongst the poor households. After 2 years of implementation and six rounds of MTAT, there was no difference in the prevalence of malaria between the poorest and less poor individuals as both socioeconomic groups experienced a reduction in the overall prevalence of malaria. Results further showed that overall there was a significant decline in the proportion of individuals using medication between the surveys. However, such a decline in medication use was no different comparing the poorest and less poor individuals. The proportion of individuals seeking care for fever was not significantly different between the poorest and less poor although the poor had an increase of about 10% such increase was no significant in the multivariate analyses. The result showed a significant reduction in DALYs lost due to malaria in the general population and no significant difference in DALYs lost between the poorest and less poor. Although the poor had the highest burden of DALYs at baseline, they gained DALYs towards the end of the study for both male and females persons Some studies had demonstrated that MTAT can reduce transmission of malaria,but none had demonstrated any equity effect of MTAT [71-73, 76] Since most parts of DALYs were malaria-specific deaths, the results show that more deaths were prevented over time. Further, households reported significant cost saving in expenditure on malaria treatment and there was cost-saving for poor and less poor households. There was a significant increase in care-seeking amongst the poor households compared to the less poor. These results demonstrated that MTAT is an important approach towards the reduction of socioeconomic inequalities and increase access to medication and treatment, especially amongst the poor individuals.

and possible elimination of Malaria among poor Individuals. The insignificant prevalence ratio results between the poor and less poor reveal equity in malaria prevalence between the two groups. This concurs with the evidence obtained from a study in Tanzania where malaria incidence did not differ across the wealth quintiles.[6]

The percentage of households that sought care was higher in the poor households in both baseline and endline. The finding is inconsistent with that conducted in Tanzania where the percentage of the households who sought care was higher in richer households. The six rounds of MTAT conducted in the community resulted in care available to the poor households located in the rural villages, observed through the significant increase in the prevalence ratio, reinforcing their understanding leading them to accept that early identification and treatment of malaria increases medication effectiveness. The identification, testing, and treatment of Malaria cases by health care providers during the community case management of malaria lead to an increase in access to care.[68, 77, 86]. We observed that the increase in care-seeking has a positive effect on the decline in malaria cases.

Mass drug administration is beneficial to poor individuals because it could results in cost savings especially if individuals do not have to travel long distances to receive medications[87, 88]. Although there was no statistical significance, the intervention led to a decrease in medication uptake and affordability in the poor and the less poor households. This is contrary to other studies that involved testing and treatment like community care management, proactive testing, and treatment where free medication was administered to patients with uncomplicated malaria leading to an increase in medication uptake.[73] The insignificant prevalence rates among the poor and the less poor revealed that there was an equal rate of taking medication and the affordability of that medication among different socioeconomic statuses.[80]

Children under five years of age had the highest YLD across the wealth quintiles which led to the highest number of DALYs. Children have a high mortality rate as compared to other age groups and are also vulnerable to infections. This is similar to a study conducted in Sudan to find out the burden on malaria focusing on the incidence, mortality, and DALYs lost. The study revealed that children <5 years of age had the highest burden of malaria which emphasized the fact that burden is highest in this age group[82]. Irrespective of gender, the poorest households had the highest gap between the ideal and current health status and after the intervention, a general decline in DALYs can be observed with the poorest households showing the highest decrease.[89] The average DALYSs reduction was more in the males compared to their female counterparts. Our results slightly differed with the same study conducted in Sudan where it was found out that females lost more DALYs than males due to their higher life expectancy than males.[82]

The study found some positive results. However, the study was conducted in the lake endemic region where malaria prevalence is very high and thus cannot be translated to other regions. Results from this study can be used to inform policy in order to establish precise estimates in places with low malaria transmission.

Conclusion

The results from this study suggest that although MTAT only reduced malaria burden by a very small margin after two years of implementing three rounds of MTAT. However, the intervention achieved equity in malaria prevalence, uptake of medication for malaria between the rich and poor. Care seeking improved and cost of treatment reduced after the intervention to favour the poor households. The benefits achieved in the two years' intervention are encouraging despite the

low impact of malaria prevalence. Equity effect contributes to the global goal of eliminating socioeconomic inequalities and monitoring equity effect of malaria interventions

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Chapter 5: Socioeconomic inequalities in population burden of malaria: Analyses of disability-adjusted life years in a health and demographic surveillance, 2006-2014, western Kenya

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Socioeconomic inequalities in population burden of malaria: Analyses of disability-adjusted life years in a health and demographic surveillance, 2006-2014, western Kenya

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Abstract:

Background. Malaria is a major contributor to the high disease burden in Kenya, especially among the economically and socially disadvantaged populations. This study assesses socioeconomic inequalities in relation to malaria burden measured in terms of Disability Adjusted Life Years (DALYs) between 2006 and2014 in western Kenya.

Methods. Malaria mortality data were obtained from the health and demographic surveillance system (HDSS), and malaria prevalence data were collected from annual cross-sectional surveys from 2006-2014 in Siaya County. Malaria deaths were determined using verbal autopsy, replaced by an inter-VA computer algorithm from 2010 onwards. Absolute DALYs were calculated as the sum of Years of Life Lost due to premature death (YLL) and Years lived and Disability (YLD) for all age groups using the Kenyan life table. Wealth quintiles were calculated using the Multiple Correspondence Analysis Model (MCA) using the household asset as a proxy for socioeconomic status (SES). The concentrated index was used together with the MCA model to test for the overall socioeconomic related inequalities.

Results. A total of 3504 malaria-related deaths occurred in the communities from 2006-2014, the highest deaths occurred in 2008
(n=788) and the least in 2014(n=170). A total of 835 deaths occurred in the poorest households and 616 in the least poor households. DALYs lost amongst the poorest households were more than twice that for the least poor households (35,197 against 14,254 DALYs).The total absolute DALYs between the poorest and least poor quintiles reduced by 15% from16, 742 to 14,221.Poorest children aged <5 years had a higher burden of DALYs (11,187; 95%CI=11085.72 -12880.01) compared to children <5 years old from least poor households (DALYs 9,987; 95%CI=9885.91 -10,088.20). Females in the poorest households

had a higher burden of DALYs compared to those in the least poor households. DALY's estimates for males were similar between the poor and less poor respectively. Children aged 5-14 years had the highest burden of years lived with disability (YLD) (malaria illness) across the wealth quintiles. Trends in DALYs, YLL, and YLD show declining trends from 2008 to 2014. Concentration index of -0.0283, 95% (CI=-0.0371 -0.0219) for females, showed that disability-adjusted life years were more heavily concentrated among poor households than the richer ones.

Conclusion: Poor households, children < 5 years in poor households and women disproportionately bore the greatest burden of malaria compared to the least poor households, older children or males. Although socioeconomic inequalities in the burden of malaria still exist, a decline was evident suggesting intensification of malaria control interventions over time. Interventions targeting the poor, female and children <5 should be considered to bring down overall morbidity and mortality due to malaria in economic perspective.

Introduction

According to the World Health Organization (WHO), an estimated,216 million cases of malaria occurred worldwide in 2016 (95% CI=196 million- 263 million), with a high proportion of nearly 90% occurring in the African region [33]. In 2016, 455,000 malaria deaths (range: 236,000–635,000) were estimated worldwide, of which 90% occurred in the African region. Between 2000 and 2016, malaria incidence rates fell by 18% globally and by 20% in Africa, and malaria mortality rates fell by 25% globally and by 66% in Africa [33]. In the global disease burden (GBD) study 2015, malaria was ranked 18th in the list of diseases accounting for the global disease burden at 1.4%; in Africa malaria ranked fourth accounting for an estimated 5.7% of the disease burden and caused approximately 35 million disability-adjusted life years (DALYs)[90]. The WHO defines disability-adjusted life years (DALYs) as the sum of the Years of Life Lost (YLL) due to premature mortality in the population and the Years lived with Disability (YLD) for people living with the health condition or its consequence. The sum of DALYs across the population, which is a measure of the burden of disease, is a measurement of the gap between the current health status and ideal health status in which the entire population lives to an advanced age, free of disease and disability [81, 91-94]. In the DALY philosophy, every person is born with a certain number of life-years potentially lived in optimal health. People may lose these healthy life years through living with illness and/or through dying before a reference life expectancy. These losses in healthy life years are exactly what is measured by the DALY metric. Ten DALYs, for instance, correspond to ten lost years of a healthy life, attributable to morbidity, mortality, or both. On a population level, diseases with a higher public health impact will thus account for more DALYs than those with a lesser impact [81].

In the DALYs approach, a disability weighted zero indicates perfect health and the one weighted 1 indicates death [81, 91-94][56]. The calculation of YLD which is one of the

components of a DALY can be performed using the prevalence of disease based approach recommended by the GBD study 2010[95, 96]. A study from Malawi showed that households with a very low income bore a disproportionate share of the economic burden of malaria, with 32% of their annual household income being lost as a result of the direct and indirect costs of malaria, compared to only 4.2% for households in the low- to high-income categories1[97]. Estimating the costs of health interventions and the impact or reduction in the burden of disease has tremendous potential for maximizing the use of available health resources [93]. Estimating the burden of disease and cost-effectiveness of interventions can assist governments in deciding which interventions to finance, intervention subsidy levels and populations to target[98]. Equitable distribution of health outcomes or interventions is a principle advocated for in most national policy documents. Equity can either be horizontal or vertical. Horizontal equity means unequal treatment of individuals with equal medical needs, regardless of socioeconomic related characteristics while vertical equity is defined as an appropriate unequal treatment of individuals with unequal medical needs based on socioeconomic related characteristics of the population.

A study conducted in Gambia between 2010 -2011 to assess the link between malaria infections and socioeconomic status (SES) showed that children aged between 6 to 59 months and 5 to 14 years from the second, third, fourth and richest quintiles were significantly less likely to have malaria infections compared to children from the poorest quintiles.[11]
A multi-cohort study and meta-analysis with individual-level data from 48 independent prospective cohort studies with information about socioeconomic status, indexed by occupational position, risk factors (high alcohol intake, physical inactivity, current smoking, hypertension, diabetes, and obesity), and mortality revealed that participants with low socioeconomic status had greater mortality compared with those with high socioeconomic status (RR 1·42, 95% CI 1·38–1·45 for men; 1·34, 1·28–1·39 for women).[99]

In Kenya for the last 10 years, there has been a downward trend in both malaria morbidity and mortality[90].In 2015, reported confirmed malaria cases both at the facility and the community levels were estimated at 1,499,027 and 82,141 respectively, while 15,061 deaths were reported in the same year.[90]In Kenya, the top three causes of DALYs in 2010 were reported as HIV/AIDS, lower respiratory infections, and malaria and out of the 25 diseases ranked in the global burden of disease profile for Kenya 2010, malaria accounted for 10% of YLL, and was ranked 3rd with 1,550 years of life lost due to malaria deaths.[95]

The concentration index is a relative measure of inequality that indicates the extent to which a health indicator is concentrated among the disadvantaged or the advantaged.[21, 100] Given that a population is ranked by increasing socioeconomic status, the concentration index has a negative value when the health indicator is concentrated among the disadvantaged and a positive value when the health indicator is concentrated among the advantaged[21]. If a single individual (the smallest possible population subgroup) accounted for 100% of a health indicator in a population (the highest relative inequality that is theoretically possible), this would cause the concentration index to approach its maximum absolute value of the either negative one or positive one. If the concentration index is greater than zero, implies health variable is disproportionately concentrated on the rich while if less than zero implies its concentrated amongst the poor[21,100]. When the concentration index is exactly zero it implies the health variable is proportionate.[15]

Since 2006 in Kenya, there has been a huge scale-up of malaria prevention and control interventions including universal coverage with long-lasting insecticidal bednets (ITNs), indoor residual spraying of insecticides, intermittent preventive treatment in pregnancy and effective case management and as a result there has been decline mortality and mortality over time in some groups in Siaya County[40, 54, 101]. However, there has been limited data on the empirical and economic burden of malaria and the microeconomic effect of malaria

prevention and control interventions over the last decade. Longitudinal data were examined on YLL, YLD and DALY burdens using malaria-specific deaths and prevalence stratified by household socioeconomic status from 2006–2014 in a malaria-endemic area of western Kenya.

Methods

Site

The Kenya Medical Research Institute (KEMRI) and Centres for Disease Control and Prevention (CDC) supported health and demographic surveillance system (HDSS) in western Kenya HDSS has been described in detail elsewhere[39, 41]. Continuous routine surveillance in three data collection rounds each year were conducted within the HDSS. The HDSS area covered a population of approximately 223,000 people residing in 393 villages and was located in three sub-counties of Siaya County spread over approximately 700 km^2 along the shores of Lake Victoria. The vast majority of the population earns their living through subsistence farming and fishing [39, 41]. Health indicators are poor compared to national level;[42, 43, 102]for example, in 2015, the infant mortality rate was 125 per 1,000 live births compared to 77 per 1,000 live births nationally, under-5 mortality was 227 per 1,000 live births compared to 115 per 1,000 nationally and overall life expectancy at birth was 38 years (i.e., 36 years for men and 39 years for women) compared to 48 years nationally[102]

Data collection

Malaria morbidity and mortality data used in this study were collected between 2006 and 2014 within KEMRI and CDC HDSS sites, which included Gem and Rarieda Sub-counties. Karemo area which is in the third Sub-county of Alego-Usonga was excluded since it only joined HDSS in 2007. An average of16, 000 households were visited every year and the number of self-reported malaria cases and deaths by the households were recorded. Verbal

autopsy interviews were conducted in every household where deaths occurred to establish the probable cause of death and then malaria-specific deaths were recorded[102].

Data collection rounds were conducted every 4 months per year, to collect data on births, deaths, pregnancies, migrations, morbidity, parent survival status, immunization for children aged under 2 years, educational status, religion, marital status and ethnicity from individuals in the households located within the HDSS. Data on socio-economic variables were collected every two years for each household. In each year malaria prevalence surveys were conducted within the HDSS in all age groups[40].

Data Analysis

Various methods have been proposed to calculate DALYs [81, 94] However, in this study we have calculated the number of DALYs using the basic DALY calculation methodology. The method was not based on age weighting and time discounting (social preferences). Malaria prevalence-specific data from 2006 to 2014 by age groups and gender were used to calculate YLD and YLL parameters. The formula adopted from the GBD study of 2010 was used to calculate these two parameters.[93, 94] The GBD 2010, deviated from the earlier years' global burden of disease studies in that their analysts chose to use disease prevalence instead of incidence to calculate YLDs [6].The YLDs were computed by multiplying the prevalence of malaria, by DW associated with the disease. Data on malaria prevalence, number of malaria deaths, life expectancy at the age of death and Disability weights were entered into programmed excel spreadsheets which automatically produced outputs in the form of YLL, YDL, and DALYs. The YLDs in this paper were calculated for three age categories (<5 years, 5–14 years and >15years) based on the malaria prevalence from the cross-sectional surveys conducted from2006-2014 and classified by wealth quintiles (SES) and gender. The YLLs were computed using the number of malaria/anaemia deaths per year(2006-2014)for

each age category, using life expectancy estimates extracted from the local WHO life tables [81].YLDs, YLLs, and DALYs were calculated for each age category and stratified by gender and household socioeconomic status (SES).

Calculation of DALYs using a prevalence-based approach

DALYs, which is the sum of YLD and YLL, were calculated using the prevalence-based approach as described in the GBD study[94]. This approach was first used in 2014 by Wagner et al [94]to analyze the burden of epilepsy among a rural population in South Africa in the absence of incidence data but has not been used to analyze malaria data in endemic areas and comparing outcomes by SES.

Years lived with Disability (YLD)

YLD was computed by multiplying the malaria prevalence for each age category, by socioeconomic status (SES) and by gender using a constant disability weight (DW) for malaria of 0.191 extracted from the WHO updates.[9, 103]

YLD_p = Prevalence * DW

Years of Life Lost due to premature death due to malaria (YLL)

The YLL was calculated as the product of the number of deaths due to malaria occurring in each age category, gender and SES per year and the average local standard life expectancy at the mean age of death extracted from WHO life tables for Kenya.

YLL = number of deaths per year * Local life expectancy at age of deat**h**

Disability Adjusted Life Years (DALYs)

DALYs were calculated by summing up the YLDs with YLL for each age category and stratified by household socioeconomic status (SES) and gender.

$DALYs = YLD_p + YLL$

Socioeconomic status (SES)

Different methodologies for assessing SES employing broad quantitative and qualitative aspects of poverty have been recommended including PCA, Polychoric PCA, and multiple component analysis (MCA) [33].SES indices were generated using MCA. The model inputs included; the occupation of household head, (categorized as; doing business, commercial ,farming, housewife, salaried worker, Skilled labor, unskilled labor and subsistence farming), primary source of drinking water, type of cooking fuel, ownership of household assets (categorized as; lantern lamp, radio, television, bicycle) and ownership of livestock (categorized as; cattle, chicken, pigs, donkey). The households were categorized into five socioeconomic quintiles, which were then aggregated into a binary variable with the first three SES quintiles classified as the 'poor' and the fourth and fifth quintiles classified as the 'less-poor'[22, 23, 62]A study from rural western Kenya compared the three methods of ranking households into SES quintiles and established that although the methods produced similar results, MCA gave the highest percentage of the total variation for the household asset variables and thus the largest weights for the variables[21].In this study household assets and characteristics, the approach was adopted because collecting data on household assets is much easier and more convenient. Unlike income or expenditure which is not easy to collect and when it is collected the data may not be accurate due to under-reporting, seasonality, recall bias and imputation of values[104].The magnitude of socioeconomic related inequalities was measured using the concentration index recommended by the WHO and World Bank guidelines.[100, 105]. Concentration index lies between (-1, 1) and when the value is negative implies the health outcome is concentrated amongst the poor and when positive implies the health value is concentrated amongst less poor[100, 105].

Results

Socio-demographic characteristics of the study population

From 2006 to 2014, a total of 3504 individual deaths were reported in all age groups across all quintiles. These ranged from 586 malaria-related deaths in 2006 to 788 in 2008 and down from 835 malaria deaths amongst the poorest quintile compared to 616 in the least poor quintile. Overall, a total of 2075 children under5 years died of malaria, 275 amongst 5-14 years and 1154 amongst the adults aged ≥15 years (Table 1). The distribution of malaria-related deaths amongst males and females by age groups, by year and wealth quintiles are described in Tables 2 and 3.

Table 1 Total malaria-related deaths in KEMRI HDSS from 2006-2014, Siaya County

Socioeconomic status	Age Category	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
n/N (n=deaths, N=Population)		n/N	n/N	n/N	n/N	n/N	n/N	n/N	n/N	n/N	n/N
Poorest	<5years	69/118	49/122	93/147	65/147	36/142	29/142	18/1750	13/1750	21/3177	393/7495
	5 -14 years	9/30	6/34	4/51	7/51	5/66	1/66	3/1591	4/1591	4/3218	43/6698
	>=15 years	104/71	97/113	78/143	47/143	22/129	10/129	11/3355	15/3355	15/6364	399/13802
	All ages	182/219	152/269	175/341	119/341	63/337	40/337	32/6696	32/6696	40/12759	835/27995
2nd poor	<5years	76/96	55/144	113/209	82/209	58/168	26/168	27/2536	30/2536	24/4547	491/10613
	5 -14 years	5/38	4/58	4/79	8/79	6/103	4/103	5/2461	7/2461	3/5055	46/10437
	>=15 years	42/84	55/116	36/161	16/161	13/157	2/157	5/3966	9/3966	7/8361	185/17129
	All ages	123/218	114/318	153/449	106/449	77/428	32/428	37/8963	46/8963	34/17963	722/38179
3rd poor	<5years	69/129	52/151	115/172	71/172	34/178	28/178	25/2895	23/2895	15/4966	432/11736
	5 -14 years	7/33	9/66	10/88	9/88	10/135	2/135	7/3083	6/3083	4/6471	64/13182
	>=15 years	28/99	37/110	36/151	15/151	17/183	4/183	14/5010	14/5010	8/10125	173/21022
	All ages	104/261	98/327	161/411	95/411	61/496	34/496	46/10988	43/10988	27/21562	669/45940
4th poor	<5years	49/99	51/183	99/187	59/187	49/171	28/171	19/3341	23/3341	19/5422	396/13102
	5 -14 years	7/50	6/81	5/100	6/100	10/97	4/97	6/3874	4/3874	6/7449	54/15722
	>=15 years	47/69	49/149	39/167	25/167	13/143	9/143	8/6440	10/6440	12/12085	212/25803
	All ages	103/218	106/413	143/454	90/454	72/411	41/411	33/13655	37/13655	37/24956	662/54627
Least poor	<5years	32/95	35/202	110/193	65/193	40/181	22/181	19/3644	25/3644	15/5527	363/13860
	5 -14 years	9/45	6/119	7/120	12/120	7/121	5/121	10/4684	7/4684	5/8990	68/19004
	>=15 years	33/78	37/177	39/158	27/158	13/171	7/171	10/8130	7/8130	12/15498	185/32671
	All ages	74/218	78/498	156/471	104/471	60/473	34/473	39/16458	39/16458	32/30015	616/65535
	Overall	586/1134	548/1825	788/2126	514/2126	333/4290	181/4290	187/56760	197/56760	170/107255	3504/236566

Table 2 Total female malaria deaths by year, age groups and by wealth quintiles, in Siaya County western Kenya

SES	Age Category	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
n/N	[n=deaths N=Population]	n/N	n/N	n/N	n/N	n/N	n/N	n/N	n/N	n/N	n/N
Poorest	<5years	37/60	21/64	51/57	26/57	15/78	13/78	9/873	6/873	8/1608	186/3748
	5 -14 years	8/16	3/13	1/26	3/26	1/20	1/20	0/801	1/801	2/1602	20/3325
	>=15 years	76/43	66/62	53/85	30/85	12/68	6/68	7/2291	11/2291	9/4169	270/9162
	All ages	121/119	90/139	105/168	59/168	28/166	20/166	16/3965	18/3965	19/7379	476/16235
2nd poor	<5years	33/42	33/70	66/102	36/102	23/77	14/77	11/1279	14/1279	12/2273	242/5301
	5 -14 years	4/19	1/31	2/37	3/37	5/58	0/58	3/1264	5/1264	0/2575	23/5343
	>=15 years	24/50	24/68	17/95	8/95	7/83	0/83	2/2643	6/2643	4/5249	92/11009
	All ages	61/111	58/169	85/234	47/234	35/218	14/218	16/5186	25/5186	16/10097	357/21653
3rd poor	<5years	37/68	24/76	52/75	36/75	15/95	15/95	13/1459	11/1459	7/2514	210/5916
	5 -14 years	2/15	3/34	5/47	6/47	2/75	1/75	4/1613	3/1613	3/3313	29/6832
	>=15 years	16/61	19/73	22/80	10/80	10/104	1/104	8/3127	8/3127	5/6128	99/12884
	All ages	55/144	46/183	79/202	52/202	27/274	17/274	25/6199	22/6199	15/11955	338/25632
4th poor	<5years	26/51	24/87	50/108	30/108	23/70	12/70	9/1678	13/1678	13/2702	200/6552
	5 -14 years	3/23	2/46	3/56	5/56	7/49	1/49	3/1973	1/1973	2/3746	27/7971
	>=15 years	26/48	27/83	16/94	15/94	6/78	6/78	3/3868	5/3868	5/7148	109/15359
	All ages	55/122	53/216	69/258	50/258	36/197	19/197	15/7519	19/7519	20/13596	336/29882
Least poor	<5years	12/43	18/104	59/87	27/87	16/81	10/81	6/1817	12/1817	5/2708	165/6825
	5 -14 years	2/31	3/67	2/68	5/68	4/62	3/62	7/2398	4/2398	1/4605	31/9759
	>=15 years	12/40	21/100	17/95	13/95	5/93	2/93	6/4617	3/4617	2/8540	81/18290
	All ages	26/114	42/271	78/250	45/250	25/236	15/236	19/8832	19/8832	8/15853	277/34874
Overall		318/610	289/978	416/1112	253/1112	151/2182	85/2182	91/31701	103/31701	78/58880	1784/130458

YLD, YLL, and DALYs for males and females

Overall, among the females, total number of years lived with disability (YLD) due to malaria illness irrespective of age category was 61.9 (95%CI=61.7-62.1) amongst the individuals in poorest households compared to 99.9 (95%CI=99.7-100.1) in the least poor households while, YLL irrespective of age was 16,680 (95% CI=16,574 -16,686) and 14,122(CI=14,016-14,227) amongst the poorest and richest households respectively. The DALYs amongst females, irrespective of age group were 15% higher amongst individuals in the poorest households than in the least poor households (**see table4**). Among males in the poorest households, YDLs was 68 (95%CI= 67.4-67.8), while in the least poor households the figure stood at 94 (95%CI=93.7-94.2). The YLL and DALYs for males in the poorest and richest households did not show any significant difference (Table 5). Among all age categories regardless of gender and socio-economic status, children under 5yrs of age disproportionately bear a higher burden of malaria in terms of DALYs (Table 4&5). Among all age categories irrespective of gender, years lived with disability (YLD) was in favour of the least disadvantaged quintiles as indicated by a positive concentration index of 0.0633(95%CI= (-0.0078 -0.1344), 0.6947(CI=0.275 -0.1114) while the Disability-adjusted life years (DALYs) was in favour of the poorest households with a negative concentration index of -0.0283(95%CI=-0.07363 -0. 0169) and -0. 0112 (95%CI=-0.041 -0.0125) for females and males respectively.

Table 3 Total male deaths by year, age and SES in the KEMRI CDC HDSS, Western Kenya 2006-2014											
socioeconomic status	Age Category	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
Poorest	<5years	32/60	28/64	42/57	39/57	21/78	16/78	9/873	7/873	13/1608	207/3748
	5 -14 years	1/16	3/13	3/26	4/26	4/20	0/20	3/801	3/801	2/1602	23/3325
	>=15 years	28/43	31/62	25/85	17/85	10/68	4/68	4/2291	4/2291	6/4169	129/9162
	All ages	61/119	62/139	70/168	60/168	35/166	20/166	16/3965	14/3965	21/7379	359/16235
2nd poor	<5years	43/42	22/70	47/102	46/102	35/77	12/77	16/1279	16/1279	12/2273	249/5301
	5 -14 years	1/19	3/31	2/37	5/37	1/58	4/58	2/1264	2/1264	3/2575	23/5343
	>=15 years	18/50	31/68	19/95	8/95	6/83	2/83	3/2643	3/2643	3/5249	93/11009
	All ages	62/111	56/169	68/234	59/234	42/218	18/218	21/5186	21/5186	18/10097	365/21653
3rd poor	<5years	32/68	28/76	63/75	35/75	19/95	13/95	12/1459	12/1459	8/2514	222/5916
	5 -14 years	5/15	6/34	5/47	3/47	8/75	1/75	3/1613	3/1613	1/3313	35/6832
	>=15 years	12/61	18/73	14/80	5/80	7/104	3/104	6/3127	6/3127	3/6128	74/12884
	All ages	49/144	52/183	82/202	43/202	34/274	17/274	21/6199	21/6199	12/11955	331/25632
4th poor	<5years	23/51	27/87	49/108	29/108	26/70	16/70	10/1678	10/1678	6/2702	196/6552
	5 -14 years	4/23	4/46	2/56	1/56	3/49	3/49	3/1973	3/1973	4/3746	27/7971
	>=15 years	21/48	22/83	23/94	10/94	7/78	3/78	5/3868	5/3868	7/7148	103/15359
	All ages	48/122	53/216	74/258	40/258	36/197	22/197	18/7519	18/7519	17/13596	326/29882
Least poor	<5years	20/43	17/104	51/87	38/87	24/81	12/81	13/1817	13/1817	10/2708	198/6825
	5 -14 years	7/31	3/67	5/68	7/68	3/62	2/62	3/2398	3/2398	4/4605	37/9759
	>=15 years	21/40	16/100	22/95	14/95	8/93	5/93	4/4617	4/4617	10/8540	104/18290
	All ages	48/114	36/271	78/250	59/250	35/236	19/236	20/8832	20/8832	24/15853	339/34874
Overall	Total	268/610	259/978	372/1112	261/1112	182/2182	96/2182	96/31701	94/31701	92/58880	1720/130458

Table 4. Absolute Malaria-related YLDs, YLLs, and DALYs amongst Females in Siaya County, Kenya

Socioeconomic status	Age Category	Years lived with disability (YLD)	95% CI Lower	95% CI Upper	Years lost due to premature death	95% CI Lower	95% CI Upper	Disability Adjusted Life Years (DALYs)	95% CI Lower	95% CI upper
Poorest	<5years	19.9	19.7	20.02	11,167	11,066	11,268	11,187	11,086	11,288
	5 -14 years	24	24	25	1,166	1,065	1,267	1,191	1,089	1,292
	>=15 years	18	17	18	4,347	4,246	4,448	4,364	4,263	4,465
	All ages	**62**	**62**	**62**	**16,680**	**16,574**	**16,686**	**16,742**	**16,636**	**16,847**
2nd poor	<5years	33	33	34	14,593	14,491	14,694	14,626	14,525	14,727
	5 -14 years	30	30	31	1,369	1,267	1,470	1,399	1,298	1,500
	>=15 years	21	21	21	2,409	2,308	2,511	2,431	2,329	2,532
	All ages	**85**	**85**	**85**	**18,371**	**18,265**	**18,476**	**18,455**	**18,350**	**18,561**
3rd poor	<5years	36	36	36	12,605	12,503	12,706	12,640	12,539	12,742
	5 -14 years	38	38	39	1,734	1,633	1,836	1,773	1,672	1,874
	>=15 years	22	21	22	2,736	2,634	2,837	2,757	2,656	2,858
	All ages	**96**	**96**	**96**	**17,074**	**16,969**	**17,180**	**17,170**	**17,065**	**17,276**
4th poor	<5years	36	36	37	12,117	12,016	12,218	12,154	12,052	12,255
	5 -14 years	38	38	38	1,578	1,477	1,679	1,616	1,515	1,717
	>=15 years	23	23	23	3,206	3,105	3,307	3,229	3,128	3,330
	All ages	**97**	**97**	**97**	**16,902**	**16,796**	**17,007**	**16,999**	**16,893**	**17,104**
Least poor	<5years	33	33	33	9,954	9,853	10,055	9,987	9,886	10,088
	5 -14 years	41	41	41	1,868	1,767	1,969	1,909	1,808	2,010
	>=15 years	26	26	26	2,299	2,198	2,400	2,325	2,224	2,426
	All ages	**100**	**100**	**100**	**14,122**	**14,016**	**14,227**	**14,221**	**14,116**	**14,327**
Concentration Index										
	<5 years	**0.0633**	-0.0078	0.1344	**-0.0289**	-0.07419	0.01643	**-0.0283**	-0.07362	0.0169
	5-14 years	**0.06623**	-0.0080	0.1405	**-0.0377**	-0.0782	0.0027	**-0.03713**	-0.07750	0.0032
	15 + years	**0.07170**	-.00151	0.14490	**-0.0224**	-0.06657	0.02172	**-0.0219**	-0.0658	0.0220

Table 5. Absolute Malaria-related YLDs, YLLs, and DALYs amongst males in Siaya County, Kenya

Socioeconomic status	Age Category	Years lived with disability	95% CI Lower	upper	Years lost due to premature death	95%CI Lower	Upper	Disability Adjusted Life Years	95% CI Lower	Upper
Poorest	<5years	25.8	25.6	26.0	11,965	11,859	12,070	11,990	11,884	12,096
	5 -14 years	31.7	31.5	31.9	1,111	1,005	1,216	1,142	1,037	1,248
	>=15 years	10.1	9.9	10.4	2,622	2,516	2,727	2,632	2,526	2,737
	All ages	**67.6**	**67.4**	**67.8**	**15,697**	**15,591**	**15,703**	**15,764**	**15,658**	**15,870**
2nd poor	<5years	29.2	29.0	29.5	14,600	14,494	14,705	14,629	14,523	14,735
	5 -14 years	27.7	27.5	27.9	1,259	1,153	1,365	1,287	1,181	1,393
	>=15 years	12.4	12.2	12.7	2,348	2,243	2,454	2,361	2,255	2,466
	All ages	**69.3**	**69.1**	**69.6**	**18,207**	**18,101**	**18,313**	**18,276**	**18,171**	**18,382**
3rd poor	<5years	34.0	33.8	34.2	12,925	12,820	13,031	12,959	12,853	13,065
	5 -14 years	44.3	44.1	44.5	2,051	1,945	2,156	2,095	1,989	2,201
	>=15 years	13.9	13.7	14.2	1,656	1,550	1,761	1,670	1,564	1,775
	All ages	**92.3**	**92**	**92.5**	**16,631**	**16,526**	**16,737**	**16,724**	**16,618**	**16,829**
4th poor	<5years	36.1	35.9	36.3	11,988	11,883	12,094	12,024	11,919	12,130
	5 -14 years	41.6	41.4	41.9	1,480	1,374	1,585	1,521	1,415	1,627
	>=15 years	15.3	15.1	15.5	2,395	2,289	2,500	2,410	2,304	2,516
	All ages	**93.0**	**92.8**	**93.3**	**15,863**	**15,757**	**15,968**	**15,956**	**15,850**	**16,061**
Least poor	<5years	28.1	27.8	28.3	11,014	10,908	11,120	11,042	10,936	11,148
	5 -14 years	45.1	44.8	45.3	2,193	2,087	2,298	2,238	2,132	2,343
	>=15 years	20.8	20.6	21.1	2,545	2,439	2,651	2,566	2,460	2,672
	All ages	**94.0**	**93.7**	**94.2**	**15,752**	**15,646**	**15,857**	**15,845**	**15,740**	**15,951**
Concentration Index										
	<5 years	**0.06947**	0.0275	0.1114	**-0.0116**	-0.04285	0.01967	**-0.0112**	-0.042	0.0200
	5-14 years	**0.06478**	0.0146	0.1149	**-0.0148**	-0.0416	0.0121	**-0.01430**	-0.041	0.0125
	15 + years	**0.06455**	0.01441	0.11468	**-0.0094**	-0.03823	0.01953	**-0.0090**	-0.038	0.0198

Trends in Socio economic inequalities in DALYs.

Over the 9 years under surveillance, DALYs reduced nearly 3-fold, from 11,283 in 2006 to 4,026 in 2014. In each socioeconomic group, the trend remains the same between 2006 and 2014 (**see table 6**). The poorest 60% of the households, accounts for more than 60% of malaria burden in terms of DALYs (52,364) while the least poor 40% of the households accounted for only 38% of the total DALYs (31,220).In all the socioeconomic groups, 99% of the total DALYs were due to YLL and only one per cent was accounted for by YLD. Disability-adjusted life years were higher amongst poor households for all the 3 age categories with negative concentration indexes of -0.0283, 95% (CI=-0.0371 -0.0219) for females and -0.0112, 95% (CI= -0.0143, - 0.0090) for males (tables 4&5).

Table 6 Distribution of DALYs amongst males, 2006 – 2014 in Siaya County, Kenya.

Socioeconomic status	Age Category	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
Poorest	<5years	1216	2081	3009	1570	952	836	594	393	536	11,187
	5 -14 years	174	448	59	181	67	64	2	66	130	1,191
	>=15 years	1122	1294	902	411	257	84	78	119	97	4,364
	All ages	**2,512**	**3,822**	**3,970**	**2,161**	**1,276**	**983**	**674**	**578**	**763**	**16,739**
2nd poor	<5years	1913	1857	3895	2174	1459	883	728	915	801	14,625
	5 -14 years	59	225	117	182	312	2	179	319	3	1,398
	>=15 years	584	662	477	230	207	2	52	131	86	2,431
	All ages	**2,556**	**2,743**	**4,489**	**2,586**	**1,978**	**887**	**959**	**1366**	**891**	**18,455**
3rd poor	<5years	1391	2081	3069	2175	956	946	842	721	460	12,641
	5 -14 years	161	120	292	361	133	64	254	194	194	1,773
	>=15 years	529	486	617	286	254	28	203	206	149	2,758
	All ages	**2,080**	**2,687**	**3,978**	**2,821**	**1,343**	**1,038**	**1,299**	**1,121**	**803**	**17,170**
4th poor	<5years	1391	1462	2950	1813	1459	757	600	853	869	12,154
	5 -14 years	109	169	176	282	434	64	193	69	122	1,618
	>=15 years	833	790	449	426	155	152	90	205	129	3,229
	All ages	**2,333**	**2,421**	**3,574**	**2,522**	**2,047**	**974**	**882**	**1,127**	**1,119**	**16,999**
Least poor	<5years	1043	697	3481	1630	994	631	393	786	331	9,986
	5 -14 years	175	105	118	303	254	187	442	258	67	1,909
	>=15 years	585	365	530	371	130	44	155	92	52	2,324
	All ages	**1,803**	**1,167**	**4,129**	**2,305**	**1,378**	**862**	**991**	**1,136**	**450**	**14,221**
	Overall	**11,283**	**12,841**	**20,141**	**12,396**	**8,022**	**4,744**	**4,806**	**5,328**	**4,026**	**83,587**

Discussion.

This study shows that the malaria burden in terms of DALYs has significantly fallen over the 9 years of surveillance. This suggests that the malaria control program implemented within Siaya County and across the country are working and able to keep down malaria morbidity and mortality. The results have also revealed that poorer households generally bear a higher burden of malaria in terms of disability-adjusted life years compared to richer households. Richer households due to their high purchasing power, are able to easily afford malaria control and treatment commodities and therefore, can easily control, manage and treat malaria cases. Our results are consistent with a study done in Malawian which he analyzed the relationship between household income and economic burden of malaria; they concluded that households with low- income disproportionately bear the economic burden of malaria compared to higher-income households[97]. This study had demonstrated more comprehensively the huge economic burden of malaria illness being borne by poor households in developing countries and especially those who are economically disadvantaged and it has added weight to international calls for more investment in disease prevention and pro-poor curative health services[97]. A South African national burden of disease study in the year 2000 estimated that HIV accounts for 39% of YLL, trauma (violence and road traffic accidents) for 10.5%, tuberculosis for 4.7% and diarrheal diseases for 4.2% of YLL[106]. These were the leading causes of premature mortality in South Africa then and together made up over 58% of YLL. Of the diseases included in the study, HIV and other communicable diseases were found to be more heavily concentrated among poor socioeconomic groups than richer socioeconomic groups[106]. The South African study investigated socio-economic related health inequality for self-reported ill health and disability in the country and reported that ill health and disability were more in favour of poor households than the rich ones.[1]The study further demonstrated that the trend in the magnitude of socioeconomic related

inequalities tended to decline overtime[107]. Our results further showed an unexpected increase in years of life lived with disability across socioeconomic groups, with the least poor households bearing the highest-burden in terms of years lived with disability, the cause of this is unclear but it could have been driven by one age category (5-14years) which has not been targeted by most malaria control interventions and has consistently maintained a high number of years lived with disability in all quintiles. Of all the age categories, children under 5years of age have the highest number of years of life lost due to premature death (YLLs) in all quintiles. The use of DALY philosophy is key in assisting governments to set health service priorities; identifying disadvantaged groups and targeting of health interventions; and providing a comparable measure of output for intervention, program and sector evaluation and planning[92]. WHO technical strategy set an ambitious but achievable goal for 2030, of reducing malaria case incidence and malaria-related mortality by at least 90%.[33]. To do this there is still a need to monitor the socioeconomic effect of malaria control intervention on equity in terms of years lost due to disability. There will still be a need to understand how malaria case incidence and mortality are distributed among various socioeconomic groups in guiding pro-poor interventions to achieve equity in the fight against malaria infection and mortality in endemic areas.

Limitations

Since our DALYs have been expressed as absolute estimates, we can only provide an idea about the total population but not the relative health status of the population. Given the absolute numbers, we might not be able to make direct comparisons of health status for different population groups (e.g. 200 per 10,000 population). Since DALYs have not been expressed relative to the number of cases, it is not easy to make a comparison of the disease impact at patient –level (e.g. 50 per 1000 cases). Second limitation; since in the calculation of

DALYs we have not applied age weighting and time discounting, it will not be easy for the DALY estimates to be compared with other similar estimates. KEMRI HDSS is situated largely a rural setting, therefore it was not easy to clearly distinguish between the poor and least poor population groups using socioeconomic indices. For example, the DALY estimates for the males in this study did not show any significant difference between the poorest and least poor households. This may cause a bias in favour of either the poor or the rich. This coupled with the fact that asset index methodology does not consider the quantity and quality of the assets possessed by the households, the difference among various socioeconomic groups could become even more obscure. A study from rural western Kenya compared the three methods of ranking households into SES quintiles and established that although the methods produced similar results, MCA gave the highest percentage of the total variation for the household asset variables and thus the largest weights for the variables. The study concluded that MCA was a better model for generating asset weights than PCA or Polychoric PCA.[21] The study further conducted comparison between ordinary PCA and MCA and established that 93% of households were placed in the same quintile by both methods, 87% of the households by ordinary PCA and Polychoric, and 91% by Polychoric and MCA and that ordinary PCA asset index was statistically significantly correlated with the index based on MCA ($r = 0.997$, $p < 0.01$[27]· The use of MCA could not have resulted in any significant bias given that it was the best amongst all the methods tested.

Conclusion.

Poor households, children < 5 years in poor households and women disproportionately bore the higher burden of malaria compared to the least poor households, older children or males. Although socioeconomic inequalities in the economic and population burden of malaria still exist, the decline may be due to increased intensification of malaria control over time.

Interventions targeting the poor, female and children <5 should be considered to bring down overall morbidity and mortality due to malaria in economic perspective. Although children 5-14 years have the highest burden of morbidity, children <5 had the highest years lost due to premature deaths hence the highest DALYs.

Declarations

Ethics approval and consent to participate

The HDSS protocol and consent procedures, including surveillance, were approved by the KEMRI scientific steering committee (SSC) (#1801) and CDC institutional review board (IRB) (#3308) annually. The malaria-specific surveys, including the collection of blood samples, received approval from the KEMRI SSC (#2031) and CDC IRB (#6012).

Abbreviations

YLL: years of life lost to premature death YLD: years lived with disability; MCA: multiple correspondence analysis CDC: Centers for Disease Control and Prevention; DALY: disability-adjusted life year; HDSS: health and demographic surveillance system; IRB: institutional review board; ITN: insecticide-treated net; KEMRI: Kenya Medical Research Institute; SES: socioeconomic status; SSC: scientific steering committee.

Conflicts of interest

The authors declare that they have no competing interests

Authors' contributions

MD, VW, SK conceived and designed the study. MD, VW, SK coordinated and performed the study. VW analysed the data. VW, MD, SK, AMB, AS, SPK, FtK, PPH and LN drafted the manuscript. All authors read and approved the final manuscript.

Disclaimer

The findings and conclusions presented in this manuscript are those of the authors and do not necessarily reflect the official position of KEMRI, Liverpool School of Tropical Medicine, U.S. President's Malaria Initiative, U.S. Agency for International Development or CDC. The corresponding author had full access to the study data and had final responsibility for the decision to submit for publication.

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Availability of data

Requests for the data may be made to the KEMRI data manager, Vincent Were, vwere@kemricdc.org.

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Chapter 6: Large-scale implementation of disease control programmes: A cost-effectiveness analysis of long-lasting insecticide-treated bed net distribution channels in a malaria-endemic area of western Kenya: Study Protocol

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Large-scale implementation of disease control programmes: A cost-effectiveness analysis of long-lasting insecticide-treated bed net distribution channels in a malaria-endemic area of western Kenya - Study Protocol

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Abstract

Introduction: Historically, Kenya has used various distribution models for long-lasting insecticide-treated nets (LLINs) with variable results in population coverage. The models presently vary widely in scale, target population, and strategy. There is limited information to determine the best combination of distribution models, which will lead to sustained high coverage and is operationally efficient and cost-effective. Standardized cost information is needed in combination with program effectiveness estimates to judge the efficiency of LLIN distribution models and options for improvement in implementing malaria control programmes. The study aims to address the information gap, estimating distribution cost and the effectiveness of different LLINs distribution models, and comparing them in an economic evaluation.

Methods: Evaluation of cost and coverage will be determined for five different distribution models in Busia County, an area of perennial malaria transmission in western Kenya. Cost data will be collected retrospectively from health facilities, Ministry of Health, donors and distributors. Program-effectiveness data, defined as the number of people with access to an LLIN per 1,000 population, will be collected through a triangulation of data from a nationally-representative, cross-sectional malaria survey, a cross-sectional survey administered to a sub-sample of beneficiaries in Busia County and LLIN distributors' records. Descriptive statistics and regression analysis will be used for the evaluation. A cost-effectiveness analysis will be performed from a health-systems perspective, and cost-effectiveness ratios will be calculated using bootstrapping techniques.

Ethics and Dissemination: The study has been evaluated and approved by the Kenya Medical Research Institute, Scientific and Ethical Review Board (SERU No. 2997).All

participants will provide written informed consent. The findings of this economic evaluation will be disseminated through peer-reviewed publications.

Keywords: Economic evaluation, Insecticide-treated bed nets, supply, and distribution, Cost analysis

Strengths and limitations of this study

- The main strength of our study is that it is the first to look at the cost-effectiveness of parallel net distribution channels and coverage results that can be expected from each channel based on financial inputs.
- The main weakness of the study is that it localized in one county of western Kenya and therefore, the results might not be representative or generalizable to all of Kenya or other countries.

Background

In Kenya, five channels of distributing long-lasting insecticide-treated bed nets (LLINs) have been used historically in the implementation of malaria control programmes with variable results in population coverage [1–6]. In 2004, when LLINs were distributed through the commercial retail sector and heavily-subsidized social-marketing schemes in rural shops and public health facilities, LLIN coverage was estimated at 7.1% [5 and 6]. By 2005, coverage with LLINs increased to 23.5% with the provision of free LLINs in antenatal care and child health clinics in public health facilities [7]. In 2011, LLIN coverage dramatically increased to 67% after the free distribution of LLINs in a Ministry of Health (MoH) mass distribution campaign with the goal of universal coverage, defined as one LLIN per two people in each household [1–4]. In addition, since 2001, heavily-subsidized LLINs have been distributed through social-marketing outlets in rural areas (i.e., approximately 600,000–800,000 nets annually) [1&3]. In 2012, the National Malaria Control Program (NMCP)/MoH, began a concerted effort to scale up malaria community case management. Using community health volunteers to distribute nets, a continuous LLIN distribution pilot project was implemented in 2014–15, in Samia, an administrative location in Funyula division of Busia County in western Kenya.

Post-campaign surveys after the rolling 2011–2012 universal coverage mass distribution demonstrated low LLIN usage among all age groups [8]. For children less than 5 years old, usage ranged from 28–59% across the different malaria epidemiological zones and 31–50% in the general population across zones [5, 9 and 10]. The proportion of persons using LLINs did not increase significantly after the year 2011–2012 mass campaign compared to the 2010 Kenya Malaria Indicator Survey (KMIS), which showed that the proportions of children under 5 years of age and general population who slept under an LLIN the previous night were 42% and 39%, respectively [5, 9 and 10].

By mid-2014, only 34% of households nationally met the universal coverage indicator of one LLIN per two people [11]. Access to nets, defined by attaining universal coverage at the household level, is directly associated with the use of nets by both children under 5 years of age and all household members. In households that met universal coverage (i.e., having at least one LLIN for every two people), 87% of children under 5 years of age slept under a net the previous night compared to 49% in households without universal coverage [7]. Thus, a major part of the solution to increasing net use in Kenya is to increase the number of nets within a household to ensure universal coverage. Despite multiple functional distribution channels and massive investments, LLIN coverage still remains well below the Kenya National Malaria Strategy 2009─2017 (NMS) and World Health Organization goals of having at least 80% of people living in malaria-risk areas using LLINs [2, 5 and 9].

Studies from various parts of Africa indicate that the use of LLINs has a beneficial effect on malaria transmission, severe malaria and mortality [12 and 13]. Similarly, there are numerous studies demonstrating the cost-effectiveness of LLINs in different parts of the world and in various contexts [14, 15, 16, 17 and 18]. However, information is limited to the actual costs of parallel distribution channels in the same context and coverage results that can realistically be achieved from each channel based on financial inputs [19]. In 2013, Kenya devolved

responsibility for health service delivery from the central government to 47 county governments as mandated in the 2010 Constitution of Kenya. This major restructuring potentially creates challenges due to inconsistencies in practice, duplicate structures, and may hamper malaria control.

In this new and evolving health services delivery context in Kenya, the NMCP/MoH, counties, donors and stakeholders require evidence-based, cost-effectiveness data on LLIN distribution channels to make informed, rational decisions for program implementation and targets. This study is intended to help provide the evidence required for decision making. The goals of this economic evaluation are, therefore, to determine the actual cost of delivering a net to the end-user in each channel and the coverage levels that can be achieved given a financial input. The economic evaluation results will help inform both policy and program implementation by establishing the costs and outcomes for each LLIN distribution channel in Kenya.

Objectives

The main objective of the economic evaluation is to assess the allocative efficiency of a limited budget to support the implementation of LLINs as a prevention strategy and determine the most cost-effective mix of LLIN distribution channels that would maximize coverage for beneficiaries.

Specific objectives

Determine and compare the unit cost associated with distributing an LLIN to a beneficiary through the following distribution channels:

a. Universal coverage mass distribution campaigns
b. Routine distribution through antenatal and child health clinics
c. Continuous community distribution by community health volunteers
d. Social marketing by community-based organizations through rural outlets

e. Commercial retail outlets

Determine and compare the proportion of coverage defined as the following:

a. Universal coverage (i.e., one LLIN per two people per household)
b. At least one LLIN per household

The principal health economic research question is: Do the current LLINs distribution channels represent an efficient allocation of scarce resources?

Therefore, specific research questions were as follows:

a. What is the impact of the current LLINs distribution channels on health-systems costs?
b. What are the costs and outcomes of the five different LLINs distribution channels?
c. What are the main cost drivers in the distribution of LLINs?

Methods and design

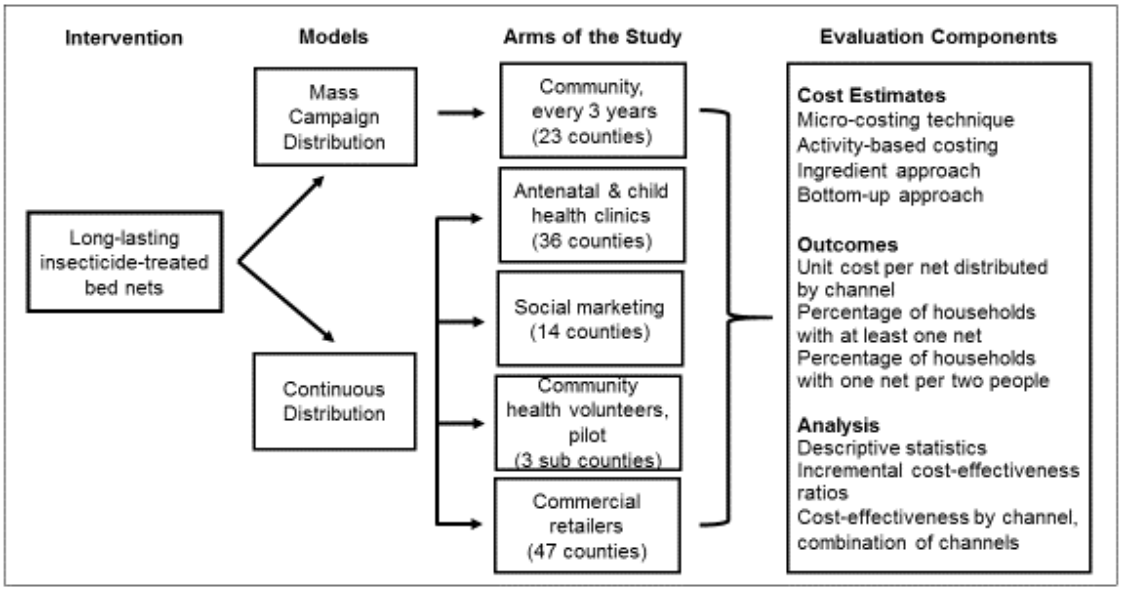
Ethical approval

The study has received ethical approval from Kenya Medical Research Institute, Scientific and Ethical Review Board (SERU No. 2997).

Costing Study design.

The study is a retrospective economic evaluation from the provider's perspective involving five arms to compare the costs and effectiveness of the LLIN distribution channels in Busia County, western Kenya. The arms of the study are shown in Figure 1.

Figure 1: Concept map of economic evaluation of long-lasting insecticide-treated bed nets distribution channels in Busia County, Kenya



Description of LLINs distribution channels (comparators)

The five different LLIN distribution channels that will be evaluated are briefly described here and illustrated in Figure 1.

1. Universal coverage mass distribution campaigns which entail the distribution of LLINs to all households in endemic and epidemic-prone areas (i.e., 23 counties) every 3 years. The campaign is planned and implemented by the NMCP/MoH with financial support from donors. The LLINs are procured by the NMCP/MoH and donors and distributed to health facilities in the 23 counties as part of the procurement contract. Prior to distribution, a household registration is undertaken whereby small teams of local MoH staff and community leaders register all households and the number of persons per household in a given geopolitical location or catchment area. The LLINs are distributed to health facilities and central storage points in each county based on the household registration. The head of the household or designated person comes to the designated health facility during the campaign time frame, which is generally 3–5 days, to collect

the number of LLINs based on the number of persons registered in their household. One LLIN per two persons per household is provided free of charge to beneficiaries. In Kenya, there is no household distribution of LLINs during the campaign or after. Registered persons who do not come to the health facilities to collect LLINs do not receive nets. Households receive communications for both the household registration and campaign distribution dates through community meetings, local radio announcements, health facilities, and other communication channels. The local MoH and county government leadership comprise the majority of staff for mass LLIN distribution campaigns. In the rolling 2014–2015 universal coverage mass distribution campaign, approximately 12.6 million LLINs will be distributed in 23 counties [5].

2. Routine distribution of one free LLIN to every pregnant woman at the first antenatal clinic visit and to every child less than 1 year of age at first immunization visit in public and not-for-profit health facilities in endemic, epidemic-prone and seasonal transmission areas (i.e., 36 counties). The distribution of LLINs via antenatal care and child health clinics is implemented by a non-governmental organization (NGO) in coordination with the NMCP/MoH and with financial support from donors. All routine LLINs are procured through one NGO partner. All routine LLINs are transported, stored in regional warehouses and distributed to health facilities by a second NGO partner. The second NGO partner manages all aspects of the supply chain for LLINs in accordance with national policy and in coordination with the NMCP/MoH. In 2015, approximately 3 million LLINs will be distributed to meet NMCP/MoH targets for routine antenatal care and child health clinic distribution.
3. Pilot continuous LLIN distribution project using community health volunteers to distribute vouchers for nets to community members in a portion of one county. The community health volunteers confirm the need for new LLINs at the household level,

either because the household does not have enough LLINs for universal coverage or to replace worn-out or non-protective nets. The voucher is taken by the community member to a designated community health facility and redeemed for free LLINs. The pilot project was implemented in three sub-counties in Busia County, western Kenya. The pilot was implemented by an NGO partner in coordination with the NMCP/MoH and with financial support from donors. All LLINs were procured, transported, stored, and distributed to health facilities by the NGO partner. The NGO partner managed all aspects of the voucher process and LLIN supply chain in coordination with the NMCP/MoH. The community health volunteers are each assigned approximately 50 households in a village and are linked to health dispensaries or health centres for reporting purposes, commodity supply (e.g., malaria rapid diagnostic tests and medications for case management) and supervision by the community health extension worker. The community health volunteers do not get a formal salary but receive a modest stipend from the county government or NGO partners [3]. Approximately 100,000 nets were intended for the continuous community distribution pilot project from October 2014 to March 2015.

4. Social marketing of heavily-subsidized LLINs in rural shops and by community-based organizations in endemic, epidemic-prone and seasonal transmission areas, including Busia County. The distribution of socially-marketed LLINs is a partnership between a primary NGO partner, multiple community-based organizations, rural outlets and the NMCP/MoH and with financial support from donors. All socially-marketed LLINs are procured, transported, stored and distributed to the sellers by one NGO partner. The NGO partner manages all aspects of the supply chain for LLINs in coordination with the NMCP/MOH. The rural shops and community-based organizations use communications mechanisms such as community gatherings, local radio, and TV shows

and advertisements, competitions, drama, and theatre to attract customers. In 2015, the target price for a socially-marketed LLIN was approximately 1.50 USD to the customer. Approximately 600,000–800,000 LLINs are sold via social-marketing channels annually.

5. Commercial, for-profit-sector retailers stock and sell LLINs at market prices throughout Kenya. Prices vary widely based on geographic location, target market, manufacturer, brand, size, material and other factors.

Study design

Cost data will be collected retrospectively from a provider's perspective from health facilities, NMCP/MoH, NGO partners, donors, stakeholders, distributors and the Kenya Medical Supply Agency (KEMSA). KEMSA is the central medical store and provides supply chain management of malaria commodities from the national to facility levels. Data on outcomes will be triangulated from a nationally-representative cross-sectional survey of over 6,300 households, a cross-sectional survey administered to a sub-sample of beneficiaries in Busia County, and distributor's records. The evaluation will involve comparing the costs of distribution and outcomes for each distribution channel. For cost estimates, we will use a bottom-up approach, combining activity-based costing (ABC), ingredient approach and budget expenditure data [20 and 22]. The bottom-up approach is an established micro-costing technique that has been successfully applied to diverse settings in corporate and healthcare sectors [20, 21, 22, 23 and 24]. In contrast to traditional costing systems, in which direct, indirect and overhead costs are aggregated and assigned proportionally based on unit volume produced or services delivered, micro-costing assigns costs more accurately by delineating specific services or processes responsible for actual resource consumption. Resources will be

organized into cost categories as summarized in Table 1. Cost drivers from each cost category will be quantified and unit cost per net distributed will be calculated.

Table 1: Description of key categories of costs and sources

Cost category	Information Source
Labor Disaggregated into cadre and type	MOH, sub-county health offices, Partner records, and staff interviews
Transport Vehicles Motorbikes Bicycles Fuel Maintenance Hired vehicles	MOH, sub-county health offices, partner records, retailers and staff interviews
Equipment Personal protective Mobile phones Laptops Other equipment	MOH, sub-county health offices, partner records and staff interviews
Supplies Mobile phone and talk time Other supplies Other inputs	MOH, sub-county health offices, partner records, donor records and staff interviews
Print and radio advertisements Community mobilization Meeting space Warehousing Security Waste management Overhead costs of partners, retailers Other inputs	MOH, county health offices, partner records, donor records and staff interviews

MOH=Ministry of Health

Cost data will be obtained from financial reports and budgets of NGO partners, NMCP/MoH, KEMSA, and Busia County Directorate of Health, community-based organizations, Ministry of Finance/National Treasury and other available sources. To ease understanding and facilitate

comparisons, costs in Kenya shillings will be converted into U.S. dollars (USD) depending on the currency of the original expenditure and the average Kenya Central Bank exchange rate for the period of the expenditure.

Sample size calculations

For outcome data, a cross-sectional survey will be conducted in randomly selected households in Busia County to collect data on coverage and source of nets. A list of households will be obtained from the community unit registers. The sample size was calculated assuming a universal coverage of 40% (defined as two persons per one LLIN per house). The least effect size in LLIN coverage levels expected from the distribution channels is 15%. This will result in a minimum sample size of 456 households to be surveyed assuming a 5% margin of error and 80% power to detect differences in coverall levels. An additional 30% to account for refusals and absentees during the survey will be added to obtain a target sample size of 592 households.

Interviewers will explain to all participants that involvement in the study is voluntary and that they have the right to withdrawal at any point in time and ask any questions. Information about the study will be read to all participants and provided in a hard copy. All consenting participants will be asked to sign two standard consent forms (that is one for the interviewee and one retained by the interviewer).

Effectiveness measures

The main effectiveness measure is the percentage of persons using an LLIN for malaria prevention in at-risk areas; the NMCP/MoH and WHO target for this indicator is at least 80% of the population [5]. Two additional effectiveness measures will based on WHO and the Roll Back Malaria Monitoring and Evaluation Reference Group (RBM MERG) indicators used for monitoring achievement of universal coverage: percentage of households with universal

coverage with LLINs (i.e., one LLIN per two persons per household) and percentage of households with at least one LLIN [5].

The main health economics-related outcomes are the total and unit cost of distributing an LLIN through each of the five current distribution channels. Additional outcomes are the mean and median cost by distribution channel categorized by quartiles and household outcome, the total and mean cost by distribution channel and by cost category and the incremental cost of the distribution channel compared with other channels. Savings will be recorded as negative incremental costs.

Economic evaluation

The cost and effectiveness of the outcomes of the five distribution channels will be compared with each other and analyzed using cost-effectiveness methods [15, 16, 17, 18 and 19]. To analyze the effectiveness of the distribution channel with regards to the cost and outcome measures, descriptive statistics and a generalized linear regression model were used because cost data is usually not normally distributed [15, 16, 17 and 18]. The analysis will include a comparison of the different distribution channels as well as a multi-level analysis focusing on cost categories.

Cost-effectiveness ratios will be calculated based on the primary outcome measure in relation to a range of health economics outcomes (e.g., total, mean, median and incremental costs) for each LLIN distribution channel. Financial costs will be adjusted to obtain economic costs and assign costs to donated items as well as the time of volunteers included in some of the distribution channels. The LLIN distribution channels are generally expected to perform for more than one year and the capital items purchased to deliver the LLINs have a life expectancy in excess of 1 year. Similarly, LLINs are intended to last for 3 years in field conditions [19, 25 and 26]. Therefore, capital costs will be expressed as an annual equivalent. Capital inputs that

will be annualized are LLINs, vehicles, and equipment using 3.5% as a discounting rate [15, 16, 17, 18 and 19].

Cost-effectiveness will be calculated for each comparison and will be expressed as incremental cost-effectiveness ratios (ICERs). Mass campaigns are by far the largest channel by volume and assumed to be the least expensive and most efficient channel for distributing LLINs in Kenya; therefore, the campaign distribution channel will be used as a baseline for the comparative analysis. Due to time and resource constraints, the economic evaluation (i.e., cost-effectiveness component) will be performed from a health-systems perspective (i.e., distributors and donors). Incremental cost-effectiveness ratios will be estimated using bootstrapping techniques and graphically presented on cost-effectiveness planes [21, 22, 23 and 24]. For comparisons and ease of understanding, costs will generally be quoted in U.S. dollars.

Cost estimates inevitably involve assumptions and uncertainty. Therefore, we will carefully identify critical assumptions and areas of uncertainty and re-estimate the results using different assumptions to test the sensitivity of the results and conclusions due to such change. We will perform both one-way and multi-way sensitivity analysis in order to assess the robustness of the results and examine the effect of common assumptions and uncertain variables on the evaluation findings [27 and 28]. An a priori analysis plan was developed and agreed upon prior to the initiation of data collection and analysis.

Discussion and conclusion

Although there is a robust literature around LLINs as the main malaria prevention and control strategy, there is very limited data on the cost-effectiveness of LLIN distribution channels in field settings. Therefore, national malaria control programmes, stakeholders and donors have limited information upon which to base policy and plan programmatic implementation to meet

national and international LLIN coverage target indicators. This economic evaluation is intended to provide the NMCP/MoH, partners, stakeholders and donor with evidence on the costs and resources required to deliver LLINs using current distribution channels and to assist in determining the efficient allocation of resources to meet target outcome measures.

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Abbreviations

ABC: Activity-based costing

ANC: Antenatal care

CHC: Child health clinics

KEMSA: Kenya Medical Supply agency

KMIS: Kenya Malaria Indicator survey

ICERs: Incremental Cost-effectiveness ratios

LLINs: Long-lasting insecticide-treated nets

MERG: Monitoring and evaluation reference group

MOH: Ministry of Health

NMCP: National malaria control program

NMS: National Malaria Strategy 2009–2017

PDAs: Portable digital assistance

RBM: Roll Back Malaria

Competing interest

The authors declare that they have no competing interests.

Author's contribution

EG, SK, and VW conceived the study protocol and drafted the first manuscript. LN assisted in the design of the study, in particular, the economic assessments, and assisted in the drafting of the manuscript. MD, PO, FW, and AMB contributed to the drafting of the manuscript.

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Chapter 7: Universal household coverage with insecticide-treated bed nets - efficiency and equity outcomes in malaria-endemic western Kenya.

Universal household coverage with insecticide-treated bed nets - efficiency and equity outcomes in malaria-endemic western Kenya.

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Abstract

Background

In malaria-endemic countries, long-lasting insecticide-treated bed nets (LLINs) have been distributed through various delivery channels. In Kenya, eight channels of distributing LLINS have been used in the implementation of malaria control programmes with variable results in population coverage. However, the is no sufficient data on the cost-effectiveness of various channels, assessing efficiency and equity effect of the interventions to aid decision-making on optimal distribution strategies to reach national/subnational targets.

Methods

We conducted a retrospective economic analysis from the provider perspective, comparing two combinations of five LLIN distribution channels: intervention arm where the channels were community health volunteers (CHV), ante-natal and child clinics (ANC), social marketing (SM) and commercial outlets (CO) and control arm where the channels were as above, yet instead of CHV distributing nets, nets were distributed via a mass distribution campaign (MD). We assessed coverage through cross-sectional surveys and interviewed program officers on costs, expenditures, and the number of nets distributed. We estimated cost per LLIN distributed from the demand and supply sides and assessed the equity effect.

Findings

The proportion of households with universal coverage (UC) was high for the pooled data (0.80; 95% confidence interval CI= [0.77-0.83]. Overall, in the pooled data, 31.1% of nets were obtained from CHVs, 51.3% in the intervention arm and 15.4% in the control arm. Most nets overall were obtained from MD (51.7%), 28.1% in the intervention arm and 70.0% in the control arm. MD channel was the most important source of nets overall and in all households followed by ANC while SM being the least important. MD had the lowest cost per net

distributed ($3·13) and CHV has the second-lowest ($10·84). SM had the highest cost ($92·41). Wealthier households owned more nets (CIn = 0.024). Of the nets obtained from CHVs, 33.4% were acquired by poorest households and 28.2% by wealthiest households. CHV followed by MD appeared to be the least inequitable channels and ANC most inequitable.

Discussion

A concerted effort with multiple distribution channels can achieve policy goals of universal LLIN coverage. Mass distribution campaigns plus other channels are the most cost-effective way to achieve universal coverage. None of the channels is pro-poor, however, community-level distribution appears to be more equitable than the other channels, but the difference is not statistically robust. The study shows that combinations of multiple channels are required to reach and maintain high levels of LLIN use and achieve equitable LLIN ownership and use.

Introduction

Long-lasting Insecticide-treated nets (LLINs) have played an important role in reducing the global malaria burden since 2000 [1] and the world health organization (WHO) Global Technical Strategy for Malaria 2016-2030 recommends universal coverage (UC) for all people at risk of malaria with either LLINs or indoor residual spraying (IRS) [108]. Throughout malaria-endemic countries, including Kenya, LLINs have been distributed through various channels [30, 109] and have been shown to be a cost-effective malaria control tool [110-114]. To achieve and maintain UC (defined as one LLIN per two persons per household), WHO recommends that countries develop and implement a single national LLIN plan and policy that includes both continuous and campaign distribution strategies through multiple channels based on identification of a combination of distribution channels with which to achieve universal coverage and minimize gaps in universal coverage[108]

.

In 2009, Kenya adopted a policy of LLIN UC in endemic and epidemic-prone areas with a targeted goal of achieving 80% of people living in malaria-risk areas using LLINs [31]. Aggressive malaria control over the last decade has led to a decline in the overall burden of malaria nationally to 8% among children <15 years of age in 2014 [4, 53, 115]. Despite substantial progress, moderate-to-high levels of malaria transmission persist in some areas, including the endemic area around Lake Victoria in western Kenya where malaria parasite prevalence is 27% in children <15 years of age [4]. Like most malaria-endemic countries, Kenya has numerous channels to distribute nets including mass distribution campaigns, routine distribution through antenatal and child health clinics, continuous community distribution by community health volunteers, social marketing by community-based organizations through rural outlets, school-based distribution and via commercial retail outlets[112, 115-118]. However, evidence on the actual household coverage and delivery costs (i.e., cost-

effectiveness) of these channels is lacking, particularly for multi-channel distribution strategies in real operational settings [119]. This study reports household coverage and use levels for LLINs, the costs of delivering nets to the end-user for each distribution channel and compares the primary outcomes of universal coverage and equity for combinations of channels. The findings of this study will help to inform the Kenya LLIN policy, strategy and program implementation and help other malaria-endemic countries to develop strategies to meet UC goals for LLINs and reduce the malaria burden. Its findings are particularly relevant in the context of devolution and decreasing donor resources which makes it imperative to ensure that limited resources are used most effectively to reach the most at-risk populations.

Methods

Study design

The study design, which is described elsewhere[30], compared the household coverage and delivery costs (i.e., total and unit cost per net distributed by channel) of the five distribution channels used in combination in one real-life intervention and one control setting. The channels evaluated were the following: 1) mass distribution campaign (MD), 2) routine continuous distribution via ante-natal clinic and child clinics (ANC), 3) a pilot of continuous net distribution using community health volunteers (CHV) to distribute LLIN vouchers to community members for redemption at health facilities (CHV), 4) continuous distribution via social marketing of subsidized LLINs in selected rural shops and commercial business outlets (SM), and 5) continuous distribution via commercial for-profit outlets that stock and sell LLINs at market prices (CO). Additional details of each distribution channel are provided in Table 1 and (2). The school-based program was not used during this period.

Two operational factors resulted in modifications to the published study design. First, the CHV pilot was initially planned to start directly after the MD to address gaps in UC and maintain

high coverage following the MD with the evaluation planned for 12 months following the MD. However, delays in the MD resulted in the pilot CHV distribution starting prior to the MD. The CHV pilot involved two phases: a 12-month top-up phase where CHVs distributed vouchers to households with the aim of achieving UC, and a 6-month continuous distribution phase where CHVs were responsible for monitoring coverage and distributing vouchers to maintain UC. In both phases of the CHV pilot, community members were responsible for travelling to health facilities to exchange vouchers for LLINs. Second, due to insufficient LLINs for the overall MD, the National Malaria Control Program (NMCP) made an operational decision to exclude from the MD the areas in Samia where the CHV distribution was piloted, hence the areas in Samia that were part of the CHV pilot distribution did not receive nets during the 2014-2015 UC MD campaign.

Study Site

The study took place in Samia Sub-county, Busia County located in western Kenya. Samia is largely rural with some peri-urban pockets and has a population of approximately 120,000 people living in 29 sub-locations, the smallest administrative unit in Kenya [120]. Samia is a malaria-endemic area with a prevalence of 27% in children <15 years of age, has a functioning health system including 12 public health facilities and an active community health volunteer (CHV) programme[4]. The 2011-2012 UC LLIN mass distribution campaign included Busia County; LLINs were distributed in Samia in 2011[118]. In 2014, 48.3% of households in Busia County had at least one LLIN for every two people [121].

Population, sampling strategy, and sample size

The modified two-arm study design therefore consisted of an intervention arm with a combination of CHV, ANC, SM, and CO channels which was implemented in 18 sub-locations

with an estimated population of 63,772 and a control arm with a combination of MD, ANC, SM, and CO channels which was implemented in 11 sub-locations in Samia with a population of 55,474. Using probability proportional to size sampling, a total of 1000 (500 in each ram) were targeted and 879 households were finally interviewed. This was higher than the 592 estimated in the protocol [30]. Households were selected randomly for the control and intervention sub-locations, from the list of households in the community unit register of the sub county[30].

Data Collection

Costs and household survey data were collected retrospectively from the provider's perspective (i.e. excluding community costs) from both the sites where intervention was implemented (use of CHVs) and areas where MD was used without CHVs (control). Therefore, the study design can be described as quasi-experimental and conducted in a real-life setting. A standardized post-intervention household survey tool was adapted to capture demographic and socioeconomic data and quantity, source and use of nets in the two arms after obtaining the consent from the head of household per protocol[30]

Data Management and Analysis

Household survey data were double entered, cleaned and analyzed in Stata and R. The cost data were calculated and analyzed in Ms excel spreadsheets. The detailed analysis is as described below

Table 1a. Description of MD and ANC Channels being implemented and evaluated in Samia Sub-County, Busia County, Kenya				
Channel	**Scale/Location**	**Timeframe**	**Responsibility for Planning, Financing, and Procurement**	**Responsibility for and Description of Distribution Activities**
Mass distribution campaign (MD)	Nationwide programme: 23 counties. In Samia, MD was carried out in 11 sub-locations referred to as control sub-locations.	Multi-phased UC campaign, 2014-2015. Mass distribution in Busia County took place during October 2015 and completed in Samia Sub-County in 1 week.	**Planning, Coordination and Management** NMCP/MoH **Donor Financing** Global Fund PMI **Procurement** Global Fund procured LLINs included distribution by the supplier to sub-county level PMI procured LLINs that were delivered to the Kenya Port.	**Enumeration** Small teams of local MoH staff and community leaders registered all households and the number of persons per household in each area to quantify nets required and alert households to the campaign. **IEC** Community meetings, local radio announcements, health facilities and other communication channels used to inform the population about household registration and campaign distribution dates. **Distribution** PSK transported PMI procured nets from port to Samia. The household head (or a representative) came to the designated health facility during the campaign time frame (usually three to five days), to collect their LLINs. One LLIN per two persons per household was provided free of charge. There was no household-level distribution of LLINs during or after the MD. Registered persons who did not come to the health facilities to collect LLINs did not receive nets. NMCP staff supervised and managed the distribution
Distribution via antenatal and child health clinics (ANC)	National: 36 of 47 counties (all except counties in low-risk transmission zone) including Busia County.	Ongoing since 2004, when free ITN distribution to pregnant women and children <5 years of age at maternal and child health (MCH) clinics started.	**Planning, Coordination and Management** NMCP/MoH **Donor Financing** DFID PMI **Procurement** JSI and PSK procured LLINs delivered to Kenya Port	**Distribution** PSK transported LLINs to the regional warehouse for storage. Nets were then distributed to health facilities by PSK who also managed the supply chain, in coordination with the NMCP/MoH. Pregnant women and children less than 1 year of age were given one free LLIN at the first antenatal clinic appointment or on first immunization at child health clinics in public and not-for-profit health facilities. All 12 public sector health facilities in Busia were involved in the distribution, but two privately run ANC clinics were not used.

Table 2b Description of CHV, SM and CO implemented and evaluated in Samia Sub-County, Busia County, Kenya				
Channel	**Scale/Location**	**Timeframe**	**Responsibility for Planning, Financing, and Procurement**	**Responsibility for and Description of Distribution Activities**
Distribution via community health workers (CHV)	Pilot in Samia sub-county. 18 intervention and 11 control sub-locations (control sub-locations received MD).	Top up Phase January - December 2014 Continuous distribution phase January - May 2015	**Planning, Coordination and Management** NMCP/MoH **Donor Financing** PMI **Procurement** PSK procured LLINs delivered to Kenya Port	**CHV recruitment and training** PSK recruited and trained CHVs to assess the need for LLINs at the household level. CHVs are linked via health dispensaries or health centres for reporting purposes, commodity supply, and supervision by the community health extension worker (CHEW). CHVs do not get a formal salary but receive a modest stipend from the County government or NGO partners [3]. There are multiple CHVs in a village and each was assigned approximately 50 households for LLIN distribution. **Net/Voucher Distribution** PSK transported, stored, and distributed LLINs to health facilities and managed the voucher process. LLIN supply chain was managed by PSK in coordination with the NMCP/MoH. During the Top-up phase, CHVs visited households to assess how to achieve UC. Damaged nets were repaired with patch kits. Vouchers for new nets were given for additional or replacement (for worn out) nets. Community members took their voucher to a designated health facility and exchanged it for free LLIN/s. During the continuous distribution phase, CHV monitored households to ensure coverage of new householders and maintain UC.
Social Marketing (SM)	Operating in 14 Counties including all Sub-Counties in Busia County	2004 to March 2016 Funding officially ended in March 2015, but the program continued through March 2016 to exhaust all nets and financial pipeline.	**Planning, Coordination and Management** NMCP/MoH **Donor Financing** PMI DFID **Procurement** PSK procured LLINs delivered to Kenya Port	**Distribution** LLINs were procured, transported, stored and distributed to the sellers by an NGO partner who managed the supply chain in coordination with the NMCP/MOH. Sellers included selected rural shops and by community-based organizations. In 2015, the target price for a socially-marketed LLIN was approximately 1.50 USD to the customer. Rural shops and community-based organizations used community gatherings, local radio and TV shows and advertisements, competitions, drama, and theatre to attract customers.
Commercial outlets (CO)	Assumed to operate throughout Kenya.	Ongoing	Private commercial retail and wholesalers finance and manage the entire process. There is no public-sector involvement in this distribution system other than via communication campaigns to promote LLIN use. Commercial for-profit retail outlets stock and sell LLINs at market prices. Prices vary widely based on geographic location, target market, manufacturer, brand, size, material and other factors. Householders visit retail outlets to purchase nets.	

Effects

As per the protocol, the main effectiveness measure is the (self-reported) proportion of the population that slept under an ITN the previous night. We also conducted a subgroup analysis on the proportion of children under five and pregnant women sleeping under a net the previous night. Next, we analysed the data from individual households and calculated the number and proportion of households with at least one LLIN and the number and proportion of households with and at least one net for two people (UC). Two additional (standard) indicators were also calculated: the proportion of the population with access to an ITN in their household and the proportion of existing LLINs use the previous night. These seven effect indicators were calculated for the whole sample (pooled data), control and intervention arms. Chi-squared or Fisher's exact test was used to test for association with study arm for each indicator. The difference in proportion between the control and intervention arm was calculated along with the confidence interval which was used to interpret the significance of any difference observed between the two arms.

The overall number and percentage of nets observed in households by channel were calculated for the pooled, control and intervention arms. Data on the number of nets and the net source could give an unclear picture if a lot of the nets were concentrated in a few households, therefore, the source of nets in individual households was also examined. Households were stratified by net coverage level (a. any net, b. at least one net but not universal coverage and c. universal coverage) and the number and percentage of households with a net from each source were calculated.

Costs

Cost data were collected retrospectively, per protocol, using questionnaires, reviews of expenditure data and meetings with implementing partners. Cost data were entered into Excel

spreadsheets, costs in Kenyan Shillings were converted to United States Dollars (USD) using the average annual exchange rate for 2015 (3). Costs incurred for activities in more than one county (e.g. Central level support) which could not be assigned using the micro-costing (bottom-up) approach, were allocated to Samia using a suitable proxy. To facilitate comparison of costs across the different distribution methods, a set of standard activities were developed that could be used to capture key activities for all distribution methods (e.g. administration, coordination, and management; communication and mobilisation; net storage and distribution; training). All costs were then allocated to one of these categories independently by two authors (EW and VW) with each discrepancy discussed and resolved. Likewise, each item was categorised by the level at which the cost was incurred (national, regional, sub-County or sub-Location) independently by EW and VW and discrepancies resolved.

As per protocol the total cost and cost by the channel are presented as financial and economic costs. In addition, annualised (total and unit) costs are also presented. Annualised financial costs are calculated by dividing capital costs (those with a useful life of more than one year) by their useful life, annualised economic costs were calculated alike and discounted at 3%. All costs are presented by channel, activity and health system level with costs are expressed as number and percentage of total costs to identify cost drivers and differences between channels. The purchase price, brand, and quantity of nets purchased by channel is presented, however, since the analysis is focussed on distribution costs of LLINs and the cost of LLINs procured differed between channels, LLIN costs were excluded from the analysis. A sub-analysis to estimate the percentage of turnover accounted for by net sales, which would lead to a break-even point given the cost of sales for the CO channel is presented.

Cost and Cost-effectiveness

As per protocol, the two main health economics outcomes are total and unit cost of distributing an LLIN through each channel (unit cost per channel). The total economic and financial costs for each channel were calculated by summing all costs for each channel, and are reported by activity, cost category, and level in USD. Annualised economic and financial costs are also presented.

Unit cost per channel was calculated separately from the supply side and demand-side perspectives. For the supply side, implementing agencies were asked to self-report the number of nets or (for the CHV channel) vouchers distributed, which was used to calculate the potential (supply side) unit cost per net or voucher delivered for each distribution channel. Since nets available for distribution may not have been distributed, and vouchers distributed may not have been exchanged for a net, household survey (demand side) data on reported net source was used to estimate the total number of nets from each channel. An estimate of the number of nets from each channel in the entire sub-County was obtained by multiplying the number of observed nets by channel by the sample proportion (879 households out of a total of 23,081 households). Total cost was divided by the estimate of nets delivered by each channel to give a demand-side estimate of unit cost per net distributed from each channel.

Mean cost per house achieving UC was calculated by dividing the total estimated costs of all channels by the estimated number of households with UC in the control, intervention and pooled households. Incremental cost per house achieving UC (cost per UC house) was calculated by dividing total estimated costs of all channels by the estimated change in the number of households with UC pre- and post-intervention, in the control, intervention and pooled households. The number of households achieving UC in each arm was estimated by multiplying the proportion of households in each arm with UC by the estimated number of

households in that arm. The change in UC in each arm was calculated by subtracting the post-intervention UC percentage from that at baseline according to the 2014 Kenya DHS survey data for Busia County (this is the lowest admin-level available from the DHS). This analysis was conducted excluding CO channel costs, representing the public-sector provider perspective (and repeated including the unadjusted CO costs obtained from a sample of CO). Uncertainty estimates on the cost-effectiveness were obtained by re-running the analysis using the 95% confidence interval range on the proportion of households with UC [122].

Equity effects

Household-level socio-economic data and asset ownership were used to construct a wealth index using principal components analysis. Each household was assigned to a wealth quintile (1 poor – 5 least poor). We calculated and plotted the number of nets observed in households in each quintile by source (channel) of nets, and the number of nets from each channel by wealth quintile of the household in which the nets were observed. To quantify in/equity, we calculated the concentration index (CI) for all nets, and for nets by channel. The CI measures the degree to which a characteristic, in this case, the destination of nets from each channel is concentrated in richer (or poorer) households, across all quintiles. A CI of 0 indicates perfect quality, –1 the highest degree of pro-poor inequalities, and +1 the highest degree of pro-rich inequality. The CI provides a measure of equity across all five quintiles that is relatively independent of the overall level of coverage. We also calculated the absolute and relative contribution of the different channels to the overall CI as a way of assessing which channel contributed most to the overall in/equity in net ownership by source observed in the sample population.

Estimating confidence intervals of the costs and effects

The confidence intervals for effects was estimated through bootstrapping techniques. This is a non-parametric method that involves repetitive computations of resampled data to estimate the shape of a statistic's sampling distributions. Using a bootstrap resamples, the procedure was repeated 1000 times to estimate cost or effects. Bootstrap standard error methods used in a bootstrap distribution to determine the limits of the confidence intervals [1]. The formula used for bootstrapping was done using Ms excel Visual Basic software. The classic formula is

$$\theta \pm t_{\alpha/2}\, \sigma\, \theta\, B$$

Where θ is the estimate, $\sigma\theta$ is the standard error of θ and $t_{\alpha/2\ is}$ the critical value of the test statistic and B is the number of bootstrap replications.

The lower and upper confidence interval of the bootstrap samples is given by

$$[\theta - t\alpha_{/2}\, \sigma\, \theta\, B,\ \theta + t_{\alpha/2}\, \sigma\, \theta\, B]$$

Results

Household coverage

A total of 879 respondents (52% control and 48% intervention) similar in sex, age, household head occupation and education level, with most being either self or unemployed with low levels of education, completed the household survey. Pooled analysis showed high and increased LLIN use the previous night (87%), UC in 80% of households and 97% of households having at least one net compared with 42%, 32%, and 59% respectively in 2014. Reported LLIN use by under-fives was also high (92%, compared with 54% in 2014) although reported use by another priority vulnerable group pregnant woman lags at 78% (compared with 51% in 2014). Statistical comparison of the control versus intervention arm.

Significantly more effective at increasing the number of households with UC, than the combination of channels used in the intervention arm. This translated into significantly higher net use (the night before the survey) in the control arm than in the intervention arm, in the overall population and in children under five (sig 95% level), use was also higher in pregnant women, but this difference was not significant. These findings are consistent with previous studies which have shown that the main barrier to net use within households is the insufficient number of nets available within households (access). The combination of channels used in the intervention arm resulted in significantly higher levels of nets being used than in the control arm. Overall, we conclude that the control arm (including MDC) is effective at increasing universal coverage and access and that this translates into higher net use at the household level. However, nets delivered by the combination of channels in the control arm (including MDC), are less likely to be used than those delivered by the combination of channels used in the intervention arm (including CHV).

MD was the most important source of nets overall and in all households, regardless of net coverage status in the pooled, and control arms, whereas CHV was the most important source in intervention households for all indicators and the second most important source of net overall in the pooled and control arms. ANC was the third most important net source overall, and for all household net coverage strata in the pooled and intervention arms. In the control arm, ANC was the second most important net source after MD. CO was the fourth most important net source overall and for all household net coverage strata, with SM being the least important net source overall and for all strata. The high proportion of nets from the MD found in the intervention arm, and CHV nets found in the control arm also imply contamination (leakage of nets) between arms and challenges with recall and differentiation on the source of nets. There may be a particular challenge for households differentiating between CO and SM nets.

Table 3 Indicators of ITN coverage, access, and use, for all households, control households, and intervention households

Indicator	Pooled data (n=879)		Control arm (n=459))		Intervention arm (n=420))		(Chi squared except[¥])	Difference in Proportions (Control – Intervention) [95% confidence interval on Difference]
	N	Proportion [95% CI]	n	Control 95% CI	n	Intervention (n=420) 95% confidence interval		
Proportion of households with at least one ITN	852	0.969 [0.956—0.979]	448	0.976 [0.957-0.987]	404	0.962 [0.939-0.977]	0.225	0.014 [-0.009-0.037]
Proportion of households with at least one ITN for every two people (universal coverage)	682	0.801 [0.773-0.827]	375	0.839 [0.802-0.870]	307	0.760 [0.716-0.799]	0.004*	0.079 [0.025-0.131]
Proportion of population with access to an ITN in their household	3276	0.879 [0.868-0.889]	1842	0.898 [0.984-0.910]	1434	0.856 [0.838-0.872]	<0.001*	0.042 [0.021-0.063]
Proportion of the population that slept under an ITN the previous night	**3251**	**0.872 [0.861-0.883]**	**1830**	**0.892 [0.878-0.905]**	**1421**	**0.848 [0.830-0.865]**	**<0.001***	**0.044 [0.022-0.0665]**
Proportion of children under five years old who slept under an ITN the previous night	475	0.983 [0.968-0.993]	275	0.958 [0.928-0.978]	170	0.876 [0.821-0.919]	<0.001*	0.082 [0.030-0.134]
Proportion of pregnant women who slept under an ITN the previous night	29	0.906 [0.750-0.980]	13	0.929 [0.661-0.998]	16	0.889 [0.653-0.986]	1[¥]	0.040 [-0.219-0.270]
Proportion of existing ITNs used the previous night	2081	0.862 [0.847—0.875]	1111	0.808 [0.786-0.829]	970	0.933 [0.916-0.947]	<0.001*	-0.125 [-0.150-0.099]

[¥]Small number of counts could lead to errors in P-value, therefore used Fisher's exact test.

* Significant at 95%

Indicators explicitly mentioned in the protocol in **bold**, main per-protocol indictor **bold underlined**, other standard indicators included but were not specifically mentioned in the protocol

Table 4 Source of nets overall (1) and by household net coverage status (2a-c) for all (pooled), control and intervention households

Channel	MD	CHV	ANC	SM	CO	Other	Total
1. Overall source of nets observed in households							
Pooled	1268 51·7%	762 31·1%	265 10·8%	10 0·4%	90 3·7%	57 2·3%	2452 100%
Control	967 70·0%	213 15·4%	122 8·8%	10 0·7%	36 2·6%	34 2·5%	1382 100%
Intervention	301 28·1%	549 51·3%	143 13·4%	0 0%	54 5·0%	23 2·1%	1070 100%
2. Source of nets within households stratified by household net coverage							
a. Any nets							
Pooled	490 57·6%	315 37·0%	162 19·0%	9 1·1%	63 7·4%	n/a	851 122·1%*
Control	352 78·7%	74 16·6%	81 18·1%	8 1·8%	27 6·0*%	n/a	307 121·3%*
Intervention	138 45·0%	241 78·5%	81 26·4%	1 0·0%	36 11·7%	n/a	307 161·9%
b. At least one net but not universal coverage3							
Pooled	86 50·9%	63 37·3%	38 22·5%	1 0·6%	6 3·6%	n/a	114·8%*
Control	51 70·8%	14 19·4%	14 19·4%	0 0·0%	3 4·2%	n/a	72 113·9%*
Intervention	35 36·1%	49 50·5%	24 24·7%	1 1·0%	3 3·1%	n/a	97 115·5%*
c. Universal coverage							
Pooled	404 59·2%	252 37·0%	124 18·2%	8 1·2%	57 8·4%	n/a	682 123·9%*
Control	301 67·3%	60 13·4%	67 15·0%	8 1·8%	24 5·4%	n/a	447 102·9%*
Intervention	138 45·0%	192 62·5%	57 18·6%	0 0·0%	33 10·7%	n/a	307 136·8%*

Shading indicates % contribution of each channel from highest (darkest) to lowest lightest/white)
Underlined text indicates this channel is operating in this arm according to study design
n/a Not applicable
*percentages add up to more than 100% because households can have at least one net from more than one source

Costs and cost-effectiveness

The results of the cost analysis by cost activity category and health system level are shown in Table S1 and Table S2. Excluding LLIN commodity costs (Table S3), CHV was the most expensive channel ($208,979), followed by ANC ($188,447) and MD ($104,115). SM had the lowest total cost ($$21,878). Reported number and cost per LLIN/voucher distributed (supply-side indicator) and estimated number and cost of LLINs (demand-side indicator) for all channels (except CO where aggregate data was not obtained) are shown in Table 5. MD distributed the most nets at the lowest cost per net distributed according to the supply and demand-side data. SM distributed the fewest vouchers at the second-lowest-cost according to the supply-side data, however, demand-side estimates put SM at the highest cost per LLIN is found in the household. CHV had the second-lowest-cost per LLIN in households followed by ANC (demand side). The cost of all channels, except MD, is higher according to demand-side estimates, with the SM channel being almost 18 times higher due to the low number of nets identified from this channel.

Results of the marginal cost estimates to achieve universal coverage are shown in table 6. The total average and marginal annualised economic cost per UC house in the pooled analysis are US$ 29.26 [95%CI=$28.34 - $30.32] and the US $73.71 [95%CI=$73.71 -$80.82] respectively. The average and marginal annualised economic cost per UC house was USD $28.31 [$27.42 - $29.34] and $71.31 [$71.31 - $78.2] respectively, and are higher in the intervention arm (US $27.5 [95%CI=$26.52 - $28.77] vs US $27.5 [95%CI=$26.52 - $28.77] than control arm (US $27.5 [95%CI=$26.52 - $28.77]and US $64.81 [95%CI=$64.81 - $72.32]). However, there isn't much difference in terms of the final cost of UC per HH between the two channels but the significant difference in marginal economic costs of distribution

per UC household table 5. By activity (Table S1) personnel costs were the highest contribution to costs in ANC and CO, whereas distribution and transport were the biggest drivers in MD and SM. Training and meeting costs were the biggest cost driver in the CHV channel. By level, (Table S2) the majority of costs are incurred at the sub-Location level in the MD, ANC and CHV channels. All costs are incurred at the sub-Location level (i.e. individual shop) for the CO channel. SM costs are heavily skewed (80%) to the national level. Annualised economic (and financial) costs are very similar to total costs due to the low proportion of capital costs on all channels. Economic and financial costs are also very similar and because no donated resources were identified in the cost the difference is entirely down to discounting of capital costs in the economic analysis.

CO data on total costs are not comparable with other channels as they only represent a sample of providers' costs. Cost per net distributed by CO can only be calculated at an individual shop level using supply-side data (Table S4) where the costs per net sold range from US$10-221·4. These results are highly sensitive to the proportion of the outlets business that is attributed to bednet sales. This was estimated at 10%, 1%, and 0·1%. Even at 1%, it appears that it would be difficult for retail outlets to cover the costs of LLIN sales. Sellers reported a mark-up of between KSH50-150 on each net, or US$0·51-1·52, which even if LLINs only made up 1% of their business turnover, would not cover the cost of sales. Only when LLINs sales account for 0·1% of turnover, might they break even/make a small profit on net sales.

Table 5 Annualised economic cost per LLIN or voucher distributed by channel using supply (a) and demand-side (b) estimates (US$2015)

Channel	MD	CHV	ANC	SM	CO	Other	Total number of nets/vouchers and cost
a. LLINs/Vouchers distributed (Supply-side indicator)							
Reported number	28,870	29,972	8,400	4,704	No data	No data	71,946
Economic/Financial cost (per LLIN/voucher)	3·61	7·23	23·31	5·16	‡	‡	7·78
Annualized financial cost[§] (per LLIN/voucher)	3·61	6·97	22·43	4·65	‡	‡	7·41
b. LLINs in the household (Demand-Side indicator)							
Estimated number	33,295	20,009	6,958	263	2,363	1,497	64,385
Economic/Financial cost (per LLIN)	3·13	10·84	28·14	92·41	‡	‡	8·70
Annualized financial cost[†] (per LLIN)	3·13	10·44	27·06	83·12	‡	‡	8·27

Shading indicates lowest cost (darkest) to highest (lightest) cost per net/voucher distributed/in household and highest (darkest) to lowest (lightest) number of nets/vouchers distributed/estimated in households
‡Cannot be computed as no estimate of LLINs distributed and/or total cost
[§] Annualised economic costs exactly equal to annualised financial costs for all channels
[†] Annualised economic costs exactly equal to annualised financial costs except for ANC 27·08, SM 83·32 and average

Costs by channel and cost per additional house with universal coverage, including and excluding commercial outlet costs

Total economic costs (excluding LLIN commodity costs), were highest for CHV ($216,821), and followed by ANCC ($195,776), MC ($104,114), and SM ($24,266). Costs were lowest for CO ($19,070), which represented eight outlets (seven retail and one wholesale) identified as selling LLINs. CHVs distributed more vouchers (29,972) than LLINs distributed by the other channels (MC=28,870, ANCC=8,400, SM=8,400) according to supply-side data. Supply-side estimated unit costs were highest for ANCC ($23·31), followed by CHV ($7·23),

SM ($5·16), and MC ($3·61). Demand-side estimates were highest for SM ($92·41), followed by ANCC ($27·92), CHV ($10·81), and MC ($3·10)

Table 6 Costs by channel and cost per additional house with universal coverage including and excluding commercial outlet costs

	Mass Campaign (MC)	**Community Health Volunteer (CHV)**	**Antenatal and child health clinic (ANC)**	**Social Marketing (SM)**	**Commercial Outlets** (CO)	The marginal cost per additional house with universal coverage
Total Economic Cost[¤]						
Intervention	24,502·53	156,088·67	104,854·04	-	11,441·79 {0}	86·44 [75·77 - 102·77] {83·11 [72·85 - 98·81]}
Control	79,612·88	60,732·68	90,922·39	24,266·12	7,627·86 {0}	69·20 [63·66 - 77·23] {67·20 [61·81 - 74·99]}
Pooled	**104,115·41**	**216,821·35**	**195,776·43**	**24,266·12**	**19,069·65** {0}	76·30 [70·54 - 83·67] {73·71 [68·13 - 80·82]}
						Annualised Financial Cost
Intervention	24,502·53	150,327·40	100,848·39	-	5,555·44 {0}	81·88 [71·78 - 97·35] {80·27 [70·36 - 95·42]}
Control	79,612·88	58,491·03	87,448·95	21,826·34	3,703·63 {0}	66·03 [60·74 - 73·68] {65·05 [59·84 - 72·6]}
Pooled	**104,115·41**	**208,818·43**	**188,297·34**	**21,826·34**	**9,259·07** {0}	72·53 [67·04 - 79·53] {71·26 [65·88 - 78·14]}
						Annualised Economic Cost
Intervention	24,502·53	150,442·71	100,928·40	-	5,662·31 {0}	67·30 [58·99 - 80·01] {80·32 [70·41 - 95·49]}
Control	79,612·88	58,535·89	87,518·33	21,877·59	3,774·87 {0}	79·34 [72·98 - 88·54] {65·10 [59·88 - 72·65]}
Pooled	**104,115·41**	**208,978·60**	**188,446·73**	**21,877·59**	**9,437·18** {0}	72·60 [67·11 - 79·61] {71·31 [65·92 - 78·2]}

[¤]Total financial cost equals the total economic cost
Cost and cost-effectiveness excluding commercial outlet costs shown in { }

Lower and upper bounds of cost-effectiveness calculated using the upper and lower confidence

Table 7 Average and marginal unit cost per house with UC for all (pooled), control and intervention households

Proxy for Cost allocation by arm (Intervention)	Average Cost per house with UC (USD)	Marginal Cost per house with UC (USD)
Excluding CO costs		
Total Economic/Financial Costs by distribution system: Intervention	$30.41 [$28.93 - $32.28]	$83.44 [$83.44 - $99.2]
Total Economic/Financial Costs by distribution system: Control	$28.39 [$27.37 - $29.7]	$66.9 [$66.9 - $74.66]
Total Economic/Financial Costs by distribution system: Pooled	**$29.26 [$28.34 - $30.32]**	**$73.71 [$73.71 - $80.82]**
Annualised Financial Costs by distribution system: Intervention	$29.37 [$27.94 - $31.18]	$80.59 [$80.59 - $95.8]
Annualised Financial Costs by distribution system: Control	$27.48 [$26.5 - $28.75]	$64.76 [$64.76 - $72.28]
Annualised Financial Costs by distribution system: Pooled	**$28.29 [$27.4 - $29.32]**	**$71.26 [$71.26 - $78.14]**
Annualised Economic Costs by distribution system: Intervention	$29.39 [$27.96 - $31.2]	$80.64 [$80.64 - $95.87]
Annualised Economic Costs by distribution system: Control	$27.5 [$26.52 - $28.77]	$64.81 [$64.81 - $72.32]
Annualised Economic Costs by distribution system: Pooled	**$28.31 [$27.42 - $29.34]**	**$71.31 [$71.31 - $78.2]**

Table S1 Total financial/economic cost (a), the annualised financial cost (b) and annualised economic cost (c) by channel and activity (2015USD), excluding LLIN commodity cost

Cost category	Admin, Coordination, and Management		Buildings		Communication and Mobilisation		Distribution and Transport		Monitoring and Evaluation		Storage		Training		Total Cost
a. Total financial/economic cost and %															
MD	31,252	30·0%	0	0%	6,576	6·3%	51,402	49·4%	0	0%	7,501	7·2%	7,385	7·1%	104,115
CHV	14,818	6·8%	0	0%	23,121	10·7%	30,110	13·9%	0	0%	4,889	2·3%	143,884	66·4%	216,821
ANC	97,154	49·6%	0	0%	0	0%	81,822	41·8%	11,819	6·0%	4,981	2·5%	0	0%	195,776
SM	5,740	23·7%	0	0%	6,481	26·7%	9,545	39·3%	0	0%	2,369	9·8%	130	0·5%	24,266
CO*	6,009	31·5%	10,219	53·6%	70	0·4%	1,840	9·6%	0	0%	931	4·9%	0	0%	19,070
Grand Total	154,973	27·7%	10,219	1·8%	36,248	6·5%	174,719	31·2%	11,819	2·1%	20,671	3·7%	151,399	27·0%	560,049
b. Annualised financial cost and %															
MD	31,252	30·0%	0	0%	6,576	6·3%	51,402	49·4%	0	0%	7,501	7·2%	7,385	7·1%	104,115
CHV	13,944	6·7%	0	0%	23,121	11·1%	22,980	11·0%	0	0%	4,889	2·3%	143,884	68·9%	208,818
ANC	96,805	51·4%	0	0%	0	0%	74,693	39·7%	11,819	6·3%	4,981	2·6%	0	0%	188,297
SM	5,402	24·7%	0	0%	6,481	29·7%	7,444	34·1%	0	0%	2,369	10·9%	130	0·6%	21,826
CO*	6,009	64·9%	409	4·4%	70	0·8%	1,840	19·9%	0	0%	931	10·1%	0	0%	9,259
Grand Total	153,413	28·8%	409	0·1%	36,248	6·8%	158,358	29·7%	11,819	2·2%	20,671	3·9%	151,399	28·4%	532,317
c. Annualised economic cost and %															
MD	31,252	30·0%	0	0%	6,576	6·3%	51,402	49·4%	0	0%	7,501	7·2%	7,385	7·1%	104,115
CHV	13,962	6·7%	0	0%	23,121	11·1%	23,122	11·1%	0	0%	4,889	2·3%	143,884	68·9%	208,979
ANC	96,812	51·4%	0	0%	0	0%	74,835	39·7%	11,819	6·3%	4,981	2·6%	0	0%	188,447
SM	5,411	24·7%	0	0%	6,481	29·6%	7,486	34·2%	0	0%	2,369	10·8%	130	0·6%	21,878
CO*	6,009	63·7%	587	6·2%	70	0·7%	1,840	19·5%	0	0%	931	9·9%	0	0%	9,437
Grand Total	153,447	28·8%	587	0·1%	36,248	6·8%	158,684	29·8%	11,819	2·2%	20,671	3·9%	151,399	28·4%	532,856

*CO costs are a sample, not full costs therefore not comparable with other channels

Table S2 Total financial/economic cost (a), the annualised financial cost (b) and, annualised economic cost (c) by channel and level (2015USD), excluding LLIN commodity cost

Health system level where the cost incurred	National		Regional		Sub-County		Sub-Location		Total Cost
a. Total financial/economic cost and %									
MD	27,331	26·3%	7,405	7·1%	27,297	26·2%	42,083	40·4%	104,115
ANC	55,704	28·5%	0	0%	67,987	34·7%	72,085	36·8%	195,776
CHV	43,410	20·0%	23,848	11·0%	10,846	5·0%	138,717	64·0%	216,821
SM	19,547	80·6%	3	0·0%	3,307	13·6%	1,409	5·8%	24,266
CO*	0	0·0%	0	0%	0	0%	19,070	100·0%	19,070
Grand Total	145,992	26·1%	31,256	5·6%	109,437	19·5%	273,364	48·8%	560,049
b. annualized financial cost and %									
MD	27,331	26·3%	7,405	7·1%	27,297	26·2%	42,083	40·4%	104,115
ANC	48,225	25·6%	0	0%	67,987	36·1%	72,085	38·3%	188,297
CHV	36,280	17·4%	22,975	11·0%	10,846	5·2%	138,717	66·4%	208,818
SM	17,495	80·2%	3	0·0%	2,920	13·4%	1,409	6·5%	21,826
CO*	0	0%	0	0%	0	0%	9,259	100·0%	9,259
Grand Total	129,331	24·3%	30,383	5·7%	109,050	20·5%	263,553	49·5%	532,317
c. Annualized economic cost and %									
MD	27,331	26·3%	7,405	7·1%	27,297	26·2%	42,083	40·4%	104,115
ANC	48,374	25·7%	0	0%	67,987	36·1%	72,085	38·3%	188,447
CHV	36,422	17·4%	22,993	11·0%	10,846	5·2%	138,717	66·4%	208,979
SM	17,536	80·2%	3	0·0%	2,930	13·4%	1,409	6·4%	21,878
CO*	0	0%	0	0%	0	0%	9,437	100·0%	9,437
Grand Total	129,663	24·3%	30,401	5·7%	109,060	20·5%	263,731	49·5%	532,856

*CO costs are a sample, not full costs therefore not comparable with other channels

Table S3 Purchase price and quantity of nets by channel and acquisition year, KSH and 2015 USD

Distribution strategy	Net Brand	Number purchased	Price in KSH	Price in 2015 USD
MD	Permanet	29000	400	4.07
CHV	Permanet	30480	400	4.07
ANC	Unstated	7826	400	4.07
SM	Supernet extra power	22000	90	0.92*
CO	Meng Mei	12	250	2.55
	Romantic house	72	350	3.56
	SafiNet	10	150	1.53
		16	450	4.58
		20	150	1.53
		30	300	3.06
	Supernet	20	250	2.55
	SupernetExtra	28	100	1.02

Table S4 Cost per net sold by a shop in CO channel (excluding the cost of nets)♦

Individual Shop	Annualised Economic Cost	Nets sold in 2015	Cost per net sold if LLIN sales represent x% of the annual turnover of each shop		
			X = 10%	X = 1%	X = 0·1%
Shop 1	722	72	10·0	1·0	0·10
Shop 2	1,328	6	221·4	22·14	2·214
Shop 3	971	30	32·4	3·24	0·324
Shop 4	1,053	14	75·2	7·52	0·752
Shop 5	864	10	86·4	8·64	0·864
Shop 6	655	20	32·7	3·27	0·327
Shop 7 (w)	2,858	20	142·9	14·29	1·429
Shop 8	987	28	35·3	3·53	0·353
Total	**9,437**	200	47·2	4·72	0·472

♦ Data, as reported by shop owners (w) wholesaler, other shops, are retail

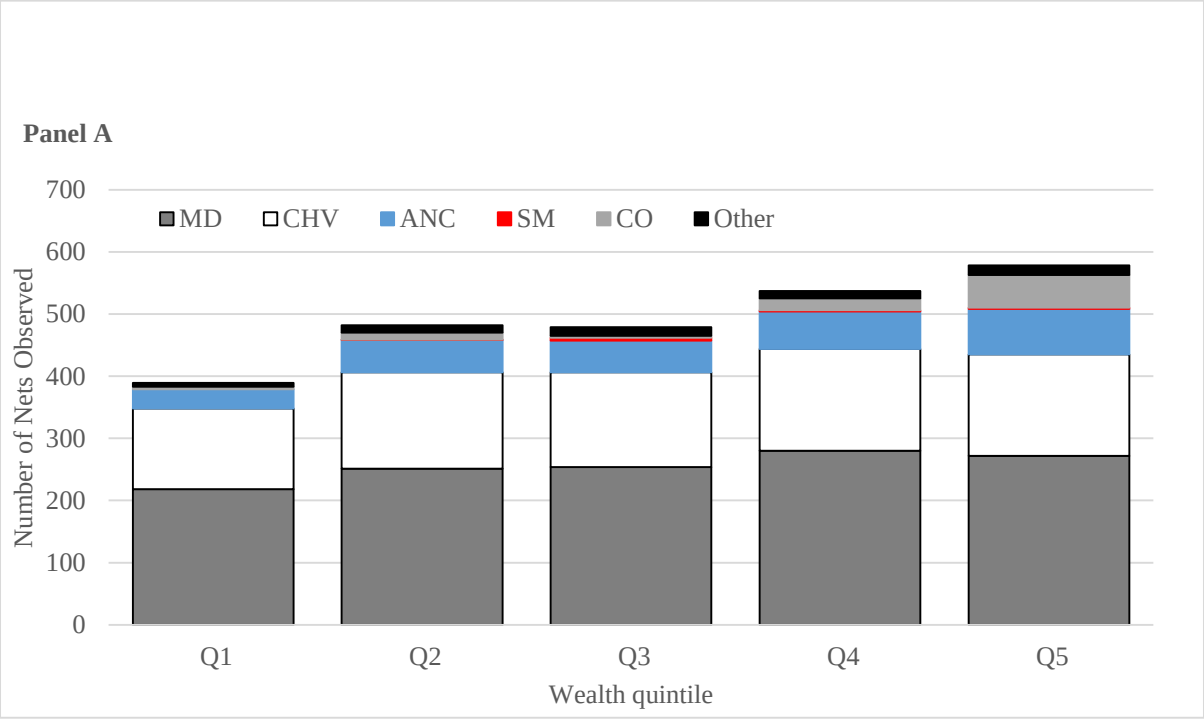
Equity effects of the LLIN distribution channels

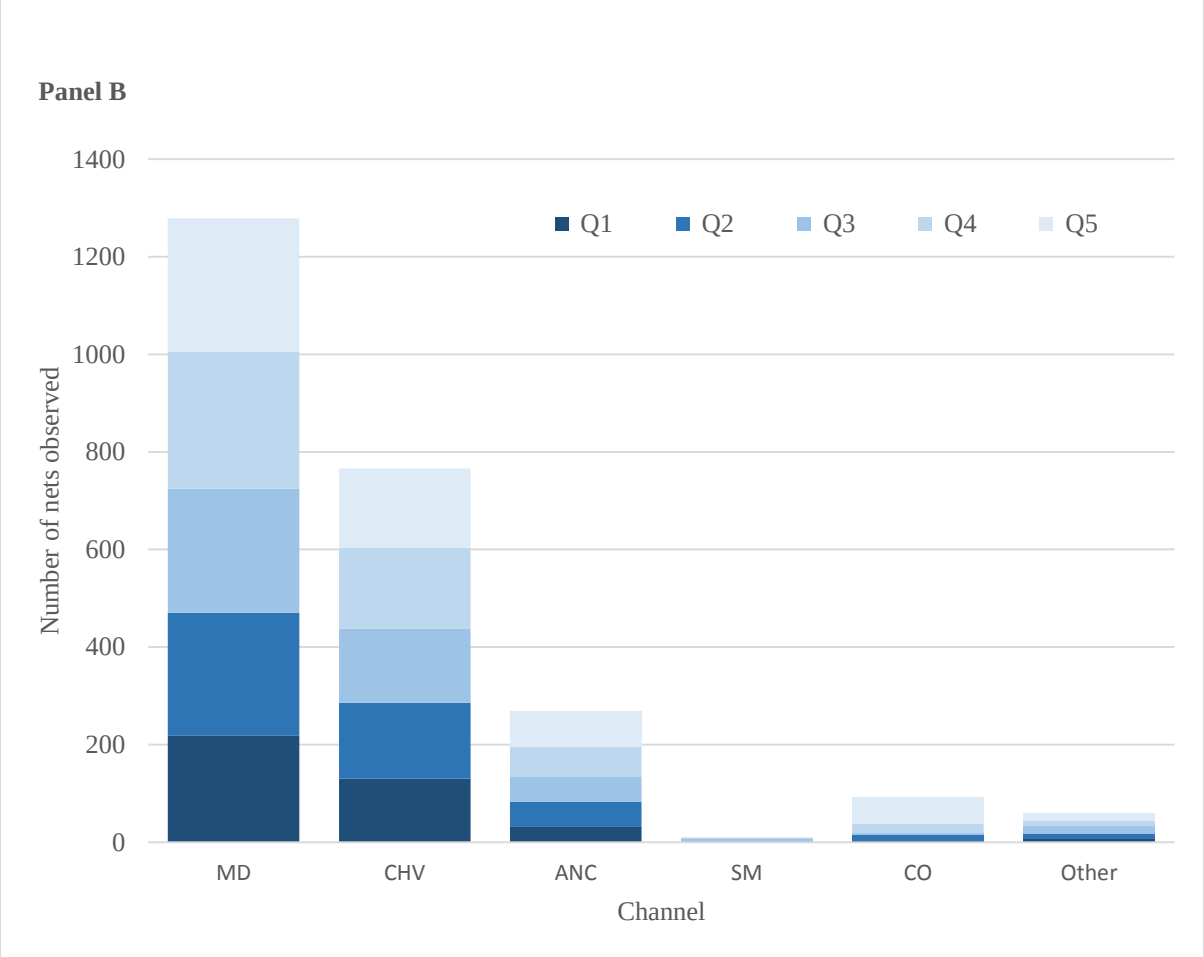
Most nets in all households came from the MD channel and the CHV channel, with the share of nets from these two channels being highest in the lowest wealth quintiles, demonstrating the importance of these two channels in ensuring access to LLINs in the poorest households (Figure 1, Panel B and Table S5). All distribution channels resulted in pro-wealthy inequitable net distribution, however, the CI for CHV and MD channels were close to zero (perfect equity). CHV was the least inequitable distribution channel (CI = 0·035) with MD being the second most equitable channel (CI = 0·039), however, as the 95% confidence interval for these channels overlaps, the difference is not statistically significant. The results showed that CHV and MD channels contributed most to the overall equity in LLIN ownership (Table 9).

Table 9 Nets categorised by channel and wealth quintile of the house where they were observed and concentration index for each channel

Channel	Wealth quintile					Concentration Index [95% confidence interval]
	Q1 [Poorest]	Q2	Q3	Q4	Q5 [Richest]	
MD	218	251	254	280	272	0·039 [0·008 to 0·07]
CHV	130	155	152	164	163	0·035 [0 to 0·071]
ANC	31	52	51	60	73	0·129 [0·033 to 0·225]
SM	0	1	5	2	2	0·147 [-0·276 to 0·569]
CO	4	11	3	19	53	0·460 [0·326 to 0·594]
Other	6	12	14	12	15	0·107 [-0·03 to 0·243]
All Channels	389	482	479	537	578	0·067 [0·024 to 0·109]

Figure 1 Panel: A Source channel of nets by household wealth quintile, Panel B: destination of nets by channel and wealth quintile[^]





Source data provided in Supplementary Table S5

Table S5a Equity data: Number and % of nets observed in the household survey by reported source and wealth quintile (Supplementary table)

Reported source of nets observed in the household survey	Indicator	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Total**
Channel							
MD	Number acquired	218	251	254	280	272	1,279
	% acquired by channel	17·04%	19·62%	19·86%	21·89%	21·27%	100%
	% of nets in this quintile from this channel	56·04%	52·07%	53·03%	52·14%	47·06%	51·89%
SM	Number acquired	0	1	5	2	2	10
	% acquired by channel	0·00%	10·00%	50·00%	20·00%	20·00%	100%
	% of nets in this quintile from this channel	0·00%	0·21%	1·04%	0·37%	0·35%	0·41%
ANC	Number acquired	31	52	51	60	73	267
	% acquired by channel	11·61%	19·48%	19·10%	22·47%	27·34%	100%
	% of nets in this quintile from this channel	7·97%	10·79%	10·65%	11·17%	12·63%	10·83%
CHV	Number acquired	130	155	152	164	163	764
	% acquired by channel	17·02%	20·29%	19·90%	21·47%	21·34%	100%
	% of nets in this quintile from this channel	33·42%	32·16%	31·73%	30·54%	28·20%	30·99%

Table S5b Equity data: Number and % of nets observed in the household survey by reported source and wealth quintile (Supplementary table)

	Indicator	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	Total
CO	Number acquired	4	11	3	19	53	90
	% acquired by channel	4·44%	12·22%	3·33%	21·11%	58·89%	100%
	% of nets in this quintile from this channel	1·03%	2·28%	0·63%	3·54%	9·17%	3·65%
others/don't know	Number acquired	1	2	2	5	0	10
	% acquired by channel	10·00%	20·00%	20·00%	50·00%	0·00%	100%
	% of nets in this quintile from this channel	0·26%	0·41%	0·42%	0·93%	0·00%	0·41%
relative/friend	Number acquired	5	10	12	7	15	49
	% acquired by channel	10·20%	20·41%	24·49%	14·29%	30·61%	100%
	% of nets in this quintile from this channel	1·29%	2·07%	2·51%	1·30%	2·60%	1·99%
Total	Number acquired	389	482	479	537	578	2,465
	% acquired by channel	15·78%	19·55%	19·43%	21·78%	23·45%	100%
	% of nets in this quintile from this channel	100%	100%	100%	100%	100%	100%

Discussion

Universal coverage and use targets of long-lasting insecticide nets were achieved in both arms through the simultaneous use of multiple channels. However, UC and use were higher in the control arm where mass distribution was used suggesting that MD are the most effective way to achieve high coverage. MD has the lowest cost per net distributed, regardless of how this is measured or estimated (SS vs D side). CHV appears to be the next lowest-cost way of distributing nets when estimated from the household survey, however, SM was the second-lowest-cost when using supplier reported data. We observed very few SM nets in the household survey which makes this the most expensive channel when estimating cost per net distributed from these data. Cost-effectiveness analysis showed the average annualized marginal costs per house with universal were significantly higher in the intervention arm (the US $ 80.64) where the CHV model was used compared to the control arm (the US $ 64.81) with MD. The study concludes that mass campaigns done together with other continuous distribution channels can be the most effective and cost-effective way to achieve universal coverage while community-based distribution channels like the use of CHVs are best in addressing equity concerns around ITN distribution, ownership and use. The study findings support the results by a study conducted in Ghana which analyzed the cost of three continuous distribution channels and established that the channels which target specific population with vulnerabilities are more likely to incur higher distribution costs than those that are intended for everybody [123]. The results of this study while reinforcing the important role in reducing the global malaria burden since 2000 [1] and global target of LLIN distribution to achieve 80% universal coverage for all people at risk of malaria with either LLINs or indoor residual spraying (IRS) by 2030 [108]. Concerted efforts with multichannel distribution can achieve a high level of ownership and contribute towards achieving a universal coverage policy goal.

ANC is an important source of nets, and although it is a relatively higher cost than the other channels, it allows targeting of key vulnerable groups and therefore should not be neglected. Equity analysis revealed that net distribution is still inequitable, with higher ownership in wealthier households. The CHV appeared to be the most equitable channel, closely followed by MD, however, these results are not statistically robust, implying weak evidence for an equity efficiency trade-off between the alternative channels with the MD being more efficient but less equitable than the CHV channel. It is notable that the ANC channel was less equitable than both the MD and CHV channel (with overlapping confidence interval) suggesting that more work needs to be done to increase access to ANC services for the poorest women and children. Cost per net distributed by the CO could not be calculated and the nets from this channel were the most inequitably distributed, however, since this channel operates without any public-sector investment its contribution is highly efficient from the (public) provider perspective and may represent a viable keep up, particularly for the upper wealth quintiles. The SM channel appears to be a poor investment when compared with other publicly financed channels, however, the poor performance of SM would be attributed to political factors rather than efficiency and economic concerns.

There is likely some recall issues with the source of net among households and this may be a particular challenge when being asked to differentiate between nets from CO and those via the SM channel. This reveals the importance of measuring outcomes of net distribution channels, rather than relying simply on supply-side data on quantity distributed as is often done in net distribution campaigns.

Studies reveal that the cost of LLIN distribution varies between locations and that economies of scale exist [124]. However, relatively little is known about the cost of alternative channels in the same setting. In spite of a large number of studies on the cost-effectiveness of LLINs [29, 110, 113, 114, 124], there have only been two other studies that compare alternative LLIN

distribution channels in the same setting. In Uganda Kolaczinski et. al compared a targeted LLIN campaign with ANC delivery and found that costs were broadly the same for campaign and ANC delivery in the same area, but that outcomes (nets retained and used) were better for the campaign [124]. In Burkina Faso, De Allegri et. al found that the economic costs of subsidised social marketing sales and free distribution to PW through ANC were the same, but they did not examine other outcomes [125]. Our study revealed that costs do differ between channels, in the same setting, however in our study, some of this variation may be due to limitations on the number of nets available to be distributed via each channel, which may have limited economies of scale for some channels. The potential of each channel to handle a higher volume of nets would improve both the efficiency and coverage outcomes, however, this was beyond our scope.

To our knowledge, this is the first study to look at the cost-effectiveness of achieving universal LLIN coverage. Yet this is the primary policy goal [1, 108, 126]. We found the marginal cost of each additional household achieving one net between two people (UC) is around $74¸ revealing the need for significant financial resources to reach and maintain universal LLIN coverage in populations. Challenge is to keep this up – sustainability and upscaling.

Study limitations include the fact that conducting evaluation alongside implementation is challenging and we had to deal with changes to the implementation. However, this type of study is more representative of real-world problems, therefore, we have to do it. Cost data may be incomplete and problems of recall and accuracy are inherent with this type of study. To address this we triangulated our results with details from donors on the finances provided to support LLIN distribution via MD and CHV channels. This is complex since donor financing agreements are not aligned with economic evaluation methods. The incremental cost-effectiveness ratio was not used as per the protocol since we did not a clear counter-factual comparator. We computed costs per outcome in each channel with 95% confidence intervals.

Universal coverage may be reached incomparable rural settings through a mix of multiple delivery channels. Long term upkeep of coverage is a separate challenge requiring long term financial and political commitment. Many countries grappling with this policy question· Transferability of results to other settings is not guaranteed therefore we recommend a repeat of similar analysis in other settings.

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Competing interest

The authors declare that they have no competing interests·

Author's contribution

EG, SK, and VW conceived the study· VW lead the collection of the field data· EW and VW completed the analyses and wrote the first draft· LN contributed to the study design, the comparative economic analyses and to first and last draft of the manuscript· MD, JO and AMB contributed all to the drafting of the various versions of the manuscript. AM contributed to the statistical analysis and assisted with interpretation.

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Chapter 8: Discussion and conclusion

Relationship between malaria infection and socioeconomic status

The study has established that the poorest individuals bore the highest burden of malaria infection compared to less poor individuals and remained most at risk. The findings from this study provide evidence on the existence of the relationship between malaria and poverty status and contribute to the evidence that socioeconomic inequalities still exist in malaria infection at the household level in Kenya. We confirmed our hypothesis that malaria infection disproportional occurs amongst the poorest individuals. A previous study by Somi et al. had also reported a large variation in parasitaemia rates between socioeconomic groups, where individuals with the lowest SES were significantly more likely to have malaria parasites than less-poor individuals [10]. However, this finding contrasted with those of de Castro and Fisher who found that SES had no association with malaria infection [8]. The de Castro study was limited to children aged 6–59 months, compared to the study by Somi et al. which did not restrict the analysis to a specific age group [8].

Persons from the poorest households spent significantly more money to purchase medications that are not recommended for malaria treatment. These medicines are likely to have less clinical efficacy and lead to unnecessary risk of adverse effects and complications of taking inappropriate medications. These findings from our study further illustrate existing socioeconomic inequalities in expenditures on non-recommended malaria medication in this rural western Kenya setting and provide further evidence that SES is still an important risk factor for malaria infection and treatment and contributes to higher burden amongst the poorest individuals.

However, the lack of a significant association between an individual's SES and care-seeking or between SES and ITN ownership demonstrate the progress towards achieving equity in accessing preventive interventions. This is in line with the principle of the Kenya Health

Policy 2014–2030 which aims to achieve equity in the distribution of health services and interventions by 2030 [49].

Application of the MCA model and its contribution

In response to previous concerns of inconsistency in findings comparing SES and malaria due to different methods of establishing household or individual SES, we aimed to apply Multiple Correspondence Analysis (MCA) to establish wealth quintiles using household assets, utilities, and characteristics. Although there was extensive literature on health inequalities and health outcomes more generally, no previous study had evaluated the relationships between malaria indicators and SES using MCA to analyse microeconomic data.

Malaria remains an important public health concern with approximately 3.2 million people at risk of infections globally [1]. The World Health Organization (WHO) estimated that a total of 216 million malaria cases occurred globally between 2010 – 2016. Sub-Saharan Africa (SSA) is disproportionally affected with over 90% (445,000) of malaria deaths reported in 2016 [33]. Malaria has a significant economic impact on national economies and to individual households [35, 62]. Total funding for malaria control and elimination efforts was estimated at US$2.9 billion globally in 2015, with governments in malaria-endemic countries providing 32% of the total funding, of which 65% or US$612 million was expenditure by national malaria control programs for program implementation and 35% or US$332 million was expenditure on health service delivery [33]. It is estimated that 3.1% of all disability-adjusted life-years (DALYs) were lost to malaria in 2002 [2] while 35 million disability-adjusted life years lost were 2015 [90]. The global sustainable development goal is to achieve a reduction in malaria mortality rates by 90%, reduce case incidence by 90%, eliminate malaria from 35 countries in which malaria was transmitted, and to prevent re-establishment of malaria in all countries that are malaria-free by the year 2030 compared to 2015 [127].

In Kenya, despite remarkable achievements in malaria prevention and control over the last 10 years, malaria remains a leading cause of morbidity and mortality with more than 70 per cent of the population at risk [3]. Malaria has been described as a disease of the poor and the relationship between malaria and poverty has often been described as a vicious cycle [12, 14] in the sense that poor individuals are more at risk of infection due to many factors including low economic power to purchase care and recommended treatment, and similarly, the disease can lead to poverty due to catastrophic expenditure and disability [8, 13].

Monitoring socioeconomic inequalities in malaria-related indices

We aimed to assess the trends in socioeconomic inequalities in malaria indicators at the household level in a malaria-endemic region of western Kenya between 2006 and 201. We had hypothesized that over time, malaria occurrence, ITN use, drug use, and related expenditure would disproportionally occur among lower economic strata in the population over time. The study established that indeed overtime, poor individuals have had a higher burden of malaria infections compared to less-poor individuals confirming our hypothesis. These results were consistent across all age groups (<5years, 5-14 years and at least 15 years) between 2006 and 2013. However, contrary to our hypothesis, the results showed reduced inequalities in care-seeking behaviour across socioeconomic groups. Similarly, over time, poor individuals were less likely to use effective antimalarial medications. In the pooled analysis, the use of ITN for malaria prevention was slightly lower amongst the poorest individuals compared to the less poor but the differences were small which suggests that ITNs are equitably used among these relatively poor rural communities.

Results showed that over time there were no socioeconomic inequalities in care-seeking for fever or use of any medications but poor individuals were still less likely to use the

recommended first-line antimalarial medications such as AL for uncomplicated malaria and quinine for complicated malaria infection or for pregnant women [44, 55, 57]. This supports our hypothesis that the use of malaria prevention and treatment disproportionately occur amongst those in low SES. A previous study had also established that the use of AL was higher in children from the lowest wealth quintile compared to those in the highest wealth quintile because of policies that systematically affected access to malaria treatment for children[31]. Prior to the 2010 introduction of the Affordable Medicine Facility– malaria (AMFm) in Kenya, AL was significantly more expensive than other non-recommended antimalarial medicines in the private sector[63]. Evidence from a similar area of rural western Kenya showed that when adults are uncertain that fever is due to malaria, they tend to choose the lowest-priced antimalarial medicine from private-sector pharmacies and retail outlets [47]. Therefore, when antimalarial medications were not available in public health facilities during the study period, individuals from poor households might have preferentially purchased non-recommended antimalarial medications in the private sector due to lower prices [40]. But despite equity in care-seeking, there still existed inequalities in ITN use and the use of effective malaria treatment. The existence of socioeconomic inequalities is a hindrance to attaining universal coverage. However, even perfectly equitable access to interventions could have an inequitable impact since the risk is strongly linked to poverty. The study examined the existence of socioeconomic inequalities or equity effects of intermittent mass screen and test for malaria treatment using data from a two-year community-based cluster-randomized trial in rural western Kenya. The results showed that after two years of implementation of six rounds of the MTAT intervention, there was no significant difference in the prevalence of malaria between the poorest and less poor individuals, implying equity in the burden of malaria had been achieved. There was also equity in care-seeking for fever and the use of medication between the poorest and the less.

These results confirm our hypothesis that MTAT intervention resulted in reduced socioeconomic inequalities in access and use of medicines and ITNs. This could be attributed to the availability of malaria medication to the participating households within their close proximity. Similarly, MTAT implementation resulted in a reduction in DALYs in the general population and non-significant differences (equity) in DALYs lost between the poorest and less poor. Even though the poor had the highest burden of DALYs at baseline (2013), they had more DALYs at the end of the study in 2015. Some studies have shown that the use of MTAT can reduce transmission of malaria, however, none to date have assessed the equity effect of MTAT on malaria indices through an economic perspective rather than purely epidemiological standpoint [71, 73, 76]. This study is perhaps the first one to demonstrate the equity effect of MTAT intervention on malaria mortality and morbidity despite over overall non-significant effect on reducing malaria burden. The above findings, demonstrate that MTAT can be an important strategy towards malaria reduction, elimination and addressing equity concerns about malaria burden between different population groups and especially at the microeconomic level. A community-based intervention would still have economic benefits to individuals in low socioeconomic status in terms of access to free medications which was readily available and they did not have to seek care as often. The MTAT provided LLINs to the target households before the start of the study with an aimed of achieving at least 80% coverage. This also resulted in equity in access to LLINs between individuals in low and high SES. The MTAT study targeted about only 30,000 individuals within the HDSS which has about 220,000 individuals [5, 41]

The study further evaluated the economic and population burden of malaria using longitudinal data collected from a health and surveillance system for nine years (Chapter 5). The HDSS had an approximate population of 220,000 individuals. The main advantage of the

surveillance data was documentation of malaria-specific deaths not only from the households that participated in previous surveys, including MTAT study but in the general population in the study area[41]. The results of the study also indicated that malaria-related mortality progressively reduced over the nine-year period of evaluation. Poorest individuals, children < 5 years and women disproportionately bore the greatest burden of malaria compared to the least poor individuals, older children or males. This finding provided evidence that socioeconomic inequalities in the burden of malaria still existed in the overall population confirming our hypothesis but there was an overall decline over time suggesting that the intensification of malaria control interventions over time resulted in reducing socioeconomic inequalities in the study area over time (2006 to 2014). A study conducted in South Africa established that socio-economic related health inequality for self-reported ill health and disability were in favour of poor households than the rich ones. However, the trend in the magnitude of socioeconomic related inequalities tended to decline over time, showing progress toward attaining SDG on reducing inequalities [107].

Monitoring socioeconomic and equity effects of malaria control programs contribute to the global agenda and have implications for five Sustainable Development Goals (SDGs). The specific SDGs relate to the reduction of health inequalities nationally and worldwide which includes poverty reduction, health, and wellbeing for all, equitable education, gender equality, and reduction of inequalities within and between countries [26, 60]. Despite intensified malaria control program in Africa and in Kenya, there was inadequate data on the impact on economic burden at the household level and on progress towards achieving equity. Socioeconomic inequalities are known barriers to achieve universal health coverage and SDGs goals by 2030 [50]. In this thesis, we hypothesized that the malaria burden and related indices are disproportionately higher amongst the poorest households compared to wealthier

ones. Data on socioeconomic are often collected but seldom utilized in analyses hindering monitoring of health-related inequalities and economic impact of the control interventions at the household level [60]. The need for such monitoring is in line with the Kenya National Malaria Strategy 2009-2017 objectives, whose aim was to reduce mortality for children less than five years by two-thirds by 2015 and eradication of malaria in Kenya by 2017. While these were not achieved [31] it highlighted the importance of monitoring epidemiological and economic benefits of control programs, as proposed in Kenya Health Policy 2014-2030 [49]. In the context of intensification of malaria control programs and due to scarce and competing resources in the health sector, policymakers increasingly request the economic impact of interventions before decisions to adopt a new intervention are taken [60]. At the same time, the effects of malaria interventions may have economic benefits or losses to households especially the need to promote equity or reduce inequality between the poor or less poor households [128].

The World Bank and WHO have recommended methods and strategies for monitoring inequality and equity in health outcomes in developing countries, but there is a need for a continuous evaluation of these methods aimed at evaluating socioeconomic inequalities and the relationship between malaria and poverty [21]. However, the lack of adequate data has hindered this monitoring consistently. In western Kenya, availability of longitudinal data or clinical trial data collected from a well-established health and demographic surveillance provide an opportunity to measure the existence of socioeconomic inequalities or equity effect and cost-effectiveness of malaria control programs at the household.

In order to comprehensively evaluate the socioeconomic inequalities, equity effects and cost-effectiveness of control programs we used data from longitudinal repeated cross-sectional surveys collected from 2006 to 2013, malaria deaths from surveillance data from 2006 to 2014 which was used to estimate DALYs lost/gains, data from a cluster-randomized trial

collected in 2013 to 2015 and costing data collected in 2015 to assesses costs and effects of LLIN distribution channels.

Relationship between malaria and socioeconomic status

We aimed to establish the existence of socioeconomic inequalities and the relationship between household socioeconomic status and malaria-related health outcomes such as ITN use, medication use and expenditure on treatment using data from a cross-sectional survey conducted in 2012. We had hypothesized that the risk of malaria-related outcomes such as malaria prevalence, care-seeking, ITN use, and expenditures disproportionately occur amongst the poorest individuals. For this analysis, we applied a multiple correspondence analysis to gauge the relative socio-economic status (SES) of the population at the household level. This model had not been used before to assess the relationship between SES and malaria indices and its application contributes to methods for assessing SES. The results have shown that individuals in the poorest households had a higher burden of malaria infection compared to those from the least poor households. Persons from the poorest households also spent significantly more money to purchase medications that are not recommended for malaria treatment. These medicines are likely to have less clinical efficacy and lead to unnecessary risk of adverse effects and complications of taking inappropriate medications. There were no significant associations between SES and care-seeking or between SES uses of ITNs.

In 2015, while the prevalence of microscopically-confirmed malaria was 8% amongst children less than 15 years (13% by malaria rapid diagnostic test nationally, it was 27% (43% by malaria RDT) in the lake-endemic region of western Kenya [4]. There has been scale-up of malaria control interventions including long-lasting insecticide nets (LLINs), indoor

residual spraying (IRS), improved case management with rapid diagnostic tests (RDTs), Artemisinin-based combination therapy (ACT) and intermittent preventive treatment (IPT) for high-risk groups[1] and most recently the use of mass test and treat MTAT has been suggested for evaluation[5]. It is known that individuals with asymptomatic parasitemia play an important role in sustaining malaria transmission during the dry season when the population of Anopheles mosquitoes has decreased, and provide a parasite reservoir at the beginning of the wet season when anopheles populations rebound [70]. Asymptomatic *Plasmodium* infections may occur between 12 and 39% of the population and systematic identification and treatment of individuals with asymptomatic infections could reduce transmission of malaria [71, 72]. Mathematical simulations have shown that MTAT can have a significant impact on malaria transmission, particularly in areas with the hypoendemic transmission or low to moderate transmission achieved through vector control [71, 73]. Empirical studies of who benefits from the distribution of public goods (whether drugs or bed nets) suggest that such programs tend to favour those who are better off, yet there are no studies to show equity effect of MTAT in malaria-endemic areas.

Chapter 3 presents findings related to the second objective of this thesis which showed that although there was equity in care-seeking behaviour for fever between individuals from poor compared to less-poor households, poor individuals were less likely to use the recommended first-line antimalarial medications, AL and quinine for pregnant women [44, 55, 57]. A previous study had suggested that the use of AL was higher in children from the lowest wealth quintile compared to the highest wealth quintile because of policies that systematically affected access to malaria treatment for children[31]. Prior to the 2010 introduction of the Affordable Medicine Facility– malaria (AMFm) in Kenya, AL was significantly more expensive than other non-recommended antimalarial medicines in the private sector[63]. Evidence from a similar area of rural western Kenya showed that when adults are uncertain

that fever is due to malaria, they tend to choose the lowest-priced antimalarial medicine from private-sector pharmacies and retail outlets [47]. Therefore, when antimalarial medications were not available in public health facilities during the study period, individuals from poor households might have preferentially purchased non-recommended antimalarial medications in the private sector due to lower prices [40]. But despite equity in care-seeking, there still existed inequalities in ITN use and the use of effective malaria treatment. The existence of socioeconomic inequalities is a hindrance to attaining universal coverage.

In chapter 4 the study examined the equity effect of the MTAT using data from a two-year community-based cluster-randomized trial in rural western Kenya. The results showed that after two years of implementation of six rounds of the MTAT intervention, there was no significant difference in the prevalence of malaria between the poorest and less poor households, implying equity in the burden of malaria had been achieved. There was also equity in care-seeking for fever and use of medication as results showed the non-significant difference between the poorest and the less. This could be attributed to the availability of malaria medication to the participating households within their close proximity. Similarly, MTAT implementation resulted in a reduction in DALYs in the general population and there was equity in terms of no notable differences in DALYs lost between the poorest and less poor. Even though the poor had the highest burden of DALYs at baseline, they gained more DALYs towards the end of the study. Some studies have shown that the use of MTAT can reduce transmission of malaria, however, none to date have demonstrated any equity impact of MTAT on malaria outcome through an economic perspective rather than purely epidemiological standpoint [71, 73, 76]. This study is perhaps, the first study to demonstrate the equity impact of MTAT intervention on malaria mortality and morbidity despite over overall non-significant effect on reducing malaria burden. The above findings, demonstrate

that MTAT can be an important strategy towards malaria reduction, elimination and addressing equity concerns about malaria burden between different population groups and especially at the microeconomic level.

The most notable finding was that poor household was made to unfairly bear a higher burden of malaria mortality compared to the least poor households, and this was observed across the socioeconomic groups and over this time. As it has been demonstrated in the previous chapters, care-seeking behaviour, access to malaria medications and ITNs use are all in favour of the least poor, the same has been reflected in malaria burden in terms of disability-adjusted life years. The rich are mostly favoured by their strong purchasing power which allows them to afford malaria treatment and prevention commodities with minimal hindrance. Our results are consistent with a study conducted in Malawi, in which the author analysed the relationship between household income and the economic burden of malaria and found out that households with low- income disproportionately bear the economic burden of malaria compared to higher-income households [97]. The study also demonstrated more comprehensively the huge economic burden of malaria illness being borne by households in developing countries and especially those who are economically disadvantaged [97]. Our finding is also in line with that of a South African national burden of disease study in 2000, in which the burden of various diseases was estimated and the disease burden apportioned based on the socioeconomic status it was established that concentrated among poor socioeconomic groups compared to the least poor socioeconomic groups [6]. Also, a study by Ataguba et al investigating socio-economic related health inequalities in self-reported ill health and disability revealed that poor people reported more ill health and disability than the least poor [107]. It further demonstrated that the trend in the magnitude of socioeconomic related inequalities tends to decline over time.

Effectiveness of interventions to control malaria and their effects on equity

Studies from various parts of Africa have indicated that the use of LLINs has a beneficial effect on malaria transmission, severe malaria and mortality [27, 28]. Similarly, there are numerous studies demonstrating the cost-effectiveness of LLINs in different parts of the world and in various contexts [29]. However, while there has been the application of various LLIN distribution methods, information is limited on the actual costs of parallel distribution channels in the same context and coverage results that can realistically be achieved from each channel based on financial inputs [30]. Similarly, there were no studies which had evaluated the cost, effects of various ITN distribution channels in a malaria-endemic area of western Kenya.

Cost-effectiveness and equity impact of LLIN distribution channels

We aimed to study cost-effectiveness and equity effects of distributing LLINs using five different channels namely; Mass distribution (MD), ANC, Social marketing (SM), CHVs and commercial outlets (CO). The findings showed that mass distribution was the most cost-effective from both provider and consumer perspectives. CHV was the next lowest costly way of distributing nets when estimated from the household survey. However, SM had the second-lowest-cost when using supplier reported data. All channels were pro- richer households. CHV approach was the least inequitable/possibly neutral, followed by MD. CO was the least equitable. ANC and SM were in between. Mass campaigns might have benefited from the economies of scale owing to a large volume of nets distributed through this channel thus lowering the cost per net distributed. The study findings support the results by a study conducted in Ghana which analysed the cost of three continuous distribution channels and established that the channels which target specific population with vulnerabilities are more likely to incur higher distribution costs than those that are intended

for everybody [123]. Concerted efforts with multichannel distribution can achieve a high level of ownership and contribute towards achieving a universal coverage policy goal. The study concludes that mass campaigns done together with other continuous distribution channels can be the most effective and cost-effective way to achieve universal coverage while community-based distribution channels like the use of CHVs are best in addressing equity concerns around ITN distribution, ownership and use.

Relationship between malaria infection and socioeconomic status

The study has established that the poorest individuals bore the highest burden of malaria infection compared to wealthier individuals and remained most at risk. The findings from this study provide evidence on the existence of a relationship between malaria and poverty status and contribute to the evidence that socioeconomic inequalities still exist in malaria infection at the household level in Kenya. We confirmed our hypothesis that malaria infection disproportionately occurs amongst the poorest individuals. A previous study by Somi et al. had also reported a large variation in parasitaemia rates between socioeconomic groups, where individuals with the lowest SES were significantly more likely to have malaria parasites than less-poor individuals [10]. However, this finding contrasted with those of de Castro and Fisher who found that SES had no association with malaria infection [8]. The de Castro study was limited to children aged 6–59 months, compared to the study by Somi et al. which did not restrict the analysis to a specific age group [8].

Persons from the poorest households spent significantly more money to purchase medications that are not recommended for malaria treatment. These medicines are likely to have less clinical efficacy and lead to unnecessary risk of adverse effects and complications of taking inappropriate medications. These findings from our study further illustrate existing socioeconomic inequalities in expenditures on non-recommended malaria medication in this

rural western Kenya setting and provide further evidence that SES is still an important risk factor for malaria infection and treatment and contributes to higher burden amongst the poorest individuals.

However, the lack of a significant association between an individual's SES and care-seeking or between SES and ITN ownership suggest progress towards achieving equity in accessing preventive interventions. This is in line with the principle of the Kenya Health Policy 2014–2030 which aims to achieve equity in the distribution of health services and interventions by 2030 [49].

Application of the MCA SES model and its contribution

In response to previous concerns of inconsistency in findings comparing SES and malaria due to different methods of establishing household or individual SES [7], we aimed to apply Multiple Correspondence Analysis (MCA) to establish wealth quintiles using household assets, utilities and characteristics to mitigate these problems. Although there is extensive literature on health inequalities and health outcomes more generally, no previous study had evaluated the relationships between malaria indicators and SES using MCA to analyse microeconomic data.

Malaria remains an important public health concern with approximately 3.2 million people at risk of infections globally [1]. The World Health Organization (WHO) estimated that a total of 216 million malaria cases occurred globally between 2010 – 2016. Sub-Saharan Africa (SSA) is disproportionally affected with over 90% (445,000) of malaria deaths reported in 2016 [33]. Malaria has a significant economic impact on national economies and to individual households [35, 62]. Total funding for malaria control and elimination efforts was estimated at US$2.9 billion globally in 2015, with governments in malaria-endemic countries

providing 32% of the total funding, of which 65% or US$612 million was expenditure by national malaria control programs for program implementation and 35% or US$332 million was expenditure on health service delivery [33]. It is estimated that 3.1% of all disability-adjusted life-years (DALYs) were lost to malaria in 2002 [2] while 35 million disability-adjusted life years lost were 2015 [90]. The global sustainable development goal is to achieve a reduction in malaria mortality rates by 90%, reduce case incidence by 90%, eliminate malaria from 35 countries in which malaria was transmitted, and to prevent re-establishment of malaria in all countries that are malaria-free by the year 2030 compared to 2015 [127].
In Kenya, despite remarkable achievements in malaria prevention and control over the last 10 years, malaria remains a leading cause of morbidity and mortality with more than 70 per cent of the population at risk [3]. Malaria has been described as a disease of the poor and the relationship between malaria and poverty has often been described as a vicious cycle [12, 14] in the sense that poor individuals are more at risk of infection due to many factors including low economic power to purchase care and recommended treatment, and similarly, the disease can lead to poverty due to catastrophic expenditure and disability [8, 13].

Monitoring socioeconomic inequalities in malaria-related indices

We aimed to assess the trends in socioeconomic inequalities in malaria indicators at the household level in a malaria-endemic region of western Kenya between 2006 and 201. We had hypothesized that over time, malaria occurrence, ITN use, drug use, and related expenditure would disproportionally occur among lower economic strata in the population over time. The study established that indeed overtime, poor individuals have had a higher burden of malaria infections compared to less-poor individuals confirming our hypothesis. These results were consistent across all age groups (<5years, 5-14 years and at least 15 years) between 2006 and 2013. However, contrary to our hypothesis, the results showed reduced

inequalities in care-seeking behaviour across socioeconomic groups. Similarly, over time, poor individuals were less likely to use effective antimalarial medications. In the pooled analysis, the use of ITN for malaria prevention was slightly lower amongst the poorest individuals compared to the less poor but the differences were small which suggests that ITNs are equitably used among these relatively poor rural communities.

Results showed that over time there were no socioeconomic inequalities in care-seeking for fever or use of any medications but poor individuals were still less likely to use the recommended first-line antimalarial medications such as AL for uncomplicated malaria and quinine for complicated malaria infection or for pregnant women [44, 55, 57]. This supports our hypothesis that the use of malaria prevention and treatment disproportionately occur amongst those in low SES. A previous study had also established that the use of AL was higher in children from the lowest wealth quintile compared to those in the highest wealth quintile because of policies that systematically affected access to malaria treatment for children[31]. Prior to the 2010 introduction of the Affordable Medicine Facility– malaria (AMFm) in Kenya, AL was significantly more expensive than other non-recommended antimalarial medicines in the private sector[63]. Evidence from a similar area of rural western Kenya showed that when adults are uncertain that fever is due to malaria, they tend to choose the lowest-priced antimalarial medicine from private-sector pharmacies and retail outlets [47]. Therefore, when antimalarial medications were not available in public health facilities during the study period, individuals from poor households might have preferentially purchased non-recommended antimalarial medications in the private sector due to lower prices [40]. But despite equity in care-seeking, there still existed inequalities in ITN use and the use of effective malaria treatment. The existence of socioeconomic inequalities is a

hindrance to attaining universal coverage. However, even perfectly equitable access to interventions could have an inequitable impact since the risk is strongly linked to poverty. The study examined the existence of socioeconomic inequalities or equity effects of intermittent mass screen and test for malaria treatment using data from a two-year community-based cluster-randomized trial in rural western Kenya. The results showed that after two years of implementation of six rounds of the MTAT intervention, there was no significant difference in the prevalence of malaria between the poorest and less poor individuals, implying equity in the burden of malaria had been achieved. There was also equity in care-seeking for fever and the use of medication between the poorest and the less. These results confirm our hypothesis that MTAT intervention resulted in reduced socioeconomic inequalities in access and use of medicines and ITNs. This could be attributed to the availability of malaria medication to the participating households within their close proximity. Similarly, MTAT implementation resulted in a reduction in DALYs in the general population and non-significance differences (equity) in DALYs lost between the poorest and less poor. Even though the poor had the highest burden of DALYs at baseline (2013), they had more DALYs at the end of the study in 2015. Some studies have shown that the use of MTAT can reduce transmission of malaria, however, none to date have assessed the equity effect of MTAT on malaria indices through an economic perspective rather than purely epidemiological standpoint [71, 73, 76]. This study is perhaps the first one to demonstrate the equity effect of MTAT intervention on malaria mortality and morbidity despite over overall non-significant effect on reducing malaria burden. The above findings demonstrate that MTAT can be an important strategy towards malaria reduction, elimination and addressing equity concerns about malaria burden between different population groups and especially at the microeconomic level. A community-based intervention would still have economic benefits to individuals in low socioeconomic status in terms of access to free

medications which was readily available and they did not have to seek care as often. The MTAT provided LLINs to the target households before the start of the study with an aimed of achieving at least 80% coverage. This also resulted in equity in access to LLINs between individuals in low and high SES. The MTAT study targeted about only 30,000 individuals within the HDSS which has about 220,000 individuals [5, 41]

The study further evaluated the economic and population burden of malaria using longitudinal data collected from a health and surveillance system for nine years (Chapter 5). The HDSS had a population of approximate 220,000. The main advantage of the surveillance data was documentation of malaria-specific deaths not only from the households that participated in previous surveys, including MTAT study but also in the general population in the study area[41]. The results of the study also indicated that malaria-related mortality progressively reduced over the nine-year period of evaluation. Poorest individuals, children < 5 years and women disproportionately bore the greatest burden of malaria compared to the least poor individuals, older children or males. This finding provided evidence that socioeconomic inequalities in the burden of malaria still existed in the overall population confirming our hypothesis but there was an overall decline over time suggesting that the intensification of malaria control interventions over time resulted in reducing socioeconomic inequalities in the study area over time (2006 to 2014). A study conducted in South Africa established that socio-economic related health inequality for self-reported ill health and disability were in favour of poor households than the rich ones. However, the trend in the magnitude of socioeconomic related inequalities tended to decline over time, showing progress toward attaining SDG on reducing inequalities [107].

Monitoring socioeconomic and equity effects of malaria control programs contribute to the global agenda and have implications for five Sustainable Development Goals (SDGs). The

specific SDGs relate to the reduction of health inequalities nationally and worldwide which includes poverty reduction, health, and wellbeing for all, equitable education, gender equality, and reduction of inequalities within and between countries [26, 60]. Despite intensified malaria control program in Africa and in Kenya, there was inadequate data on the impact on economic burden at the household level and on progress towards achieving equity. Socioeconomic inequalities are known barriers to achieve universal health coverage and SDGs goals by 2030 [50]. In this thesis, we hypothesized that the malaria burden and related indices are disproportionately higher amongst the poorest households compared to wealthier ones. Data on socioeconomic are often collected but seldom utilized in analyses hindering monitoring of health-related inequalities and economic impact of the control interventions at the household level [60]. The need for such monitoring is in line with the Kenya National Malaria Strategy 2009-2017 objectives, whose aim was to reduce mortality for children less than five years by two-thirds by 2015 and eradication of malaria in Kenya by 2017. While these were not achieved [31] it highlighted the importance of monitoring epidemiological and economic benefits of control programs, as proposed in Kenya Health Policy 2014-2030 [49]. In the context of intensification of malaria control programs and due to scarce and competing resources in the health sector, policymakers increasingly request the economic impact of interventions before decisions to adopt a new intervention are taken [60]. At the same time, the effects of malaria interventions may have economic benefits or losses to households especially the need to promote equity or reduce inequality between the poor or less poor households [128].

The World Bank and WHO have recommended methods and strategies for monitoring inequality and equity in health outcomes in developing countries, but there is a need for a continuous evaluation of these methods aimed at evaluating socioeconomic inequalities and the relationship between malaria and poverty [21]. However, the lack of adequate data has

hindered this monitoring consistently. In western Kenya, availability of longitudinal data or clinical trial data collected from a well-established health and demographic surveillance provide an opportunity to measure the existence of socioeconomic inequalities or equity effect and cost-effectiveness of malaria control programs at the household.

In order to comprehensively evaluate the socioeconomic inequalities, equity effects and cost-effectiveness of control programs we used data from longitudinal repeated cross-sectional surveys collected from 2006 to 2013, malaria deaths from surveillance data from 2006 to 2014 which was used to estimate DALYs lost/gains, data from a cluster-randomized trial collected in 2013 to 2015 and costing data collected in 2015 to assesses costs and effects of LLIN distribution channels.

Relationship between malaria and socioeconomic status

We aimed to establish the existence of socioeconomic inequalities and the relationship between household socioeconomic status and malaria-related health outcomes such as ITN use, medication use and expenditure on treatment using data from a cross-sectional survey conducted in 2012. We had hypothesized that the risk of malaria-related outcomes such as malaria prevalence, care-seeking, ITN use, and expenditures disproportionately occur amongst the poorest individuals. In this analysis, we applied a multiple correspondence analysis to gauge the relative socio-economic status (SES) of the population at the household level. This model had not been used before to assess the relationship between SES and malaria indices and its application contributes to methods for assessing SES. The results have shown that individuals in the poorest households had a higher burden of malaria infection compared to those from the least poor households. Persons from the poorest households also spent significantly more money to purchase medications that are not recommended for malaria treatment. These medicines are likely to have less clinical efficacy and lead to

unnecessary risk of adverse effects and complications of taking inappropriate medications. There were no significant associations between SES and care-seeking or between SES uses of ITNs.

In 2015, while the prevalence of microscopically-confirmed malaria was 8% amongst children less than 15 years (13% by malaria rapid diagnostic test nationally, it was 27% (43% by malaria RDT) in the lake-endemic region of western Kenya [4]. There has been scale-up of malaria control interventions including long-lasting insecticide nets (LLINs), indoor residual spraying (IRS), improved case management with rapid diagnostic tests (RDTs), Artemisinin-based combination therapy (ACT) and intermittent preventive treatment (IPT) for high-risk groups[1] and most recently the use of mass test and treat MTAT has been suggested for evaluation[5]. It is known that individuals with asymptomatic parasitemia play an important role in sustaining malaria transmission during the dry season when the population of Anopheles mosquitoes has decreased, and provide a parasite reservoir at the beginning of the wet season when anopheles populations rebound [70]. Asymptomatic *Plasmodium* infections may occur between 12 and 39% of the population and systematic identification and treatment of individuals with asymptomatic infections could reduce transmission of malaria [71, 72]. Mathematical simulations have shown that MTAT can have a significant impact on malaria transmission, particularly in areas with the hypoendemic transmission or low to moderate transmission achieved through vector control [71, 73]. Empirical studies of who benefits from the distribution of public goods (whether drugs or bed nets) suggest that such programs tend to favour those who are better off, yet there are no studies to show equity effect of MTAT in malaria-endemic areas.

Although there was equity in care-seeking behaviour for fever between individuals from poor compared to less-poor households, poor individuals were less likely to use the recommended

first-line antimalarial medications, AL and quinine for pregnant women [44, 55, 57]. A previous study had suggested that the use of AL was higher in children from the lowest wealth quintile compared to the highest wealth quintile because of policies that systematically affected access to malaria treatment for children[31]. Prior to the 2010 introduction of the Affordable Medicine Facility– malaria (AMFm) in Kenya, AL was significantly more expensive than other non-recommended antimalarial medicines in the private sector[63]. Evidence from a similar area of rural western Kenya showed that when adults are uncertain that fever is due to malaria, they tend to choose the lowest-priced antimalarial medicine from private-sector pharmacies and retail outlets [47]. Therefore, when antimalarial medications were not available in public health facilities during the study period, individuals from poor households might have preferentially purchased non-recommended antimalarial medications in the private sector due to lower prices [40]. But despite equity in care-seeking, there still existed inequalities in ITN use and the use of effective malaria treatment. The existence of socioeconomic inequalities is a hindrance to attaining universal coverage.

This study examined the equity effect MTAT using data col from a two-year community-based cluster-randomized trial in rural western Kenya. The results showed that after two years of implementation of six rounds of the MTAT intervention, there was no significant difference in the prevalence of malaria between the poorest and less poor households, implying the presence of equity in the burden of malaria had been achieved. There was also equity in care-seeking for fever and use of medication as results showed the non-significant difference between the poorest and the less. This could be attributed to the availability of malaria medication to the participating households within their close proximity. Similarly, MTAT implementation resulted in ina reduction in DALYs in the general population and there was equity in terms of no notable differences in DALYs lost between the poorest and

less poor. Even though the poor had the highest burden of DALYs at baseline, they gained more DALYs towards the end of the study. Some studies have shown that the use of MTAT can reduce transmission of malaria, however, none to date have demonstrated any equity impact of MTAT on malaria outcome through an economic perspective rather than purely epidemiological standpoint [71, 73, 76]. This study is perhaps, the first study to demonstrate the equity impact of MTAT intervention on malaria mortality and morbidity despite over overall non-significant effect on reducing malaria burden. The above findings, demonstrate that MTAT can be an important strategy towards malaria reduction, elimination and addressing equity concerns about malaria burden between different population groups and especially at the microeconomic level.

The most notable finding was that poor household was made to unfairly bear a higher burden of malaria mortality compared to the least poor households, and this was observed across the socioeconomic groups and over this time. As it has been demonstrated in the previous chapters, care-seeking behaviour, access to malaria medications and ITNs use are all in favour of the least poor, the same has been reflected in malaria burden in terms of disability-adjusted life years. The rich are mostly favoured by their strong purchasing power which allows them to afford malaria treatment and prevention commodities with minimal hindrance. Our results are consistent with a study conducted in Malawi, in which the author analysed the relationship between household income and the economic burden of malaria and found out that households with low- income disproportionately bear the economic burden of malaria compared to higher-income households [97]. The study also demonstrated more comprehensively the huge economic burden of malaria illness being borne by households in developing countries and especially those who are economically disadvantaged [97]. Our finding is also in line with that of a South African national burden of disease study in 2000, in

which the burden of various diseases was estimated and the disease burden apportioned based on the socioeconomic status it was established that concentrated among poor socioeconomic groups compared to the least poor socioeconomic groups [6]. Also, a study by Ataguba et al investigating socio-economic related health inequalities in self-reported ill health and disability revealed that poor people reported more ill health and disability than the least poor [107]. It further demonstrated that the trend in the magnitude of socioeconomic related inequalities tends to decline over time.

Effectiveness of interventions to control malaria and their effects on equity

Studies from various parts of Africa have indicated that the use of LLINs has a beneficial effect on malaria transmission, severe malaria and mortality [27, 28]. Similarly, there are numerous studies demonstrating the cost-effectiveness of LLINs in different parts of the world and in various contexts [29]. However, while there has been the application of various LLIN distribution methods, information is limited on the actual costs of parallel distribution channels in the same context and coverage results that can realistically be achieved from each channel based on financial inputs [30]. Similarly, there were no studies which had evaluated the cost, effects of various ITN distribution channels in a malaria-endemic area of western Kenya.

Cost-effectiveness and equity effect of LLIN distribution channels

We aimed to study cost-effectiveness and equity effects of distributing LLINs using five different channels namely; Mass distribution (MD), ANC, Social marketing (SM), CHVs and commercial outlets (CO). The findings showed that mass distribution was the most cost-effective from both provider and consumer perspectives. CHV was the next lowest costly way of distributing nets when estimated from the household survey. However, SM had the

second-lowest-cost when using supplier reported data. All channels were pro- richer households. CHV approach was the least inequitable/possibly neutral, followed by MD. CO was the least equitable. ANC and SM were in between. Mass campaigns might have benefited from the economies of scale owing to a large volume of nets distributed through this channel thus lowering the cost per net distributed. The study findings support the results by a study conducted in Ghana which analyzed the cost of three continuous distribution channels and established that the channels which target specific population with vulnerabilities are more likely to incur higher distribution costs than those that are intended for everybody [123]. Concerted efforts with multichannel distribution can achieve a high level of ownership and contribute towards achieving a universal coverage policy goal. The study concludes that mass campaigns done together with other continuous distribution channels can be the most effective and cost-effective way to achieve universal coverage while community-based distribution channels like the use of CHVs are best in addressing equity concerns around ITN distribution, ownership and use.

Strengths and Limitations of studies presented in this Ph.D. thesis

Strengths

The strength of the first two papers presenting the data in chapter two and three is the application of multiple correspondence analysis to establish wealth quintiles using household assets, utilities, and characteristics. Although there is extensive literature on health inequalities and health outcomes more generally, no previous study has evaluated the relationships between malaria indicators and SES using MCA to analyse microeconomic data. The use of eight years of repeated annual cross-sectional pooled data provided more power to assess socioeconomic inequalities and equity trends. In that analysis, we have used multivariate regression models accounting for clustering to assess the equity effect of

enhanced malaria control interventions. However, unlike longitudinal surveys, these studies provide results based on the proportionate representation of select socioeconomic groups at different time periods. However, the use of longitudinal monitoring provides an opportunity to monitor the effectiveness of policy intervention over time. However, because the datasets used in chapters two and three are from sectional surveys with limitations of inability to establish cause-effect, in chapter four, we used data collected from a cluster-randomized trial when MTAT intervention was implemented for two years to establish the effect on reducing malaria burden. This was the first study to the best of our knowledge to assess equity effect and socioeconomic inequalities using disability-adjusted life years in the MTAT trial and provided an opportunity to assess the economic benefits of a clinical trial.

While the studies analysed so far were restricted to participating households, the analyzing in chapter 6 applied pooled population-level data from a health and demographic surveillance data and assessed the health indicators irrespective of trails and control programs. This is also the first study to monitor equity and socioeconomic trends at the household level in western Kenya assessing years of life lost and DALYs. In Chapter 7 we compared the cost-effectiveness of five LLIN distribution channels and the equity effect. The strength of this paper is to answer the critical question of whether malaria control methods aimed to achieve universal coverage in a cost-effective and equitable manner or not. This is the first study to achieve this in western Kenya. The analysis applied both statistical, epidemiological and econometric methods and provides future research with approaches to monitor the impact of control interventions from economic perspectives.

Limitations

The study had a number of limitations. First, some of the findings were based on data from cross-sectional surveys preventing any evaluation of cause-and-effect of SES on malaria indicators over time. Second, only households with children <5 years were included in the surveys based on protocol-specific objectives. Although all children <5 years in a household were surveyed annually, only a small proportion of persons ≥5 years were included in the survey samples. Similarly, different sampling techniques were applied over the course of the study which may have moderated different potential selection effects, yet, given the sample size, the actual differences in the impact will be limited. The analysis of the data, however, accounted for stratification and clustering both at study areas and at households. This limits the bias of sampling

Although we applied MCA to rank households into SES, we did not present comparison results of using other methods such as PCA. This could have provided an opportunity to demonstrate that MCA better ranks households than other methods but we relied on evidence already provided in a previous analysis in the same study area [22]. This actually promotes internal validity, yet external validity might be limited and may need the use of the traditional PCA approach.

In the absence of relevant recent data, these studies limited the analysis to the period 2006–2015. Nevertheless, the findings of these studies would have long-term relevance, as it focuses on socioeconomic inequalities, which have persistent influence in the behavioural aspects of healthcare services utilization and malaria control efforts.

The DALY estimates have been expressed as absolute estimates, and hence we can only provide the idea about the total population burden but not the relative health status of the

population. Given the absolute numbers, we might not be able to make direct comparisons of health status for different population groups (e.g. 200 per 10,000 population). Since DALYs have not been expressed relative to the number of cases, it is not easy to make a comparison of the disease impact at patient –level (e.g. 50 per 1000 cases). Secondly, the study sites are situated largely in a rural setting, therefore it was not easy to clearly distinguish between the poor and least poor population groups using socioeconomic indices, and we describe relative, not absolute poverty. For example, the DALY estimates for the males in this study did not show any significant difference between the poorest and least poor households. This may cause a bias in favour of either the poor or the less poor. This coupled with the fact that asset index methodology does not consider the monetary and quality of the assets possessed by the households, the difference among various socioeconomic groups could become even more obscure.

For the LLIN cost-effectiveness study, the main limitations were that conducting evaluation alongside programme implementation was challenging and changes in implementation led to redefining the evaluation. Secondly, cost data may be incomplete because of reporting issues from the provider perspectives. However, we compared these data against donor information before applying them. Complex donor financing agreements make this challenging. Thirdly, there are inevitably recall issues regarding household sources of nets (especially in differentiating CO and SM channels), transferability of results to other settings is not guaranteed therefore we recommend repeating the approach while up-scaling, using similar analysis in other (Kenyan) settings.

Summary findings of the doctorate study

The study has established that socioeconomic inequalities still exist between the poor and less poor. The burden is highest amongst children under five in terms of DALYs lost to malaria deaths and infections. Community-based distribution of interventions such as MTAT resulted in equity gains for poor individuals providing access to ITN and medications directly to households hence removing the financial hardship. A combination of the community-based mass campaign together with a targeted approach such as the use of Community health volunteers is the most cost-effective and equitable way of achieving universal coverage. The policy will require continuous monitoring of socioeconomic inequalities and identify gaps to achieved sustainable development goals.

Methodological considerations

A previous study assessing the multi-level nature of socioeconomic inequalities in malaria disease had shown that socioeconomic factors determine where people live and the distribution of risk [129, 130]. By applying a multi-level logistic regression model, a previous study was able to address cluster- and district-level variability which helped to explain variation in the outcomes than with SES and covariates alone, and also supported the view that socio-economic factors influence malaria [131]. This has also been the case in our analysis where we included individual, cluster-level covariate in our analyses to strengthen the analyses. The concentration index and Gini coefficient have been used to assess socioeconomic inequalities in health outcomes and income. However, its application often lacks the statistical and epidemiological rigour required in controlling for confounders, effect modifiers, clustering, accurate estimating risks and complex nature of datasets and study designs [100, 132]. In this thesis, we improved on these methods by first, applying MCA to establish wealth quintiles because it has more statistical power, generates better factor

weights making classification of households into quintiles more distinct compared to other methods like PCA [22, 60]. Secondly, we applied robust generalized linear modelling controlling for confounding factors and clustering at the household level. This approach is superior to using multi-level logistic regression which tends to over-estimate the risk of health outcomes in a cross-sectional study where the outcomes are common [60]. We also used a morbidity approach to complement the calculation of disability-adjusted life years for cross-sectional studies where incidence rates are missing. Monitoring socioeconomic inequalities in health is a key global and national agenda of public health surveillance [133]

Policy recommendations

There has been a mass distribution of LLINs in Kenya since 2006, conducted every three years which has increased the availability of LLIN in households. Although universal coverage has not been achieved, there is progress towards attaining 80% by 2030. The result shown in chapter seven indicated that up to 80% [ranging from 77.3% to 82.7%] of households achieved universal coverage. The result from this study also showed that half of the LLINs observed in households originated from mass distributions (MD), one third from the community health volunteer (CHV) approach while one in ten nets were obtained through the antenatal care clinic targeting pregnant women and children. These findings demonstrate that the MD and CHV approach can achieve both universal coverage and equity when used together. Distribution channels that have cost barriers such subsidized nets through social marketing, ANC (travel cost) and the commercial outlets are most inequitable and have the least chance of reaching the poorest households. Mass distribution campaigns have been shown to influence bednet usage irrespective of household socioeconomic status. The result from this study has shown that household socioeconomic status had an influence on LLIN ownership, however, once a household has nets, the probability of usage is increased.

Ensuring mass distribution of LLINs will achieve universal coverage but strategies to target poor households will result in equity by ensuring that the availability of nets in households achieves equity and universal coverage [134, 135].

Results from these studies have shown that malaria is associated with poverty and previous studies had already reported high poverty levels reported in endemic areas of western Kenya[61], the fight against malaria would be compromised. Policy efforts should be geared towards reducing socioeconomic inequalities and targeting vulnerable groups like the poorest persons, children and women especially in the malaria-endemic area because our data has shown the children <5, women and poorest individuals lost most DALYs due to malaria infections.

This study has demonstrated that malaria is unfairly concentrated amongst the poorest households and hence interventions against malaria should be done simultaneously with poverty eradication programs. Targeting at-risk populations is an essential component for achieving equity despite the fact that it requires more resources than mass distribution. Since malaria is unfairly distributed amongst the poorest individuals, achieving both universal coverage and equity by 2030 will be a challenge. However, aiming to universal coverage and at the same time documenting any equitable coverage in at-risk populations is still key to the control program through monitoring and evaluations[75].

The study has shown that care-seeking and taking medication is equitable due to non-significance difference between the poorest and wealthier individuals. However, when the poorest individuals seek care for fevers, they purchase non-effective medications unlikely to treat malaria. Regulation of quality of medicines sold off-the-counter sale may cushion the poor against the adverse effect of poor treatment.

Recommendations for specific future research

The use of cross-sectional data meant that we were unable to assess cause-effect relationships, however, a future study could design a longitudinal cohort study that can monitor changes in wealth quintiles and health outcomes for specific individuals and households over time. A better defined randomized trial to evaluate the cost-effectiveness and equity impact which addresses the limitations experienced in our study can improve the study of a cost analysis of LLIN distribution channels and doing these studies in setting with urban and rural areas can provide more definitive data on differing subpopulations, allowing greater generalizability. A future study could also be done to assess the comparison of socioeconomic inequalities using MCA and PCA at the same time, to validate the superiority of MCA in SES classifications.

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